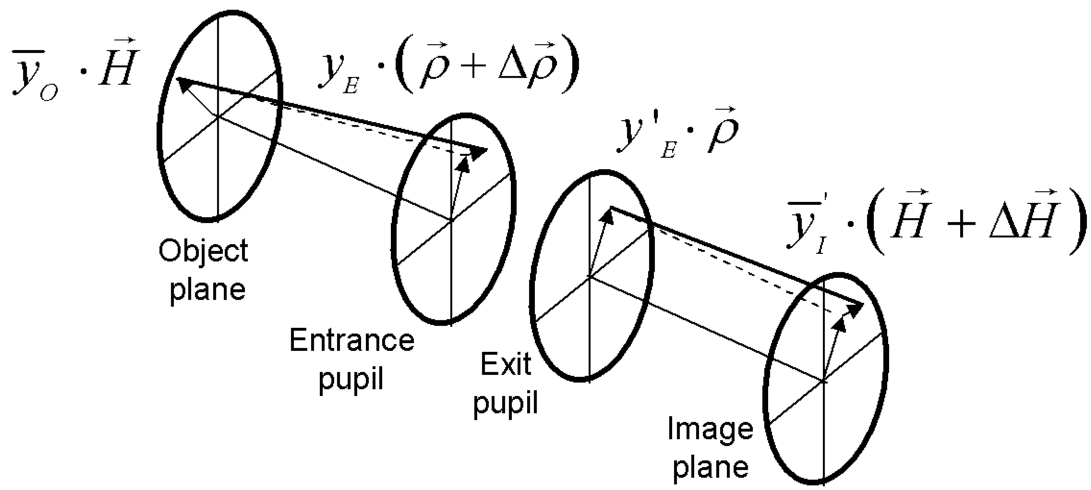
Introduction to aberrations

OPTI 518
Lecture 16
Reflective Systems

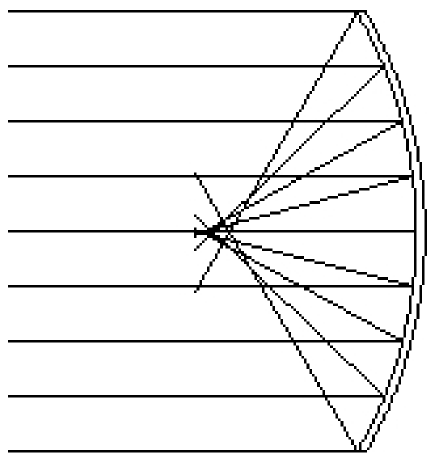


Prof. Jose Sasian
OPTI 518

College of Optical Sciences
The University of Arizona®

Topics

- Mirror systems
- Examples



Prof. Jose Sasian
OPTI 518

College of Optical Sciences
The University of Arizona®

Seidel sums in terms of structural aberration coefficients

$$S_I = \frac{1}{4} y_P^4 \Phi^3 \sigma_I$$

$$S_{II} = \frac{1}{2} \text{Ж} y_P^2 \Phi^2 \sigma_{II}$$

$$S_{III} = \text{Ж}^2 \Phi \sigma_{III}$$

$$S_{IV} = \text{Ж}^2 \Phi \sigma_{IV}$$

$$S_V = \frac{2 \text{Ж}^3 \sigma_V}{y_P^2}$$

Pupils located at principal planes

Stop shifting from principal planes

$$\sigma_I^* = \sigma_I$$

$$\sigma_{II}^* = \sigma_{II} + \bar{S}_\sigma \sigma_I$$

$$\sigma_{III}^* = \sigma_{III} + 2\bar{S}_\sigma \sigma_{II} + \bar{S}_\sigma^2 \sigma_I$$

$$\sigma_{IV}^* = \sigma_{IV}$$

$$\sigma_V^* = \sigma_V + \bar{S}_\sigma \left(\sigma_{IV} + 3\sigma_{III} \right) + 3\bar{S}_\sigma^2 \sigma_{II} + \bar{S}_\sigma^3 \sigma_I$$

Stop shifting from principal planes

$$\Delta\bar{S}_{\sigma} = \frac{y_P \Delta\bar{y}_P \Phi}{2Ж} = \frac{y_P^2 \Phi}{2Ж}\bar{S}$$

$$\bar{S}_{\sigma} = \frac{y_P \bar{y}_P \Phi}{2Ж} = \frac{\Phi \cdot \bar{s}}{(Y-1)\cdot\Phi\cdot\bar{s} - 2n} = \frac{\Phi \cdot \bar{s}'}{(Y+1)\cdot\Phi\cdot\bar{s}' - 2n'}$$

Φ is the lens system optical power.

$\bar{s}$ is the distance from the front principal point to the entrance pupil.

$\bar{s}'$ is the distance from the rear principal point to the exit pupil.

y_P is the marginal ray height at the principal planes.

$\bar{y}_P$ is the chief ray height at the principal planes.

College of Optical Sciences
The University of Arizona®

Structural coefficients of a system of N components/surfaces/subsystems

$$\sigma_I = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right)^3 \left(\frac{y_{P,k}}{y_P}\right)^4 \sigma_{I,k}$$

$$\sigma_{II} = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right)^2 \left(\frac{y_{P,k}}{y_P}\right)^2 \left(\sigma_{II,k} + \bar{S}_k \sigma_{I,k}\right)$$

$$\sigma_{III} = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right) \left(\sigma_{III,k} + 2\bar{S}_k \sigma_{II,k} + \bar{S}_k^2 \sigma_{I,k}\right)$$

$$\sigma_{IV} = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right) \sigma_{IV,k}$$

$$\sigma_V = \sum_{k=1}^{N} \left(\frac{y_P}{y_{P,k}}\right)^2 \left(\sigma_{V,k} + \bar{S}_k \left(\sigma_{IV,k} + 3\sigma_{III,k}\right) + 3\bar{S}_k^2 \sigma_{II,k} + \bar{S}_k^3 \sigma_{I,k}\right)$$

$$\sigma_L = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right) \left(\frac{y_{P,k}}{y_P}\right)^2 \sigma_{L,k}$$

$$\sigma_T = \sum_{k=1}^{N} \left(\sigma_{T,k} + \bar{S}_k \sigma_{L,k}\right)$$

$$\bar{S}_k = \frac{\Phi_k \cdot y_{P,k} \cdot \bar{y}_{P,k}}{2Ж}$$

College of Optical Sciences
The University of Arizona

Conjugate factor

$$Y = \frac{1+m}{1-m}$$

Not defined for m=1

Y=1, m=0, object at infinity
Y=0, m=-1, equal conjugate distances

Prof. Jose Sasian
OPTI 518

Aspheric cap contribution in general

$$S_I = \frac{1}{4} y_P^4 \Phi^3 \sigma_{ICap} = K y^4 c^3 \Delta(n) + 8 A_4 y^4 \Delta(n) = \frac{K y^4 \phi_{Surface}^3}{\left(\Delta(n)\right)^2} + 8 A_4 y^4 \Delta(n)$$

$$\sigma_{ICap} = \frac{4K \left(y / y_P\right)^4 \left(\phi_{Surface} / \Phi\right)^3}{\left[\Delta(n)\right]^2} + \frac{32 A_4 \left(y / y_P\right)^4 \Delta(n)}{\Phi^3}$$

Φ is the optical power of the system

$\phi_{Surface}$ is the optical power of the aspheric surface

y is the marginal ray height at the aspheric surface

y_P is the marginal ray height at the system principal planes

College of Optical Sciences
The University of Arizona®

Spherical mirror

stop at mirror

	$Y=1$	$Y=0$
$\sigma_I = Y^2$	$\sigma_I = 1$	$\sigma_I = 0$
$\sigma_{II} = -Y$	$\sigma_{II} = -1$	$\sigma_{II} = 0$
$\sigma_{III} = 1$	$\sigma_{III} = 1$	$\sigma_{III} = 1$
$\sigma_{IV} = -1$	$\sigma_{IV} = -1$	$\sigma_{IV} = -1$
$\sigma_V = 0$	$\sigma_V = 0$	$\sigma_V = 0$
$\sigma_L = 0$	$\sigma_L = 0$	$\sigma_L = 0$
$\sigma_T = 0$	$\sigma_T = 0$	$\sigma_T = 0$

$$C_{Petzval} = n'\phi$$

$$C_{Saggital} = 0$$

$$C_{Medial} = -n'\phi$$

$$C_{\mathrm{Tan}} = -2n'\phi$$

$$\phi = \frac{n'-n}{r}$$

Stop shifting

$$\bar{S}_{\sigma} = \frac{y_P \bar{y}_P \Phi}{2Ж} = \frac{\Phi \cdot \bar{s}}{(Y-1)\cdot\Phi\cdot\bar{s} - 2n} = \frac{\Phi \cdot \bar{s}'}{(Y+1)\cdot\Phi\cdot\bar{s}' - 2n'}$$

$$Y = \frac{1+m}{1-m}$$

Φ is the lens system optical power.

$\bar{s}$ is the distance from the front principal point to the entrance pupil.

$\bar{s}'$ is the distance from the rear principal point to the exit pupil.

y_P is the marginal ray height at the principal planes.

$\bar{y}_P$ is the chief ray height at the principal planes.

College of Optical Sciences
The University of Arizona®

Spherical mirror: with stop shift

With stop shift

$$\sigma_I = Y^2$$
$$\sigma_{II} = -Y\left(1-\bar{S}_\sigma Y\right)$$
$$\sigma_{III} = \left(1-\bar{S}_\sigma Y\right)^2$$
$$\sigma_{IV} = -1$$
$$\sigma_V = \bar{S}_\sigma\left(1-\bar{S}_\sigma Y\right)\left(3-\bar{S}_\sigma Y\right)$$

Stop at CC

$$\left(1-\bar{S}_\sigma Y\right) = 0$$
$$\sigma_I = Y^2$$
$$\sigma_{II} = 0$$
$$\sigma_{III} = 0$$
$$\sigma_{IV} = -1$$
$$\sigma_V = 0$$

$$Y = 0 \qquad \bar{S}_\sigma = -\frac{\phi\bar{s}}{2+\phi\bar{s}}$$

$$\sigma_I = 0$$
$$\sigma_{II} = 0$$
$$\sigma_{III} = 1$$
$$\sigma_{IV} = -1$$
$$\sigma_V = -\frac{2\phi\bar{s}}{2+\phi\bar{s}}$$

$$Y = 1 \qquad \bar{S}_\sigma = -\frac{1}{2}\phi\bar{s}$$

$$\sigma_I = 1$$
$$\sigma_{II} = -\frac{1}{2}\left(2+\phi\bar{s}\right)$$
$$\sigma_{III} = \frac{1}{4}\left(2+\phi\bar{s}\right)^2$$
$$\sigma_{IV} = -1$$
$$\sigma_V = -\frac{1}{8}\phi\bar{s}\left(2+\phi\bar{s}\right)\left(4+\phi\bar{s}\right)$$

College of Optical Sciences
The University of Arizona®

Spherical Mirror

Object at infinity Y=1

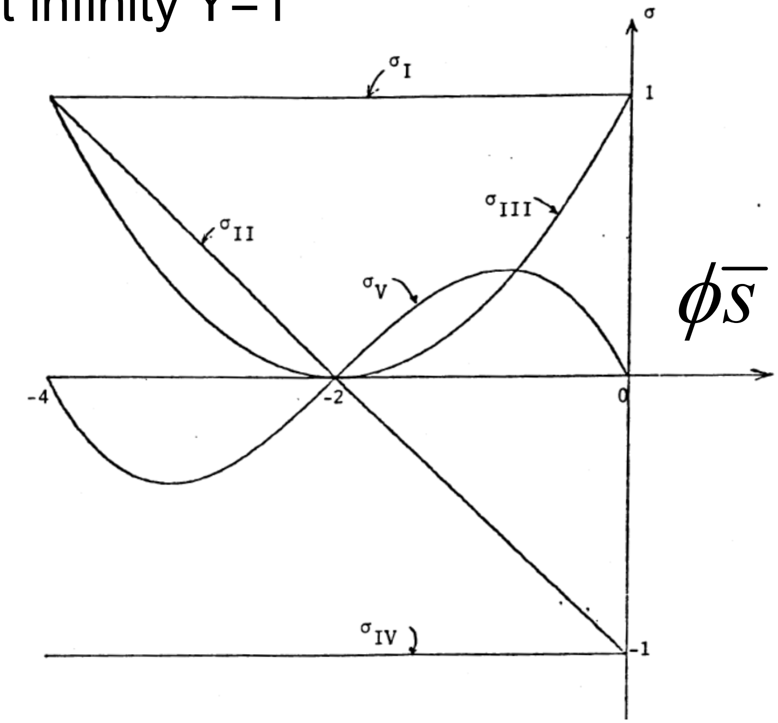
$$\sigma_I = 1$$

$$\sigma_{II} = -\frac{1}{2}\left(2+\phi\bar{s}\right)$$

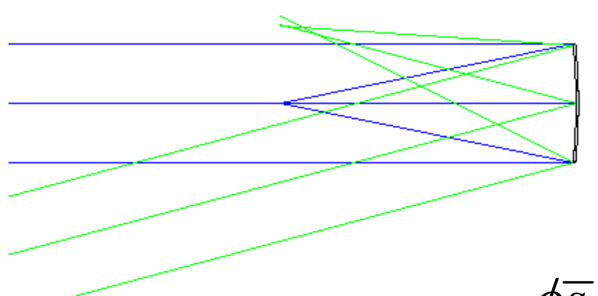
$$\sigma_{III} = \frac{1}{4}\left(2+\phi\bar{s}\right)^2$$

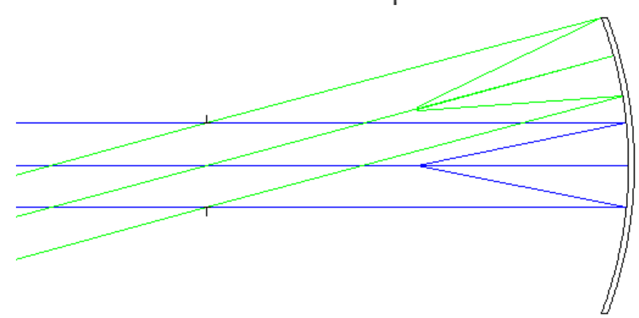
$$\sigma_{IV} = -1$$

$$\sigma_V = -\frac{1}{8}\phi\bar{s}\left(2+\phi\bar{s}\right)\left(4+\phi\bar{s}\right)$$



$\phi\bar{s}$





$$\phi\bar{s} = \frac{-2}{r}\bar{s}$$

Prof. Jose Sasian
OPTI 518

College of Optical Sciences
THE UNIVERSITY OF ARIZONA®

Conic mirror

$$\sigma_{ICap} = \frac{4K\left(y/y_P\right)^4\left(\phi_{Surface}/\Phi\right)^3}{\left[\Delta(n)\right]^2}$$

$$y/y_P = 1$$

$$\phi_{Surface}/\Phi = 1$$

$$\left[\Delta(n)\right]^2 = 4$$

$$\sigma_{ICap} = K = -\varepsilon^2$$

Stop at mirror

$$\sigma_I = Y^2 + K$$

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

$$\sigma_{III} = 1$$

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

$$\sigma_V = 0$$

$$\sigma_I = 0$$

$$\sigma_{ICap} = K = -Y^2$$

Axial object and image points are foci of conic

College of Optical Sciences
The University of Arizona®

Conic mirror with stop shift

With stop shifting

$$\sigma_I = Y^2 + K$$
$$\sigma_{II} = -Y\left(1-\bar{S}_\sigma Y\right) + \bar{S}_\sigma \cdot K$$
$$\sigma_{III} = \left(1-\bar{S}_\sigma Y\right)^2 + \bar{S}_\sigma^2 \cdot K$$
$$\sigma_{IV} = -1$$
$$\sigma_V = \bar{S}_\sigma \cdot \left(1-\bar{S}_\sigma Y\right) \cdot \left(2-\bar{S}_\sigma Y\right) + \bar{S}_\sigma^3 \cdot K$$

No Spherical aberration

$$\sigma_I = 0$$
$$\sigma_{II} = -Y$$
$$\sigma_{III} = 1 - 2\bar{S}_\sigma Y$$
$$\sigma_{IV} = -1$$
$$\sigma_V = \bar{S}_\sigma \cdot \left(2 - 3\bar{S}_\sigma Y\right)$$

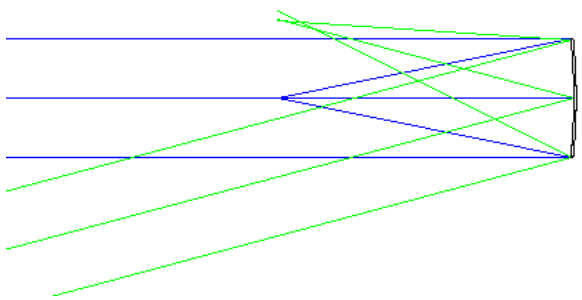
Paraboloid with object at Infinity; Y=1, K=-1

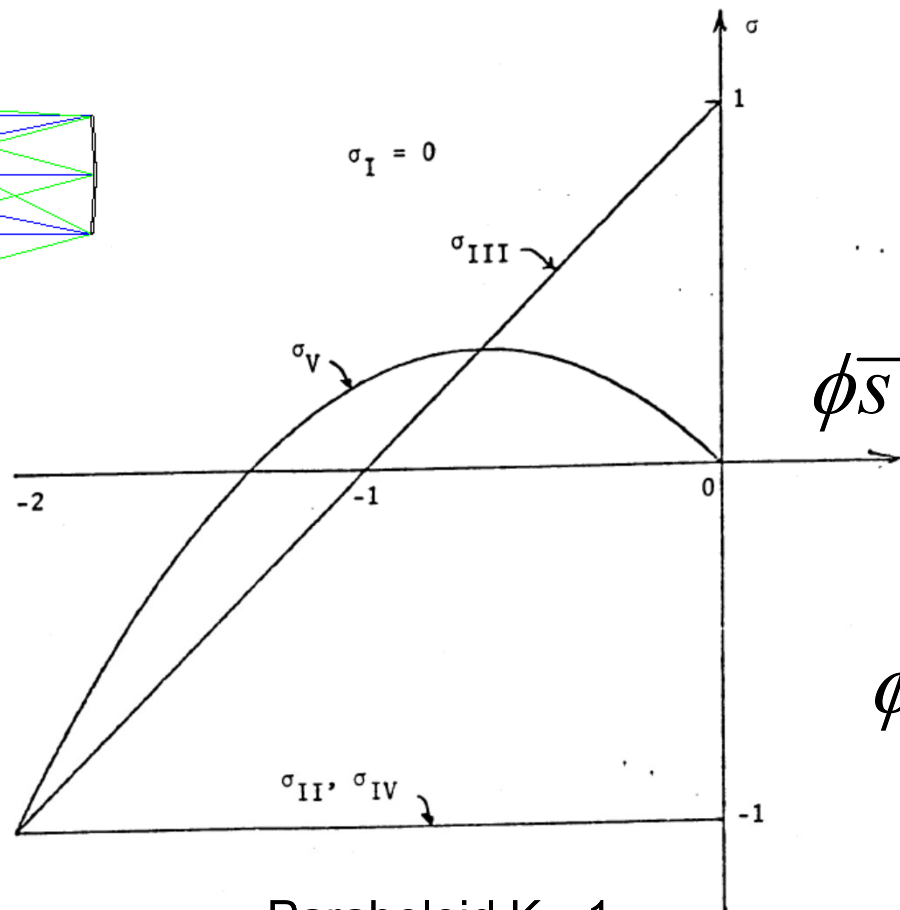
$$\bar{S}_\sigma = -\frac{\phi \bar{s}}{2}$$

$$\sigma_I = 0$$
$$\sigma_{II} = -1$$
$$\sigma_{III} = 1 + \phi \bar{s}$$
$$\sigma_{IV} = -1$$
$$\sigma_V = -\frac{\phi \bar{s}}{4}\left(3\phi \bar{s} + 4\right)$$

College of Optical Sciences
The University of Arizona®

Paraboloid with object at infinity





$\phi\bar{s}$

$$\phi\bar{s} = \frac{-2}{r}\bar{s}$$

Paraboloid K=-1

Prof. Jose Sasian
OPTI 518

Stop shifting from principal planes

$$\sigma_I^* = \sigma_I + \sigma_{ICap}$$

$$\sigma_{II}^* = \sigma_{II} + \bar{S}_\sigma \left(\sigma_I + \sigma_{ICap}\right)$$

$$\sigma_{III}^* = \sigma_{III} + 2\bar{S}_\sigma \sigma_{II} + \bar{S}_\sigma^2 \left(\sigma_I + \sigma_{ICap}\right)$$

$$\sigma_{IV}^* = \sigma_{IV}$$

$$\sigma_V^* = \sigma_V + \bar{S}_\sigma \left(\sigma_{IV} + 3\sigma_{III}\right) + 3\bar{S}_\sigma^2 \sigma_{II} + \bar{S}_\sigma^3 \left(\sigma_I + \sigma_{ICap}\right)$$

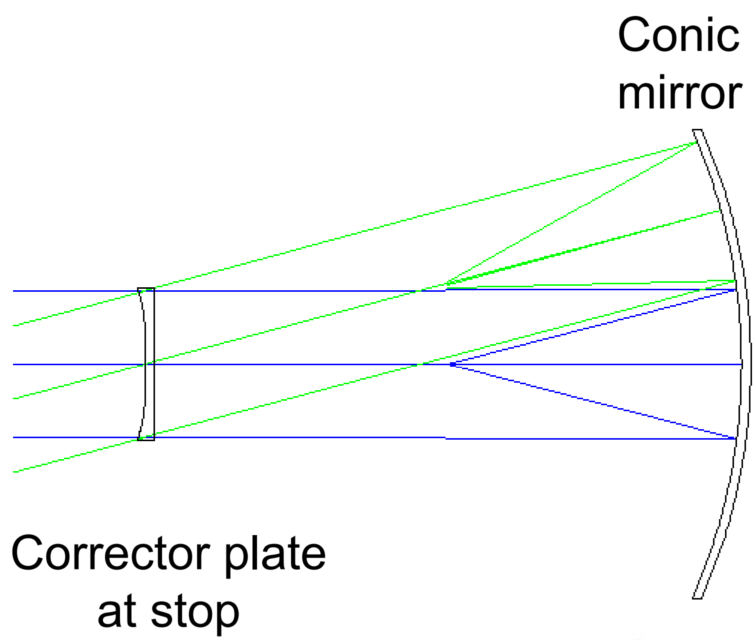
College of Optical Sciences
The University of Arizona®

Conic mirror with corrector plate

Corrector plate at stop and shift the mirror

$$\sigma_I = Y^2 + K + \sigma_{ICap}$$
$$\sigma_{II} = -Y\left(1-\bar{S}_\sigma Y\right) + \bar{S}_\sigma \cdot K$$
$$\sigma_{III} = \left(1-\bar{S}_\sigma Y\right)^2 + \bar{S}_\sigma^2 \cdot K$$
$$\sigma_{IV} = -1$$
$$\sigma_V = \bar{S}_\sigma \cdot \left(1-\bar{S}_\sigma Y\right)\cdot\left(2-\bar{S}_\sigma Y\right) + \bar{S}_\sigma^3 \cdot K$$

$$\sigma_{ICap} = \frac{32 A_4 \left(y / y_P\right)^4 \Delta\left(n\right)}{\Phi^3} = \frac{32 A_4 \Delta\left(n\right)}{\Phi^3}$$



Prof. Jose Sasian
OPTI 518

College of Optical Sciences
The University of Arizona®

Special aplanatic cases

$$\sigma_I = Y^2 + K + \sigma_{ICap}$$
$$\sigma_{II} = -Y\left(1-\bar{S}_\sigma Y\right) + \bar{S}_\sigma \cdot K$$
$$\sigma_{III} = \left(1-\bar{S}_\sigma Y\right)^2 + \bar{S}_\sigma^2 \cdot K$$
$$\sigma_{IV} = -1$$
$$\sigma_V = \bar{S}_\sigma \cdot \left(1-\bar{S}_\sigma Y\right) \cdot \left(2-\bar{S}_\sigma Y\right) + \bar{S}_\sigma^3 \cdot K$$

$$\sigma_{ICap} = -Y^2 - K$$

$$K = Y\frac{\left(1-\bar{S}_\sigma Y\right)}{\bar{S}_\sigma}$$

$$K = Y\frac{\left(1-\bar{S}_\sigma Y\right)}{\bar{S}_\sigma} = \frac{\left(Y-\bar{S}_\sigma Y^2\right)}{\bar{S}_\sigma}$$
$$= \frac{Y}{\bar{S}_\sigma} - Y^2 = \frac{Y}{\bar{S}_\sigma} + K + \sigma_{ICap}$$

Aplanatic solution

$$\sigma_{ICap} = -\frac{Y}{\bar{S}_\sigma}$$
$$K = -Y^2 + \frac{Y}{\bar{S}_\sigma}$$

Wright and Schmidt systems

Object at infinity

$$Y = 1 \qquad \bar{S}_{\sigma} = -\frac{\phi\bar{s}}{2} \qquad K = -1 - \frac{2}{\phi\bar{s}} \qquad \sigma_{ICap} = \frac{2}{\phi\bar{s}}$$

With stop shift

$$\sigma_I = 0$$
$$\sigma_{II} = 0$$
$$\sigma_{III} = \frac{1}{2}\left(2 + \phi\bar{s}\right)$$
$$\sigma_{IV} = -1$$
$$\sigma_V = -\frac{\phi\bar{s}}{2}\left(2 + \phi\bar{s}\right)$$

Wright

$$\phi\bar{s} = -1$$
$$K = 1$$
$$\sigma_{ICap} = -2$$
$$\sigma_{III} = \frac{1}{2}$$
$$\sigma_{IV} + 2\sigma_{III} = 0$$
$$\sigma_V = \frac{1}{2}$$

Field curve curvature in terms of structural coefficients
$C_{Petzval} = -n'\phi \cdot \sigma_{IV}$
$C_{Sagittal} = -n'\phi \cdot \left(\sigma_{IV} + \sigma_{III}\right)$
$C_{Medial} = -n'\phi \cdot \left(\sigma_{IV} + 2\sigma_{III}\right)$
$C_{Tangential} = -n'\phi \cdot \left(\sigma_{IV} + 3\sigma_{III}\right)$

Schmidt

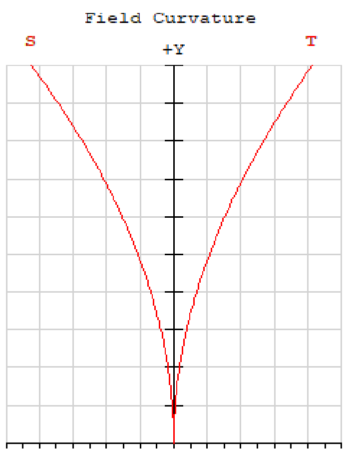
$$\phi\bar{s} = -2$$
$$K = 0$$
$$\sigma_{ICap} = -1$$

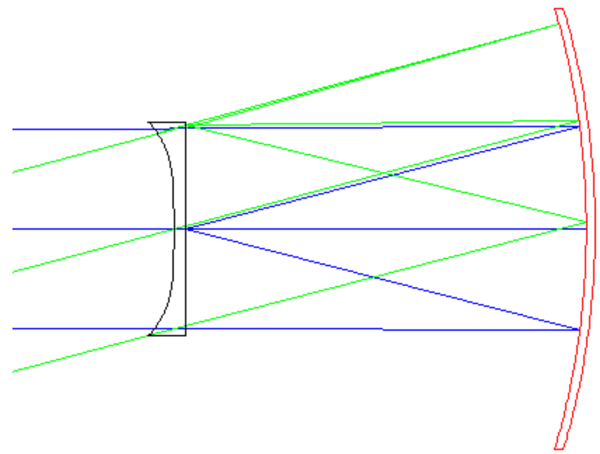
$$\sigma_I = 0$$
$$\sigma_{II} = 0$$
$$\sigma_{III} = 0$$
$$\sigma_{IV} = -1$$
$$\sigma_V = 0$$

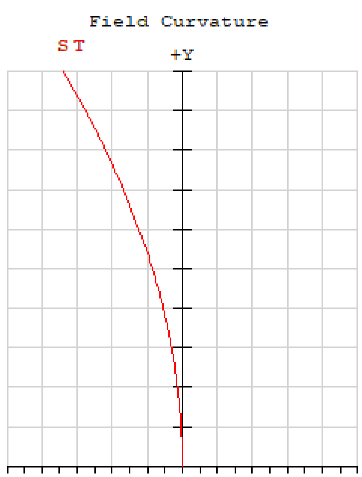
Spherical mirror
Stop at CC

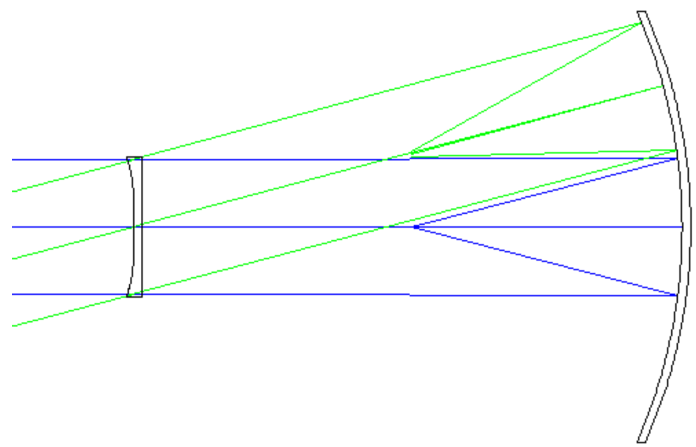
Prof. Jose Sasian
OPTI 518

Wright and Schmidt systems



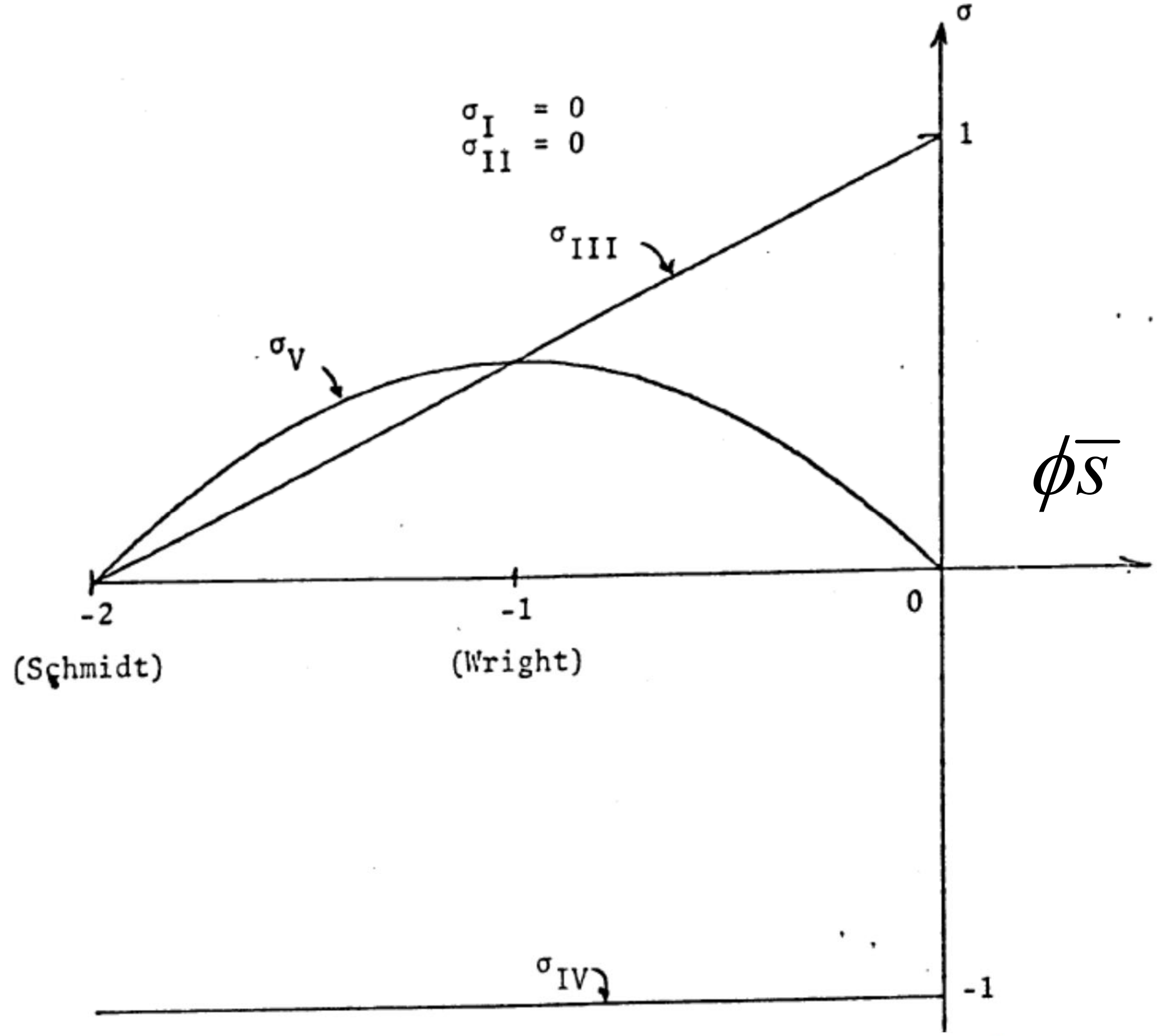




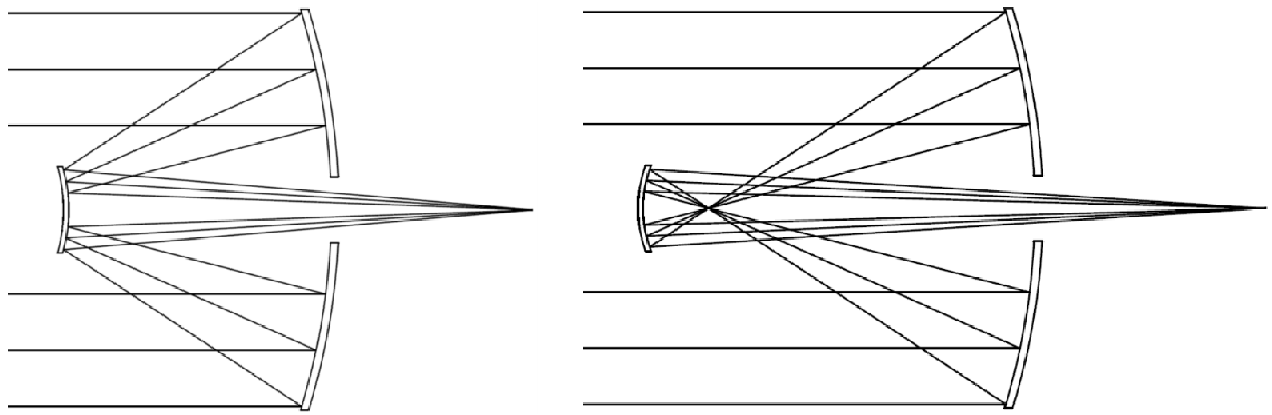


Wright and Schmidt systems

$$\sigma_I = 0$$
$$\sigma_{II} = 0$$
$$\sigma_{III} = \frac{1}{2}\left(2 + \phi\bar{s}\right)$$
$$\sigma_{IV} = -1$$



Cassegrain and Gregorian systems



Prepare the first-order quantities required in the structural coefficients formulas

L is the ratio of the mirror separation to the back focal distance

$$\varphi = 1$$
$$y_P = 1$$
$$Ж = 1$$

$$L = \frac{\bar{y}_2}{y_2}$$
$$M = \frac{1 - y_2}{\bar{y}_2}$$

$$\phi_1/\phi = M$$
$$y_1/y_P = 1$$
$$\bar{S}_{\sigma 1} = 0$$
$$Y_1 = 0$$

$$\phi_2/\phi = (1-M)(1+ML)$$
$$y_2/y_P = \frac{1}{(1+ML)}$$
$$\bar{S}_{\sigma 2} = \frac{1}{2}\frac{(1-M)L}{(1+ML)}$$
$$Y_2 = \frac{(1+M)}{(1-M)}$$

College of Optical Sciences
The University of Arizona

Structural coefficients of a system of N components/surfaces/subsystems

$$\sigma_I = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right)^3 \left(\frac{y_{P,k}}{y_P}\right)^4 \sigma_{I,k}$$

$$\sigma_{II} = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right)^2 \left(\frac{y_{P,k}}{y_P}\right)^2 \left(\sigma_{II,k} + \bar{S}_k \sigma_{I,k}\right)$$

$$\sigma_{III} = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right) \left(\sigma_{III,k} + 2\bar{S}_k \sigma_{II,k} + \bar{S}_k^2 \sigma_{I,k}\right)$$

$$\sigma_{IV} = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right) \sigma_{IV,k}$$

$$\sigma_V = \sum_{k=1}^{N} \left(\frac{y_P}{y_{P,k}}\right)^2 \left(\sigma_{V,k} + \bar{S}_k \left(\sigma_{IV,k} + 3\sigma_{III,k}\right) + 3\bar{S}_k^2 \sigma_{II,k} + \bar{S}_k^3 \sigma_{I,k}\right)$$

$$\sigma_L = \sum_{k=1}^{N} \left(\frac{\Phi_k}{\Phi}\right) \left(\frac{y_{P,k}}{y_P}\right)^2 \sigma_{L,k}$$

$$\sigma_T = \sum_{k=1}^{N} \left(\sigma_{T,k} + \bar{S}_k \sigma_{L,k}\right)$$

$$\bar{S}_k = \frac{\Phi_k \cdot y_{P,k} \cdot \bar{y}_{P,k}}{2\text{Ж}}$$

College of Optical Sciences
The University of Arizona®

Structural coefficients of a two mirror system

Stop at primary mirror. Object at infinity;
m is the transverse magnification of the secondary mirror, and
L is the ratio of the mirror separation to the back focal distance.

$$\sigma_I = m^3\left(1+K_1\right)+\frac{\left(1-m\right)^3}{1+mL}\left(\left(\frac{1+m}{1-m}\right)^2+K_2\right)$$

$$\sigma_{II} = -m^2+\left(1-m\right)^2\left(-\left(\frac{1+m}{1-m}\right)\left(1-\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}\left(\frac{1+m}{1-m}\right)\right)+\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}K_2\right)$$

$$\sigma_{III} = -1+\left(1-m\right)\left(1+mL\right)\left(\left(1-\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}\left(\frac{1+m}{1-m}\right)\right)^2+\left(\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}\right)^2K_2\right)$$

$$\sigma_{IV} = -m-\left(1-m\right)\left(1+mL\right)$$

$$\sigma_V = \frac{1}{\left(1+mL\right)^2}\left(\left(\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}\right)\left(1-\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}\frac{1+m}{1-m}\right)\left(2-\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}\frac{1+m}{1-m}\right)+\left(\frac{1}{2}\frac{\left(1-m\right)L}{1+mL}\right)^3K_2\right)$$

College of Optical Sciences
The University of Arizona®

Conic constants of Cassegrain type configurations corrected for spherical aberration		
Configuration	Primary mirror	Secondary mirror
Cassegrain	$K_1 = -1$	$K_2 = -\left(\frac{1+m}{1-m}\right)^2$
Dall-Kirkham	$K_1 = -1 - \frac{(1-m)(1+m)^2}{m^3(1+mL))}$	$K_2 = 0$
Pressman-Carmichel	$K_1 = 0$	$K_2 = -\left(\frac{1+m}{1-m}\right)^2 - \frac{m^3(1+mL)}{(1-m)^3}$
Ritchey-Chretien (aplanatic)	$K_1 = -1 - \frac{2}{Lm^3}$	$K_2 = -\left(\frac{1+m}{1-m}\right)^2 - \frac{2(1+mL)}{L(1-m)^3}$

Two mirror afocal system

Application to a two mirror Mersenne system

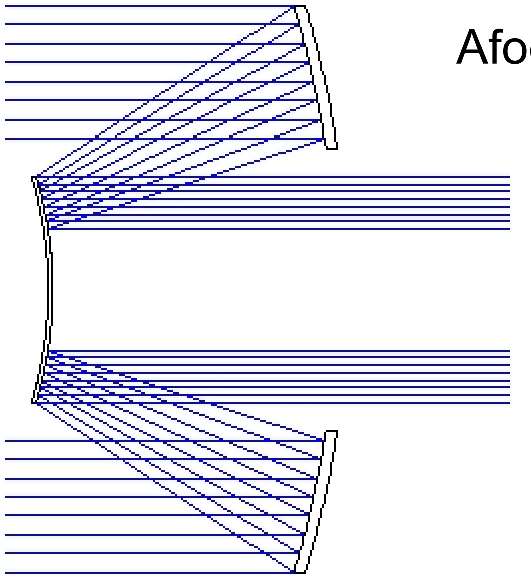
In this section we determine the aberration coefficients of a two mirror afocal system as shown in the figure We normalize the system parameters and set $Ж = 1$, $\Phi_1 = 1$, $y_1 = 1$, $\bar{y}_1 = 0$ and set the magnification to be m and therefore $y_2 = m$. We have that $\bar{y}_2 = 1 - m$, $\Phi_2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

$$Y_1 = 1$$

$$Y_2 = -1$$

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

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



Afocal

- We need the conjugate factors Y and the stop shifting parameter for each mirror

College of Optical Sciences
The University of Arizona®

Structural coefficients for each mirror

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	$\frac{m-1}{2}\frac{m+1}{2}\frac{m+3}{2}+\left(\frac{m-1}{2}\right)^3\alpha_2$

$$\sigma_{ICap}=\alpha=K$$

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

$$\alpha = K$$

College of Optical Sciences
THE UNIVERSITY OF ARIZONA®

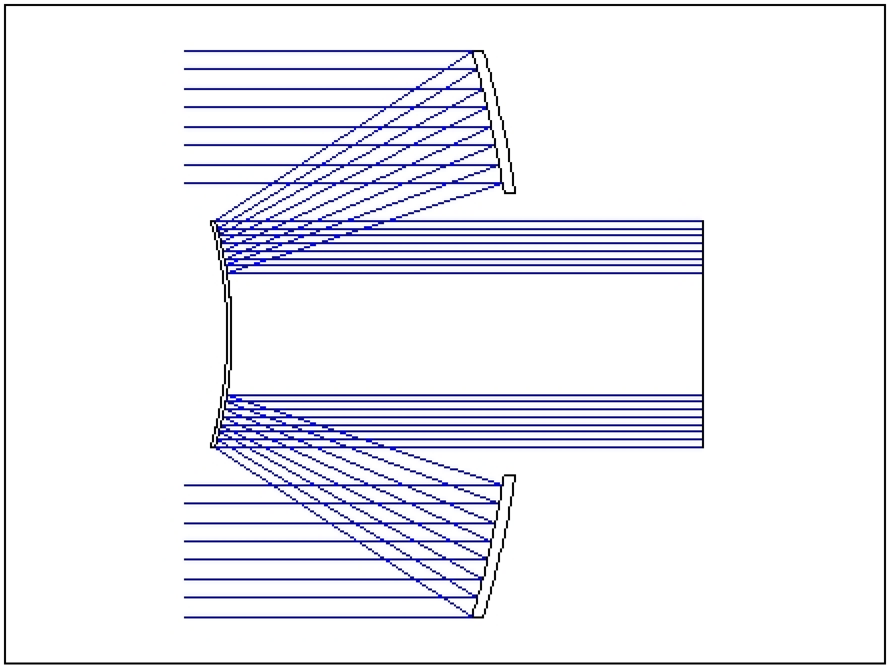
Case of parabolic mirrors $\alpha = K = -1$

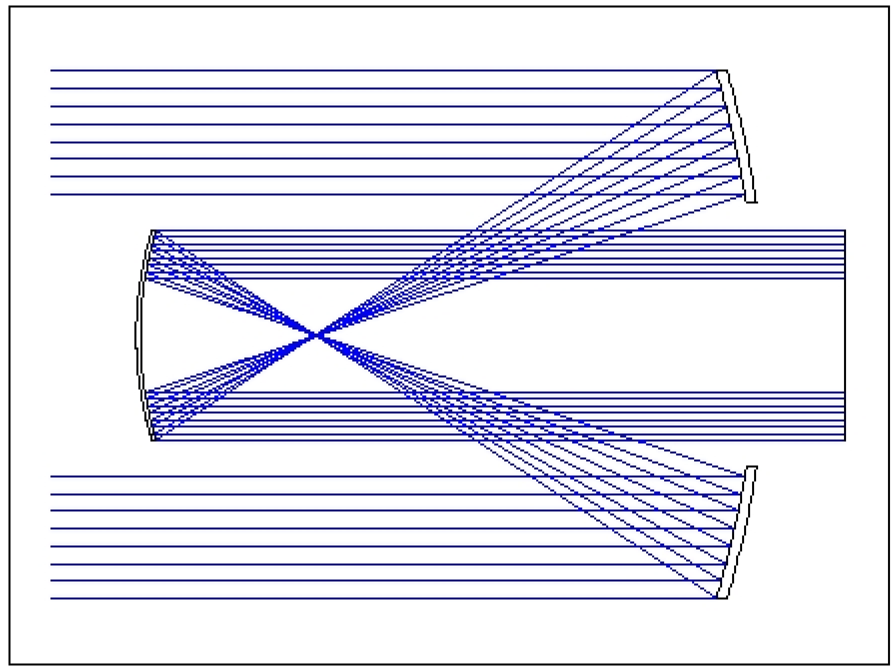
Seidel sums for afocal system using parabolas
$S_I = 0$
$S_{II} = 0$
$S_{III} = 0$
$S_{IV} = -\frac{m-1}{m}$
$S_V = \frac{1}{2}\frac{m-1}{m^2}(3m+1)$

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

College of Optical Sciences
THE UNIVERSITY OF ARIZONA®

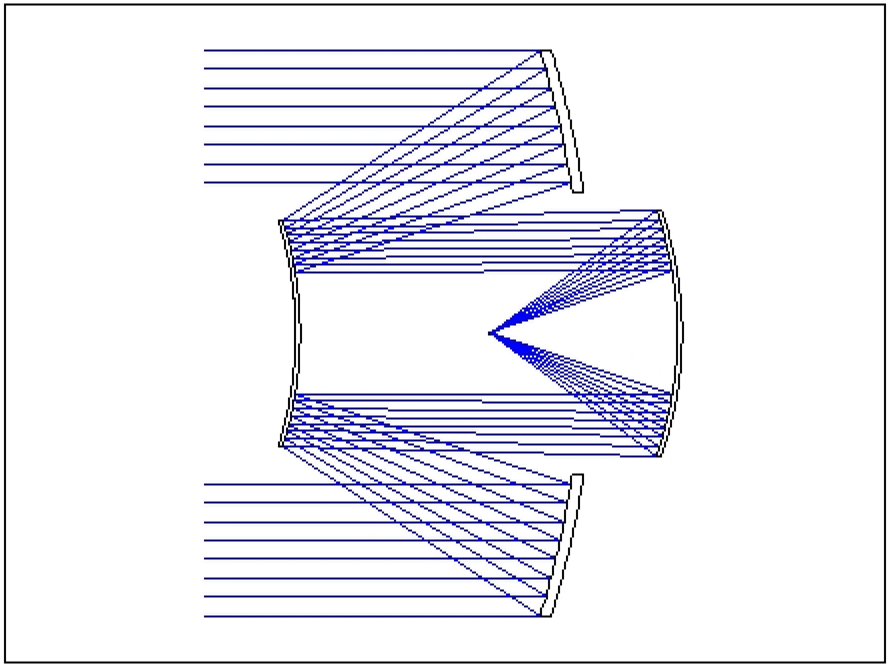
Merssene afocal system
Anastigmatic
Confocal paraboloids

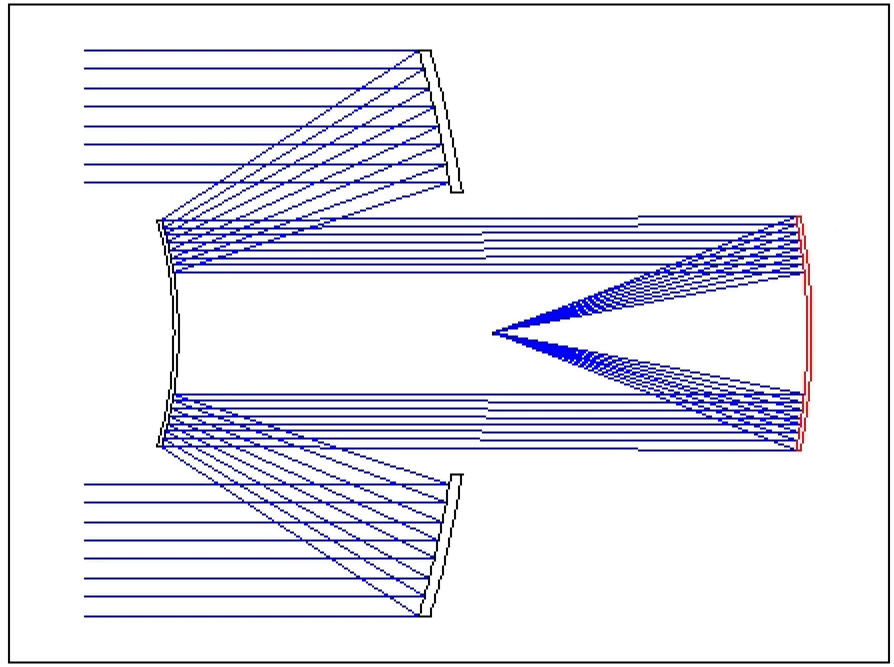




Prof. Jose Sasian
OPTI 518

Paul and Paul-Baker systems
Anastigmatic-Flat field

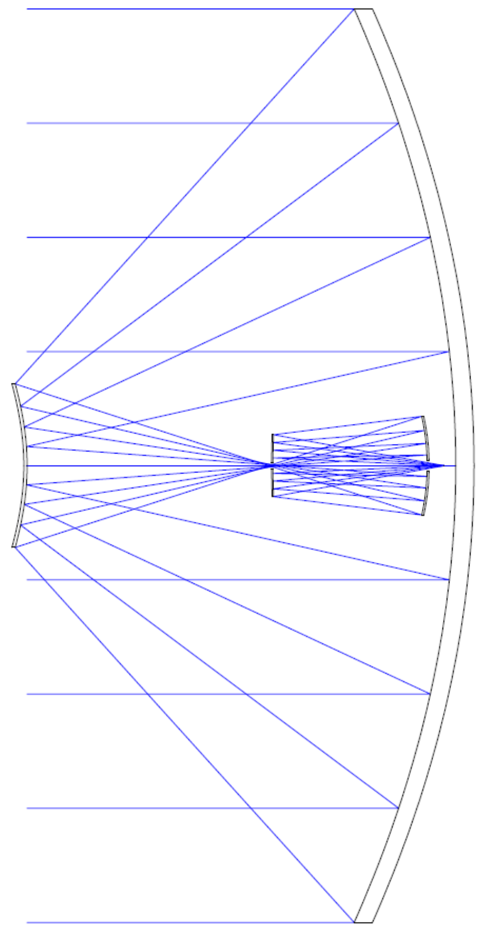




- Anastigmatic
- Parabolic primary
- Spherical secondary and tertiary
- Curved field
- Tertiary CC at secondary

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

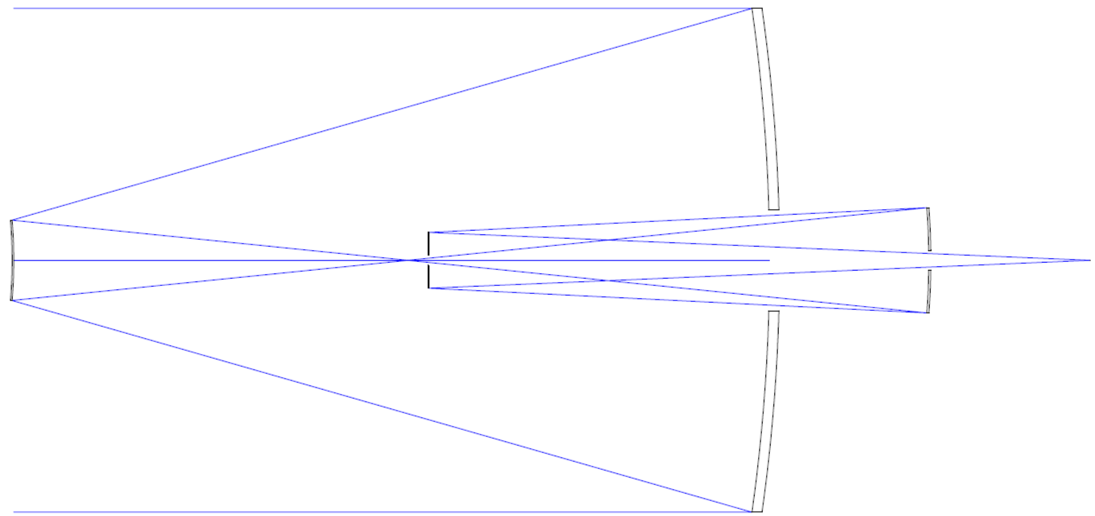
Meinel's two stage optics concept (1985)



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.

Summary

- Reflective systems
- Single mirror
- Two mirror
- Mersenne, Paul and Paul-Baker systems
- Wright and Schmidt system
- Cassegrain-Gregorian systems
- Two stage optics

College of Optical Sciences
The University of Arizona®