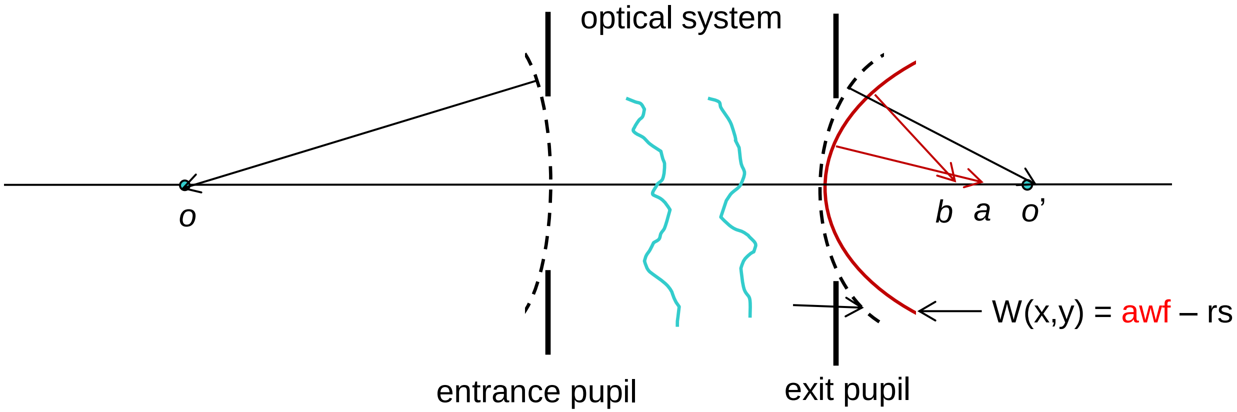
Wave-Front Aberrations

We've seen previously that a wave-front aberration function *W*(*x,y*) for optical systems with rotational symmetry can be expressed as a sum of even-order terms, each describing the optical path difference between the aberrated wave front and a spherical reference wave front. Here we further explore how each of these terms varies with optical system parameters.



Wave front polynomial parameters

The parameters used in the wave front aberration polynomial are the normalized field height $\bar{H}$, the normalized pupil (radial) coordinate ρ, and the angle between them, φ.

Sasian notation …

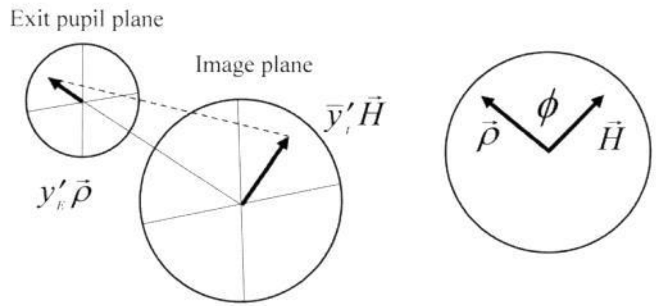


Figure 5.2 The field and aperture vectors (scaled by the marginal ray height at the exit pupil and the chief ray height at the image plane) and the angle ϕ between them looking down the optical axis.

Geary notation …

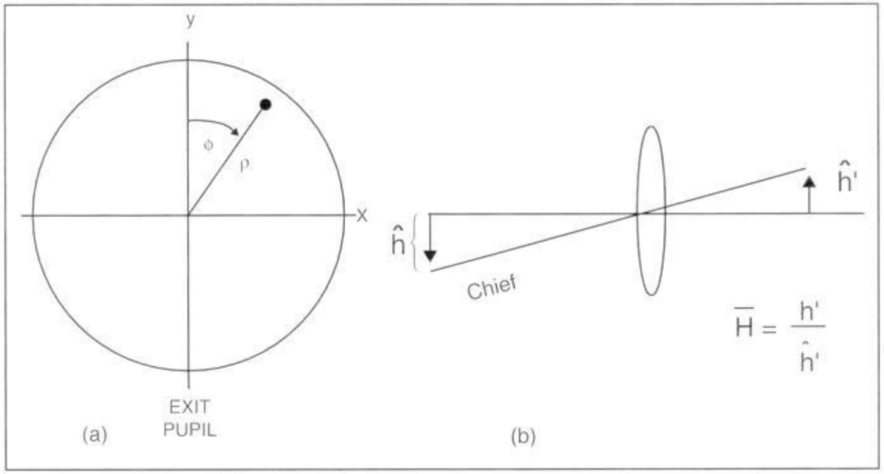
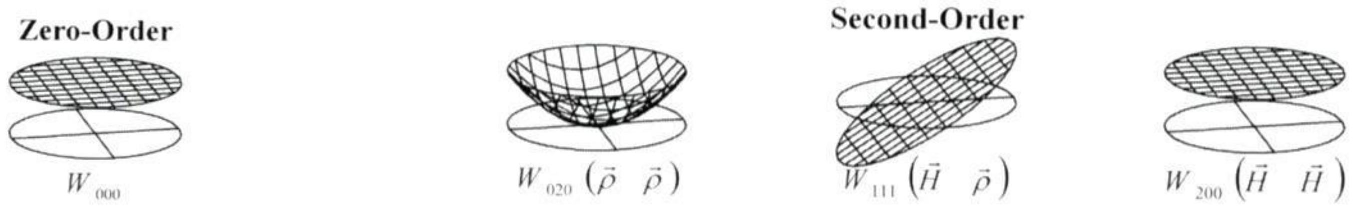


Fig. 7.18 *Coordinate system for Seidel aberrations: (a) point location in exit pupil; (b) point location in image.*

Wave front polynomial terms (order 0, 2, 4)



W_{000}
piston

$W_{020}\rho^2$
defocus

$W_{111}H\rho\cos\varphi$
tilt

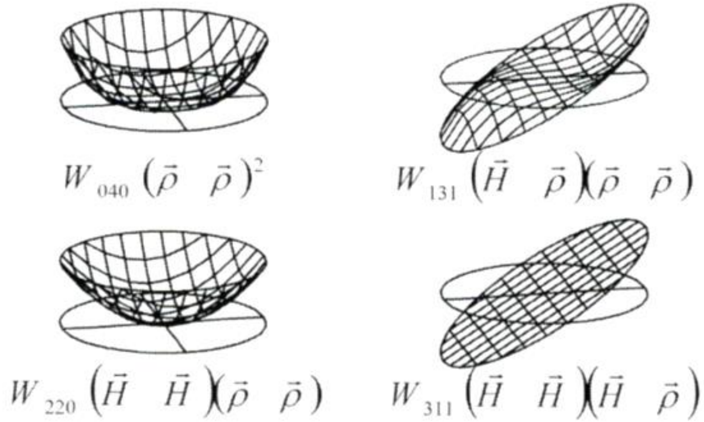
$W_{200}H^2$
quadratic piston

$W_{040}\rho^4$
spherical

$W_{131}H\rho^3\cos\varphi$
coma

Fourth-Order

$W_{222}H^2\rho^2\cos^2(\varphi)$
astigmatism



$W_{220}H^2\rho^2$
field curvature

$W_{311}H^3\rho\cos\varphi$
distortion

$W_{400}H^4$
quartic piston

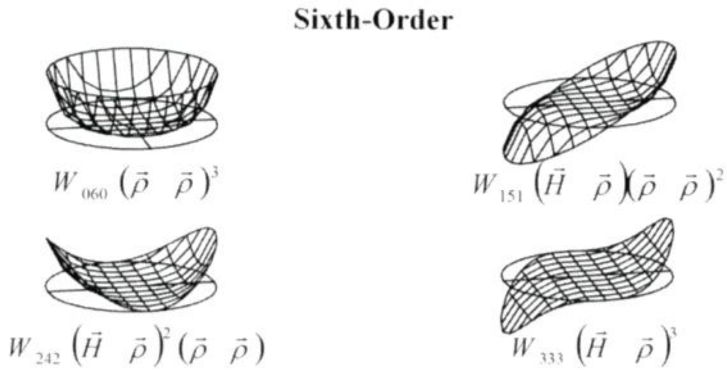
Seidel aberrations

J. Sasian, *Introduction to aberrations in optical imaging systems*, Fig. 5.1

Some "higher-order" wave front terms (order 6)

$W_{040}\rho^6$
6th-order spherical

$W_{131}H\rho^5\cos\varphi$
Unnamed (~ coma)



$W_{222}H^2\rho^4\cos^2(\varphi)$
unnamed (~astigmatism)

$W_{222}H^3\rho^3\cos^3(\varphi)$
unnamed (~coma)

J. Sasian, *Introduction to aberrations in optical imaging systems*, Fig. 5.1

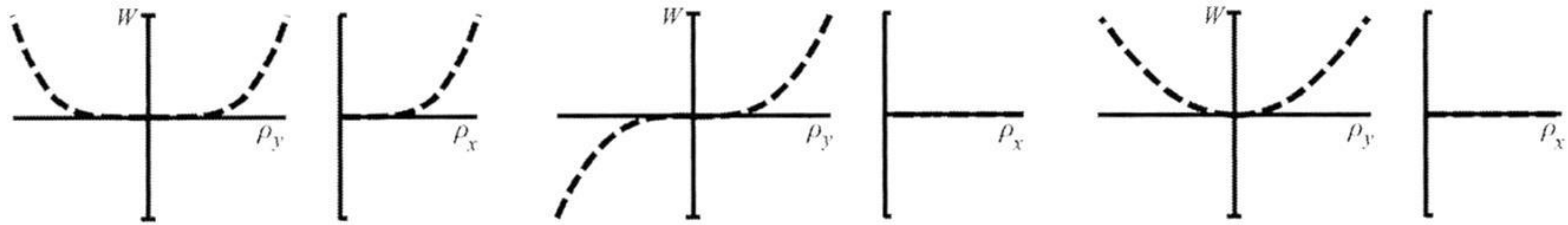
Wave front aberrations through order 6

Aberration name	Vector form	Algebraic form	j	m	n
Zero order					
Uniform piston	W_{000}	W_{000}	0	0	0
Second order					
Quadratic piston	$W_{200}(\vec{H}\ \ \vec{H})$	$W_{200}H^2$	1	0	0
Magnification	$W_{111}(\vec{H}\ \ \vec{\rho})$	$W_{111}H\rho\cos(\phi)$	0	1	0
Focus	$W_{020}(\vec{\rho}\ \ \vec{\rho})$	$W_{020}\rho^2$	0	0	1
Fourth order					
Spherical aberration	$W_{040}(\vec{\rho}\ \ \vec{\rho})^2$	$W_{040}\rho^4$	0	0	2
Coma	$W_{131}(\vec{H}\ \ \vec{\rho})(\vec{\rho}\ \ \vec{\rho})$	$W_{131}H\rho^3\cos(\phi)$	0	1	1
Astigmatism	$W_{222}(\vec{H}\ \ \vec{\rho})^2$	$W_{222}H^2\rho^2\cos^2(\phi)$	0	2	0
Field curvature	$W_{220}(\vec{H}\ \ \vec{H})(\vec{\rho}\ \ \vec{\rho})$	$W_{220}H^2\rho^2$	1	0	1
Distortion	$W_{311}(\vec{H}\ \ \vec{H})(\vec{H}\ \ \vec{\rho})$	$W_{311}H^3\rho\cos(\phi)$	1	1	0
Quartic piston	$W_{400}(\vec{H}\ \ \vec{H})^2$	$W_{400}H^4$	2	0	0
Sixth order					
Oblique spherical aberration	$W_{240}(\vec{H}\ \ \vec{H})(\vec{\rho}\ \ \vec{\rho})^2$	$W_{240}H^2\rho^4$	1	0	2
Coma	$W_{331}(\vec{H}\ \ \vec{H})(\vec{H}\ \ \vec{\rho})(\vec{\rho}\ \ \vec{\rho})$	$W_{331}H^3\rho^3\cos(\phi)$	1	1	1
Astigmatism	$W_{422}(\vec{H}\ \ \vec{H})(\vec{H}\ \ \vec{\rho})^2$	$W_{422}H^4\rho^2\cos^2(\phi)$	1	2	0
Field curvature	$W_{420}(\vec{H}\ \ \vec{H})^2(\vec{\rho}\ \ \vec{\rho})$	$W_{420}H^4\rho^2$	2	0	1
Distortion	$W_{511}(\vec{H}\ \ \vec{H})^2(\vec{H}\ \ \vec{\rho})$	$W_{511}H^5\rho\cos(\phi)$	2	1	0
Piston	$W_{600}(\vec{H}\ \ \vec{H})^3$	$W_{600}H^6$	3	0	0
Spherical aberration	$W_{060}(\vec{\rho}\ \ \vec{\rho})^3$	$W_{060}\rho^6$	0	0	3
Un-named	$W_{151}(\vec{H}\ \ \vec{\rho})(\vec{\rho}\ \ \vec{\rho})^2$	$W_{151}H\rho^5\cos(\phi)$	0	1	2
Un-named	$W_{242}(\vec{H}\ \ \vec{\rho})^2(\vec{\rho}\ \ \vec{\rho})$	$W_{242}H^2\rho^4\cos^2(\phi)$	0	2	1
Un-named	$W_{333}(\vec{H}\ \ \vec{\rho})^3$	$W_{333}H^3\rho^3\cos^3(\phi)$	0	3	0

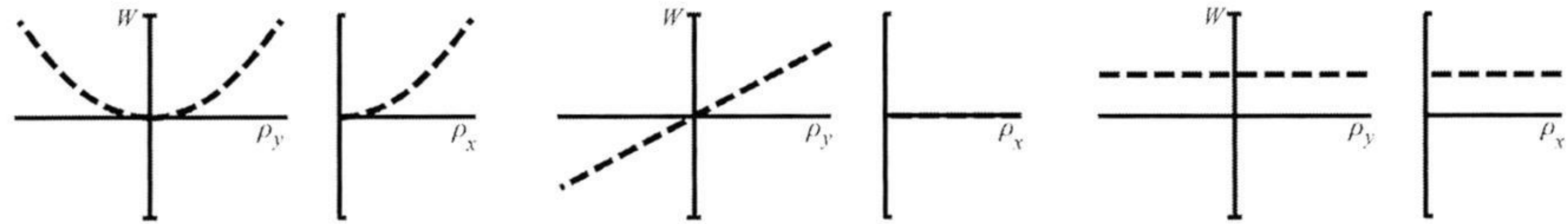
J. Sasian, *Introduction to aberrations in optical imaging systems,* Table 5.1

Wave fans

“Wave fans” plot the amount of wave front aberration vs the normalized pupil coordinate ρ in the meridional (‘tangential’) and sagittal planes. Note that the field (H) dependence is not shown explicitly (H changes the scale of the wave fan but not the shape).



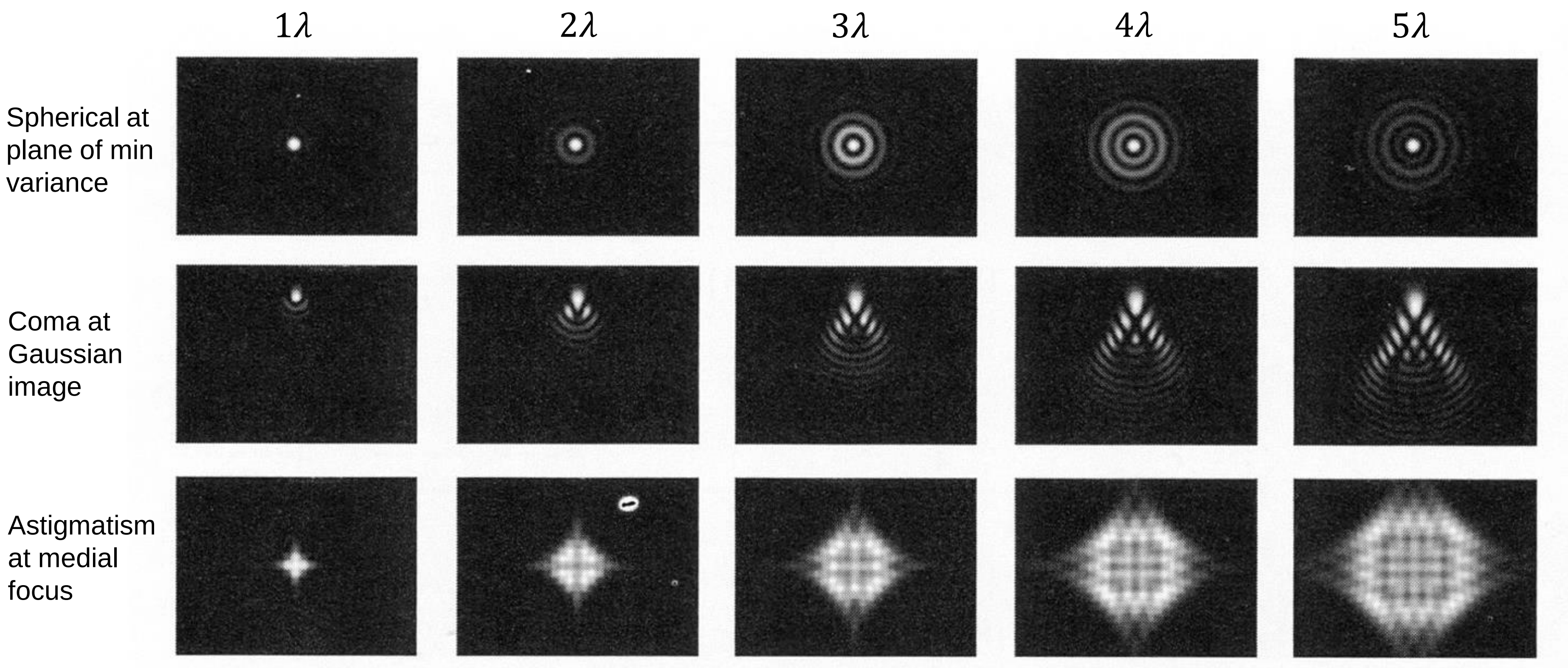
$W_{040}(\vec{\rho}\cdot\vec{\rho})^2$ $\qquad$ $W_{131}(\vec{H}\ \vec{\rho})(\vec{\rho}\ \vec{\rho})$ $\qquad$ $W_{222}(\vec{H}\ \vec{\rho})^2$



$W_{220}(\vec{H}\ \vec{H})(\vec{\rho}\ \vec{\rho})$ $\qquad$ $W_{311}(\vec{H}\ \vec{H})(\vec{H}\ \vec{\rho})$ $\qquad$ $W_{400}(\vec{H}\ \vec{H})^2$

J. Sasian, *Introduction to aberrations in optical imaging systems,* Fig. 7.2

Images with pure spherical, coma, and astigmatism



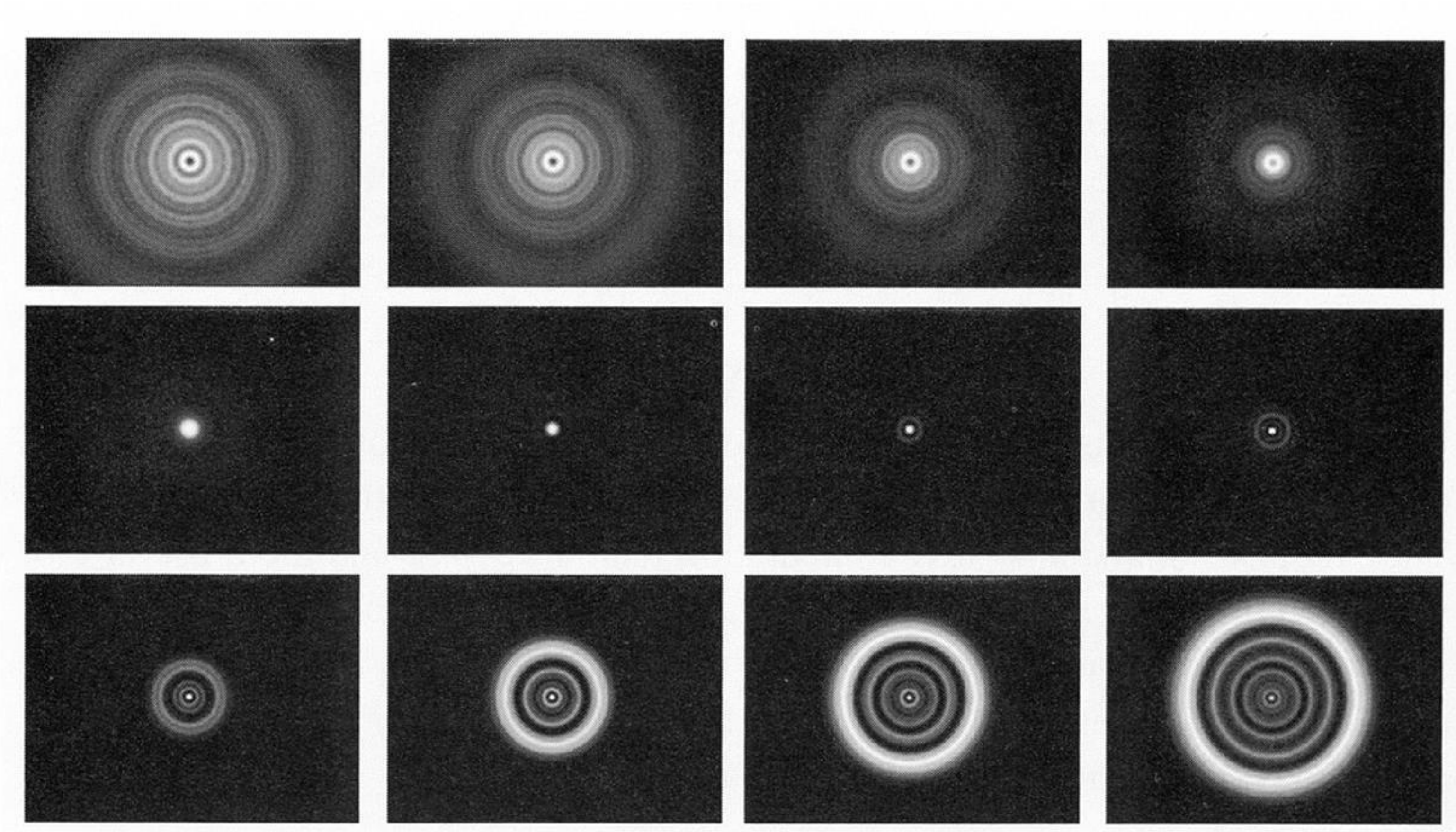
J. Sasian, *Introduction to aberrations in optical imaging systems,* Fig. 7.3

Through-focus images with pure spherical ($W_{040} = 2\lambda$)

4λ 1λ

0 -3λ

-4λ -7λ



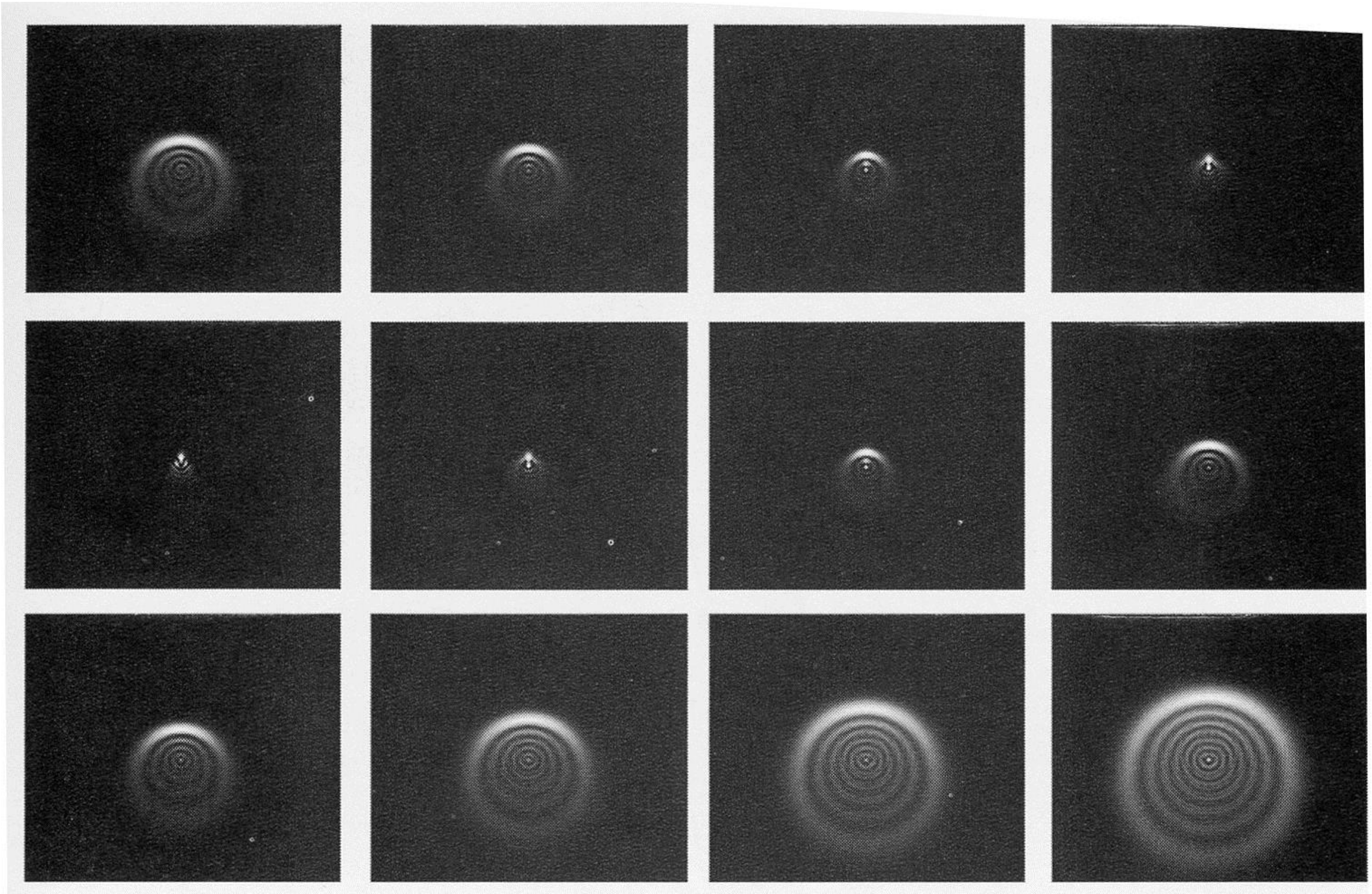
J. Sasian, *Introduction to aberrations in optical imaging systems,* Fig. 7.4

Through-focus images with pure coma ($W_{131} = 2\lambda$)

4λ 1λ

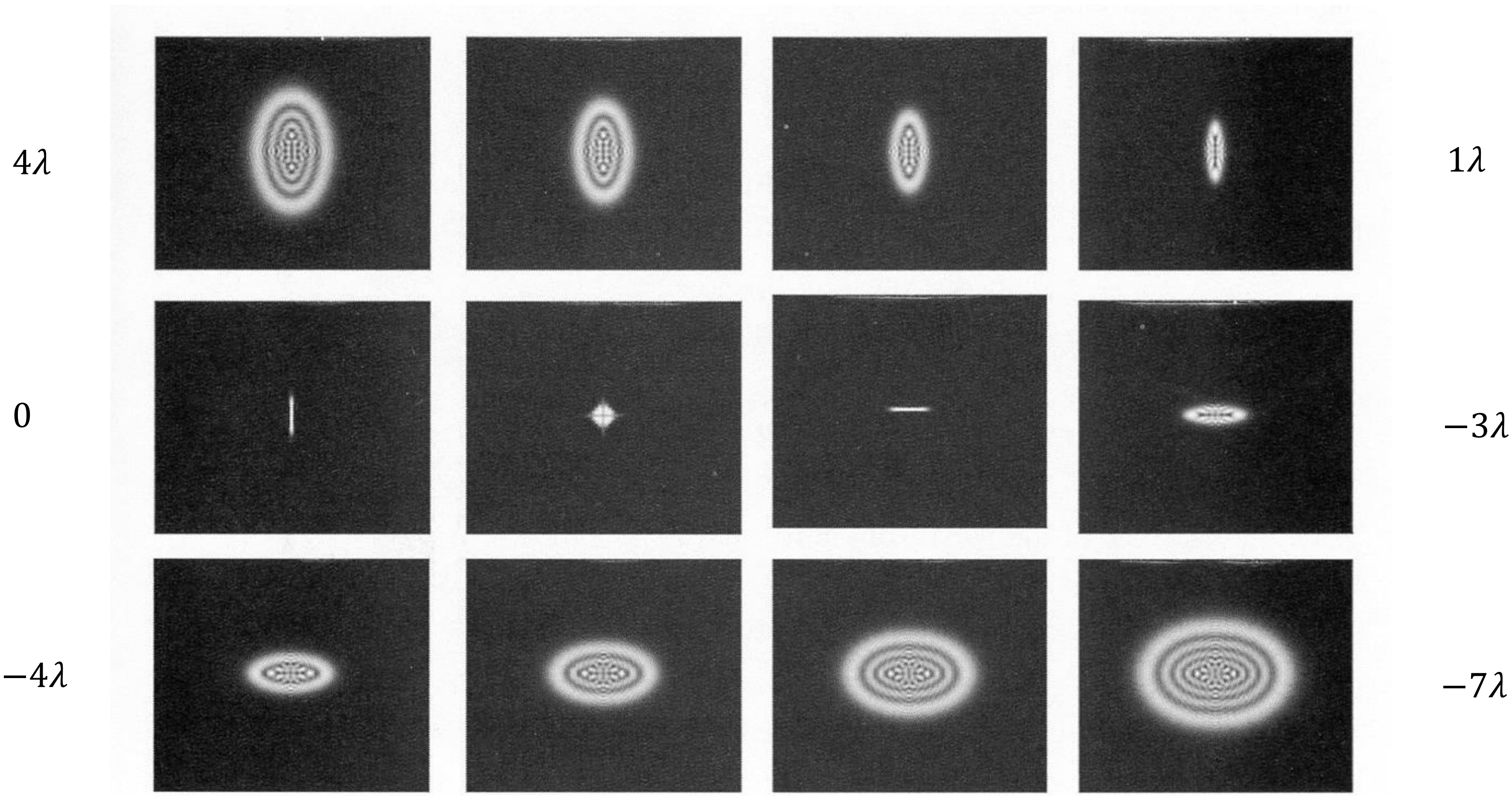
0 -3λ

-4λ -7λ



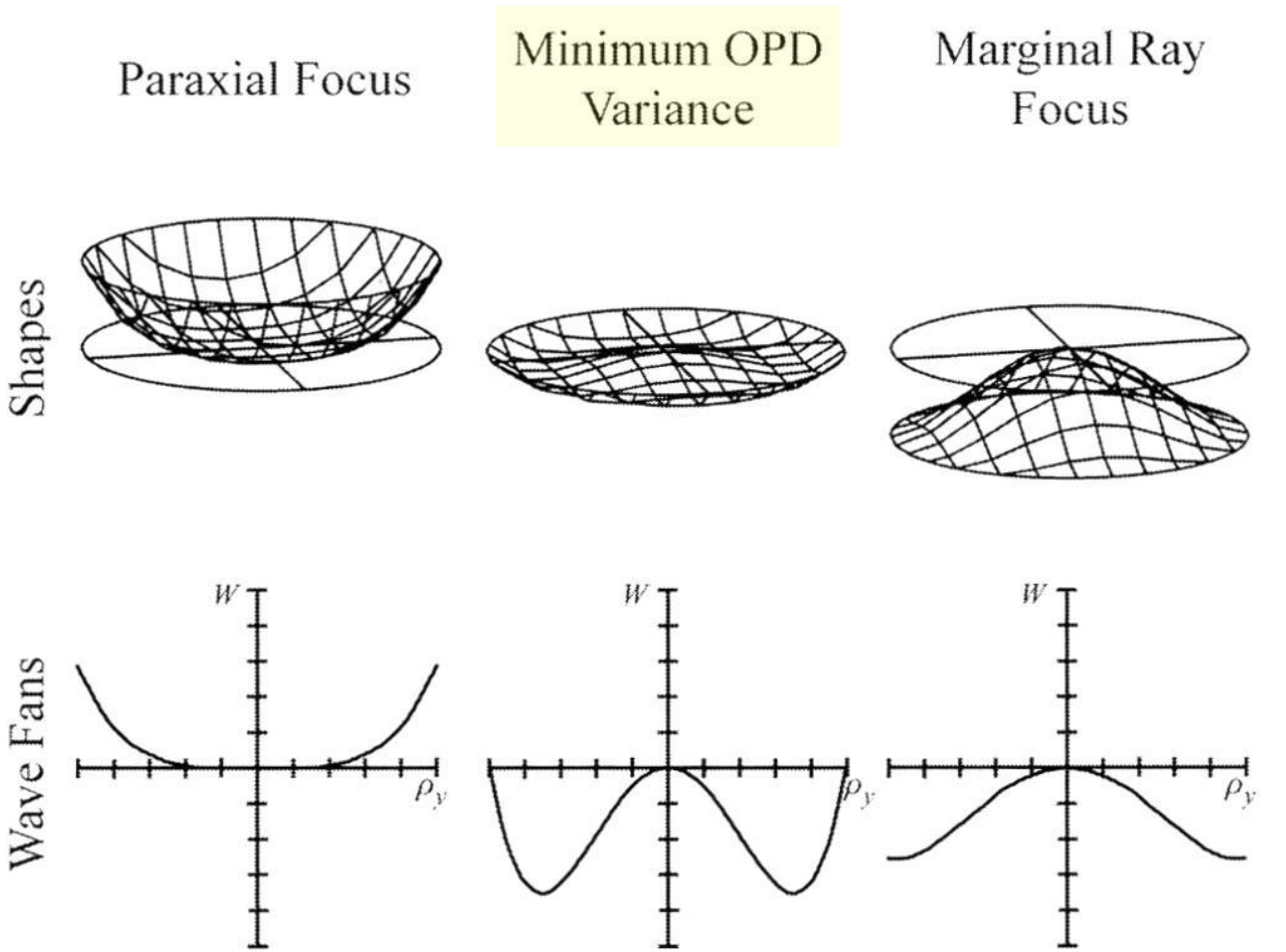
J. Sasian, *Introduction to aberrations in optical imaging systems,* Fig. 7.5

Through-focus images with pure astigmatism ($W_{222} = 2\lambda$)



J. Sasian, *Introduction to aberrations in optical imaging systems,* Fig. 7.6

Spherical balanced with defocus



J. Sasian, *Introduction to aberrations in optical imaging systems,* Fig. 7.7