Demonstrating optical aberrations in the laboratory

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OPTICAL ABERRATIONS

AN OPTICAL ABERRATION IS A DISTORTION OF AN IMAGE AS COMPARED TO THE OBJECT DUE TO DEFECTS IN AN OPTICAL SYSTEM

**TILT** IS THE DEVIATION OF A LASER BEAM OFF THE OPTICAL AXIS
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DEFOCUS

OCCURS WHEN AN IMPERFECT WAVEFRONT IS FOCUSED TO A POINT THAT IS EITHER BEFORE OR AFTER THE PARAXIAL FOCUS
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ASTIGMATISM

ARISES WHEN THE TANGENTIAL AND SAGITTAL FOCI DO NOT COINCIDE AND THE SYSTEM APPEARS TO HAVE 2 POINTS OF FOCUS
OPTICAL ABERRATIONS...

**ASTIGMATISM**

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<th>Compromise</th>
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ASTIGMATISM

ARISES WHEN THE TANGENTIAL AND SAGITTAL FOCI DO NOT COINCIDE AND THE SYSTEM APPEARS TO HAVE 2 POINTS OF FOCUS
**COMA**

**COMA** IS PRODUCED WHEN A WAVEFRONT FROM AN OFF-AXIS OBJECT POINT ARE IMAGED BY DIFFERENT ZONES OF THE LENS.
OPTICAL ABERRATIONS...

COMA
COMA IS PRODUCED WHEN A WAVEFRONT FROM AN OFF-AXIS OBJECT POINT ARE IMAGED BY DIFFERENT ZONES OF THE LENS.
SPHERICAL ABERRATION IS A DEVIATION OF THE LASER WAVEFRONT FROM AN IDEAL SPHERICAL SHAPE.
OPTICAL ABERRATIONS...

SPHERICAL ABERRATION
SPHERICAL ABERRATION

SPHERICAL ABERRATION IS A DEVIATION OF THE LASER WAVEFRONT FROM AN IDEAL SPHERICAL SHAPE.
ZERNIKE POLYNOMIALS ARE AN ORTHOGONAL SET

EACH POLYNOMIAL HAS AN ASSOCIATED WEIGHTING COEFFICIENT

\[ Z_n^m(r, \theta) = R_n^m(r) e^{i m \theta} \]

\[ Z_n^m(r, \theta) = R_n^m(r) \cos(m \theta) + i R_n^m(r) \sin(m \theta) \]

ABERRATION PHASE

\[ \Phi(r, \theta) = \sum_{n=0}^{\infty} \sum_{m=0}^{n} \left[ A_n^m R_n^m(r) \cos(m \theta) + B_n^m R_n^m(r) \sin(m \theta) \right] \]

ZERNIKE POLYNOMIALS ARE FITTED TO 3-DIMENSIONAL DATA TO DESCRIBE THE ABERRATIONS OF WAVEFRONT MEASUREMENTS
IMPORTANT ELEMENTS OF DESIGN INCLUDE A LENSLET ARRAY AND A POSITION-SENSING DETECTOR

THE POSITION OF THE FOCAL SPOTS IS DIRECTLY RELATED TO THE AVERAGE WAVEFRONT SLOPE ACROSS THE LENSLET

ABERRATED WAVEFRONT

FOCAL SPOTS

Focal spots

INCOMING WAVEFRONT

LENSLET ARRAY

ABERRATED WAVEFRONT

FOCAL SPOTS

DISPLACED FOCAL SPOTS

DETECTOR ARRAY
DEMONSTRATING OPTICAL ABERRATIONS

Focal length from Defocus

- Theoretical
- Experimental

Nominal Focal Length (mm) vs. Measured Focal Length (mm)
Demonstrating Optical Aberrations

DUE TO SPHERICAL ABERRATION

\[ w_f = \frac{4k w_0^3}{f^2} \]

DUE TO DIFFRACTION

\[ w_f = \frac{M^2 \lambda f}{\pi W_0} \]

Spherical Aberration

Diffraction

\[ w_0^* = \left( \frac{M^2 \lambda f^3}{4\pi k} \right)^{1/4} \]
DEMONSTRATING OPTICAL ABERRATIONS

LENS QUALITY

WRONG WAY

RIGHT WAY

HeNe LASER

FM

DIVERGING TELESCOPE

TEST LENS

IMAGING TELESCOPE

MAGNIFICATION 5

SHACK-HARTMANN WAVEFRONT SENSOR
M^2 Comparison on increasing beam width

Curved Surface of Plano-Convex
Flat Surface of Plano-Convex
Aberrations on the increase of $M^2$

- Astigmatism with axis ± 45 Degrees
- Astigmatism with 0 Degrees or 90 Degrees axis
- Third Order Coma along x-axis
- Third Order Coma along y-axis
- Third Order Spherical Aberration

Beam width to Lens width
DEMONSTRATING OPTICAL ABERRATIONS...

SPATIAL LIGHT MODULATOR

COMA

ASTIGMATISM

DEFOCUS
DEMONSTRATING OPTICAL ABERRATIONS...

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Contact: Dr Andrew Forbes or Dr Stef Roux

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