Subjective Image Quality Metrics from The Wave Aberration

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William G. Allyn Professor of Medical Optics
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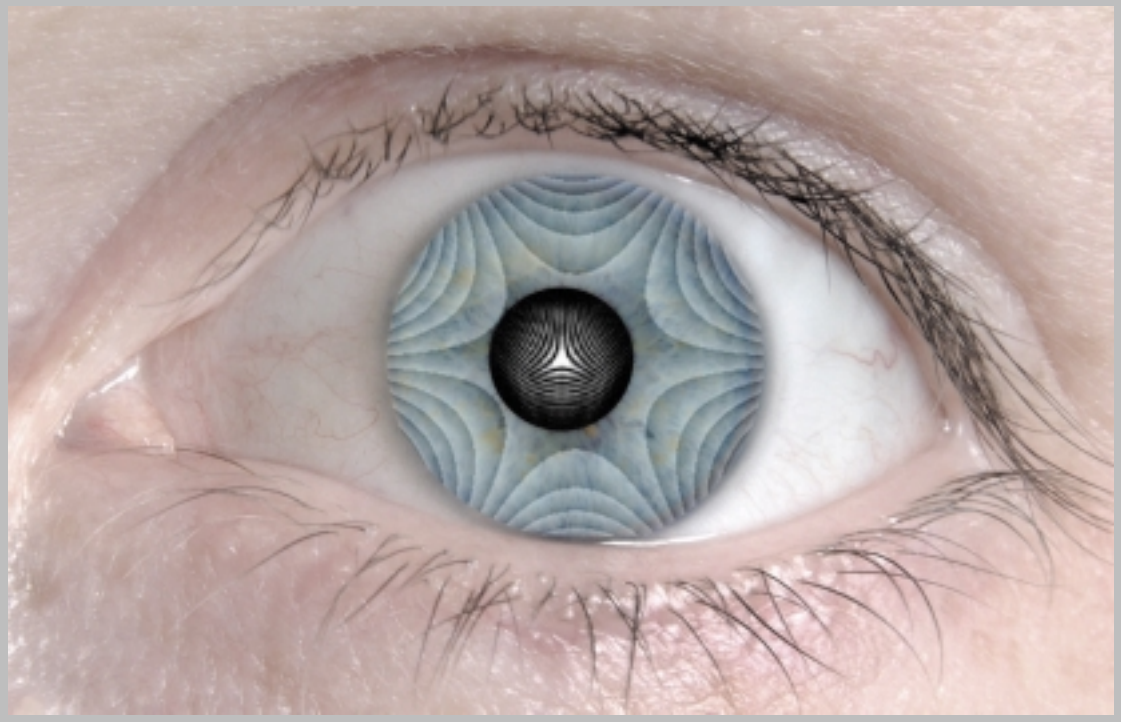

Commercial Relationship:

Bausch and Lomb

Funding:

Bausch and Lomb

NSF Science and Technology
Center for Adaptive Optics

Collaborators:

Univ of Rochester:

Li Chen
Nathan Doble
Heidi Hofer
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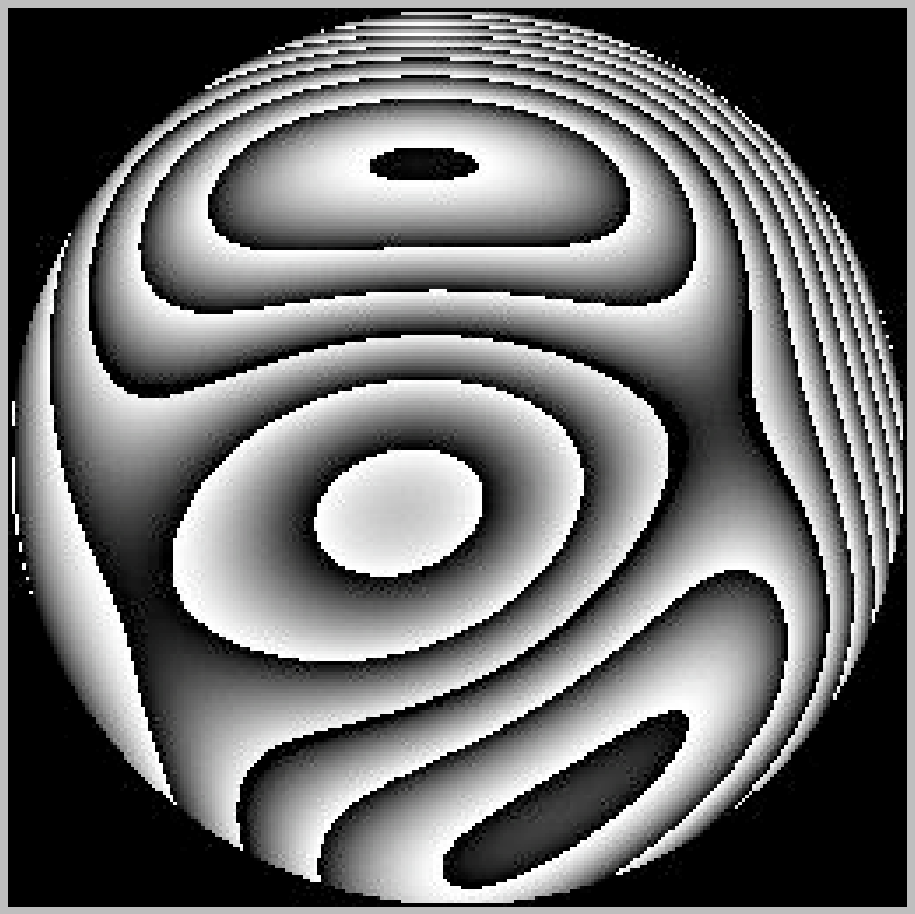
Jason Porter
Ben Singer
Remy Tumbar

Ian Cox, Bausch and Lomb
Ray Applegate, University of Houston
Larry Thibos, Indiana University

How Bad Is This Wave Aberration?



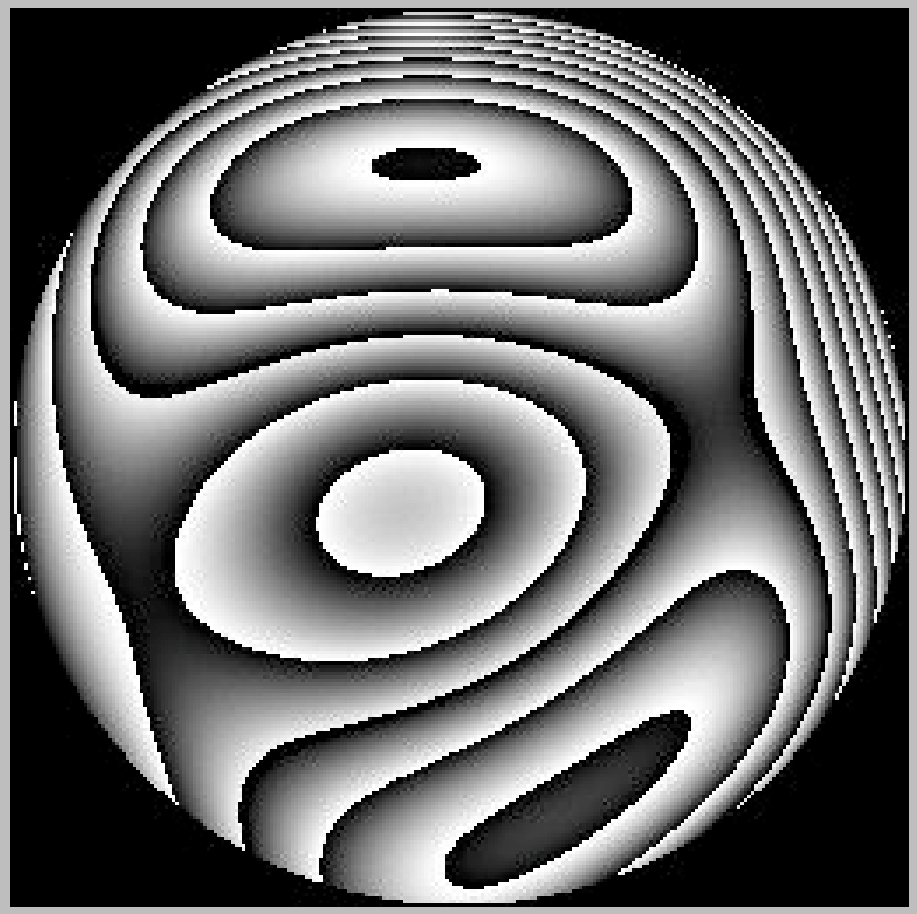
Goal:

To compute a number that captures the subjective effect of the eye's wave aberration.

Uses:

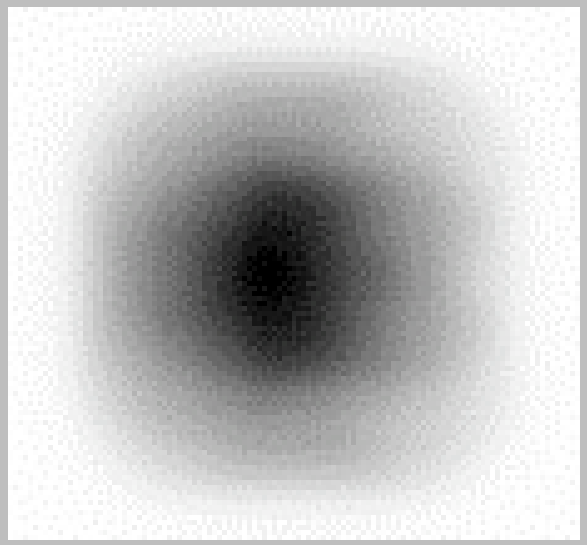
Assessing severity of the wave aberration
Calculating the best correction

How Bad Is This Wave Aberration?

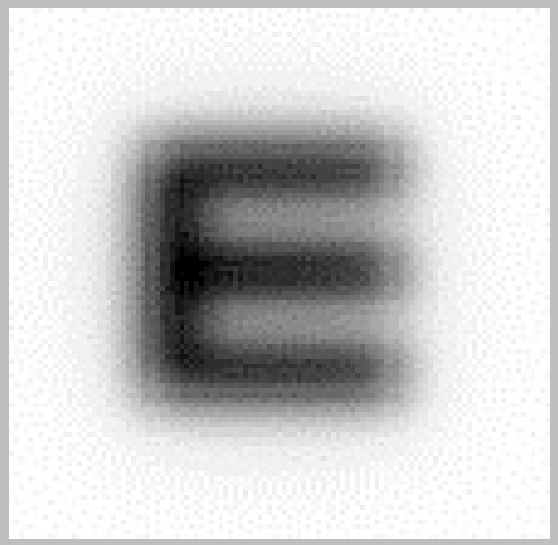


RMS Wavefront Error = 0.87 μm

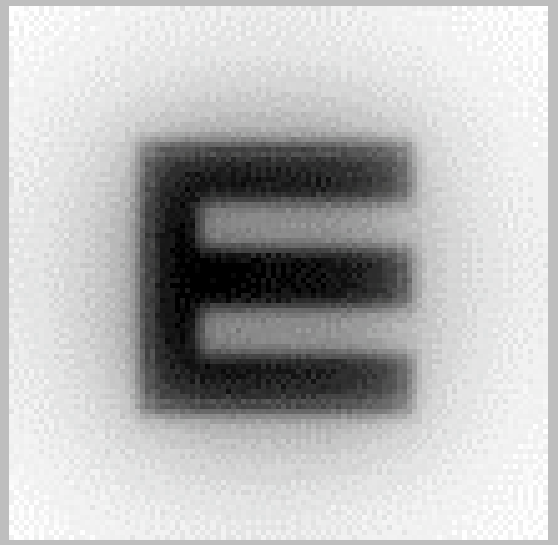
Some Aberrations Interact Strongly in Image Blur



Defocus
rms = 0.5 μm



Spherical Aberration
rms = 0.16 μm

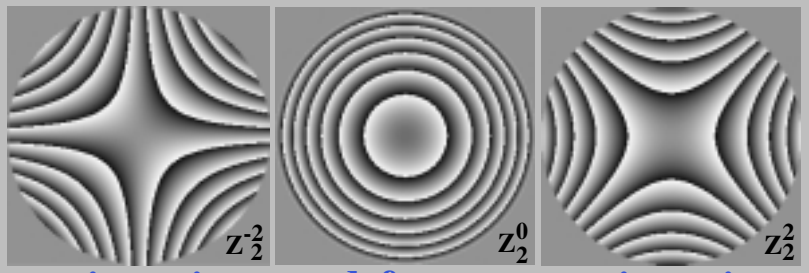


Defocus and Spherical Aberration
rms = 0.52 μm

Zernike Modes

radial order

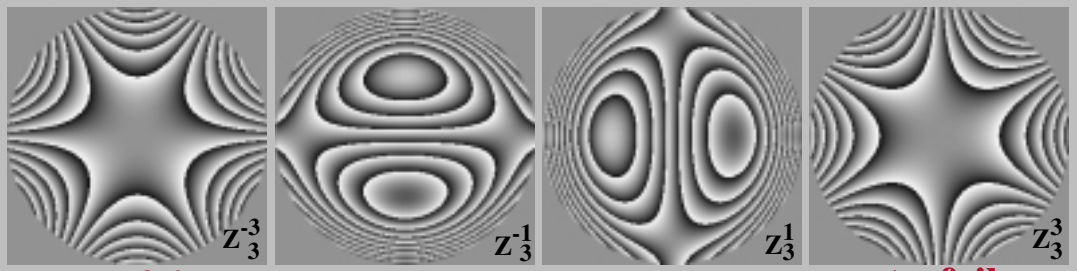
2nd



astigmatism defocus astigmatism

Lower Order Aberrations

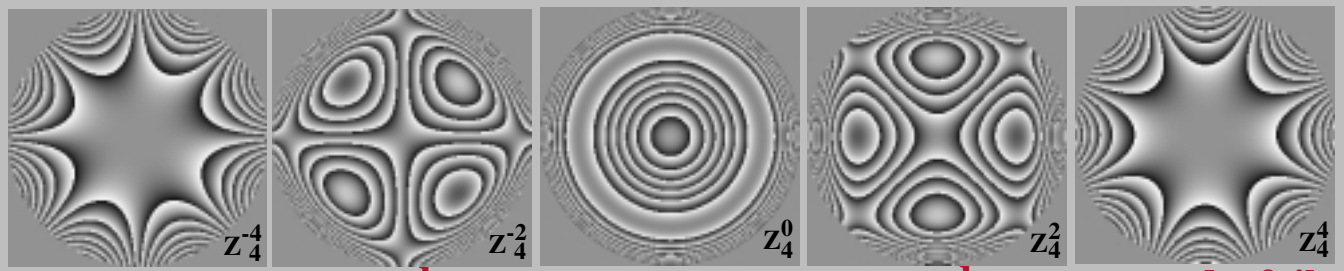
3rd



trefoil coma coma trefoil

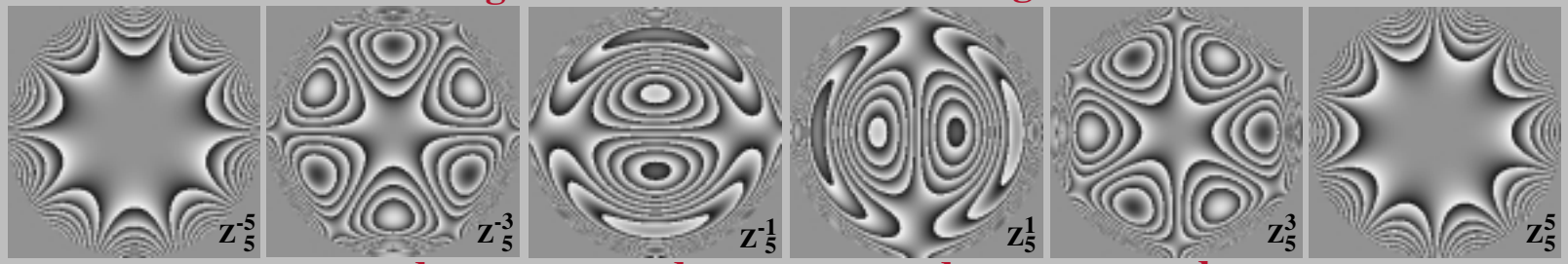
Higher Order Aberrations

4th



quadrafoil secondary astigmatism spherical secondary astigmatism quadrafoil

5th

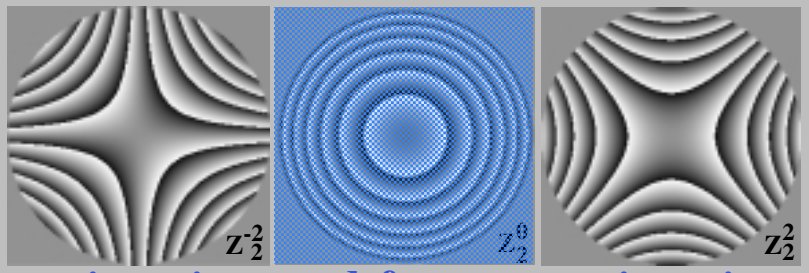


pentafoil secondary trefoil secondary coma secondary coma secondary trefoil pentafoil

Zernike Modes

radial order

2nd



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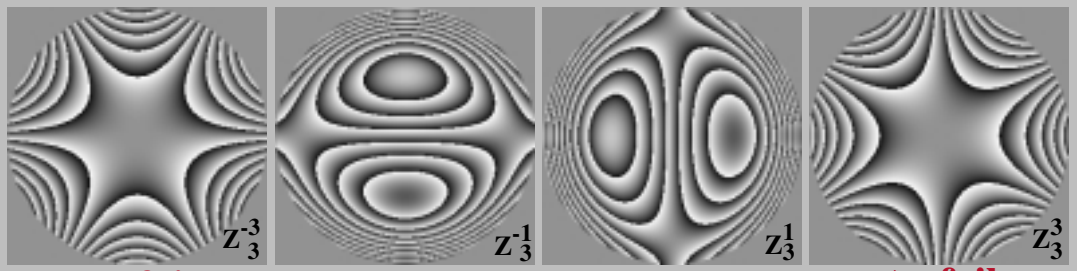
Lower Order Aberrations

3rd



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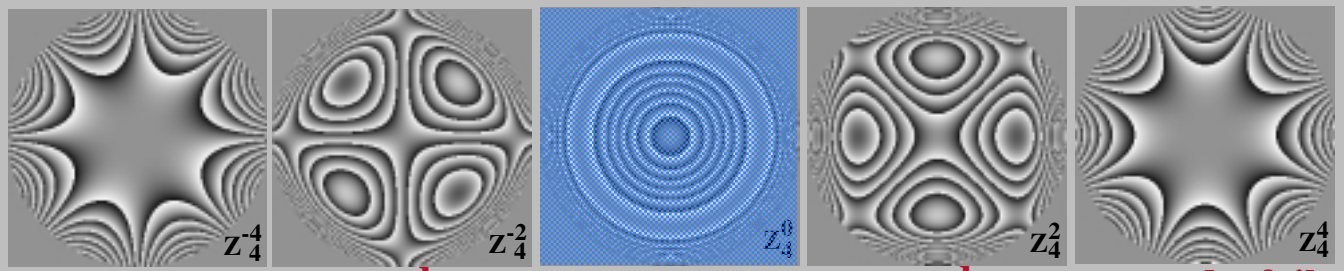
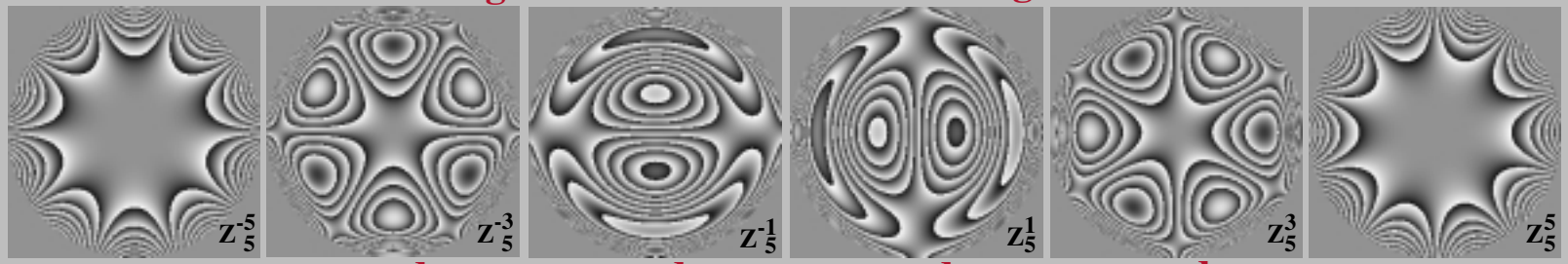


quadrafoil secondary astigmatism spherical secondary astigmatism quadrafoil

5th

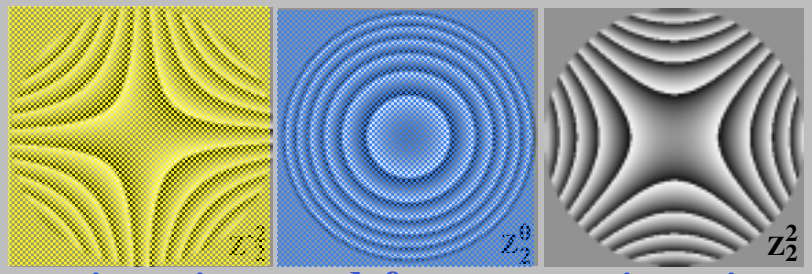


pentafoil secondary trefoil secondary coma secondary coma secondary trefoil pentafoil

Zernike Modes

radial order

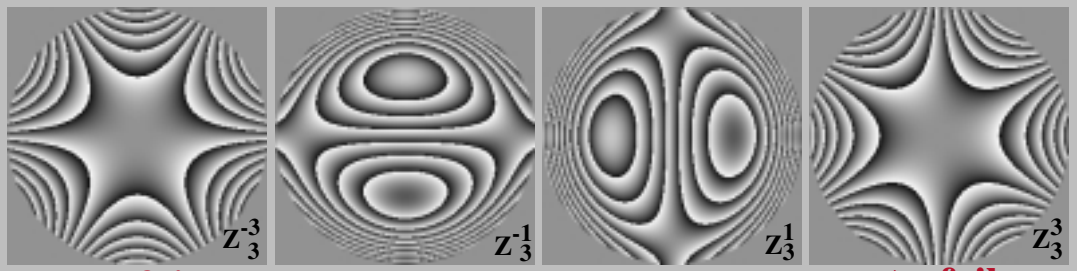
2nd



astigmatism defocus astigmatism

Lower Order Aberrations

3rd



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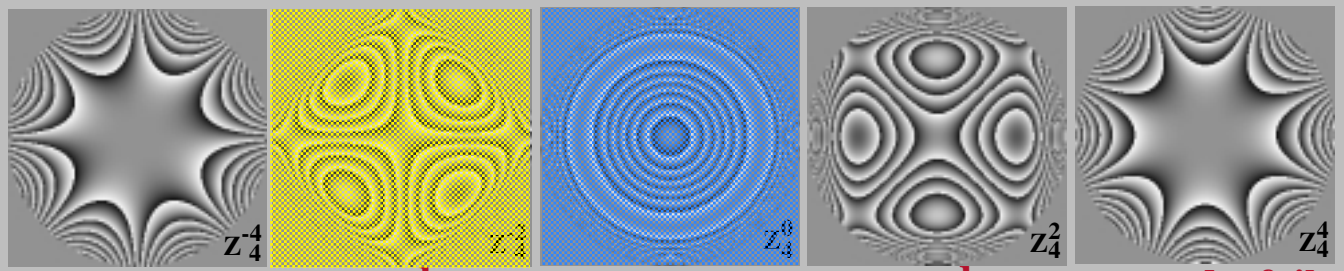
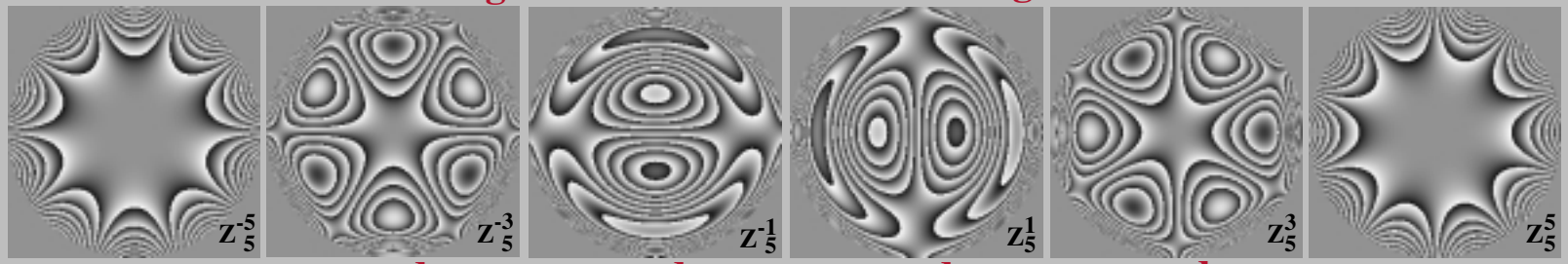


quadrafoil secondary astigmatism spherical secondary astigmatism quadrafoil

5th



pentafoil secondary trefoil secondary coma secondary coma secondary trefoil pentafoil

Zernike Modes

radial order

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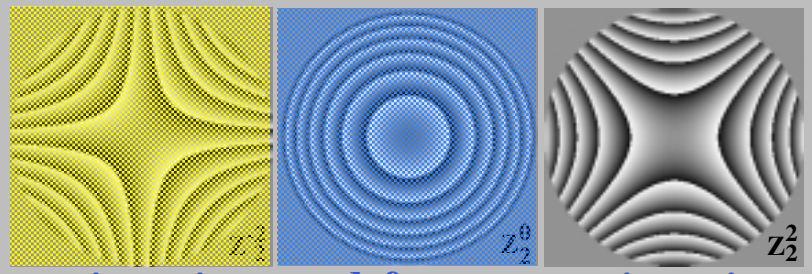
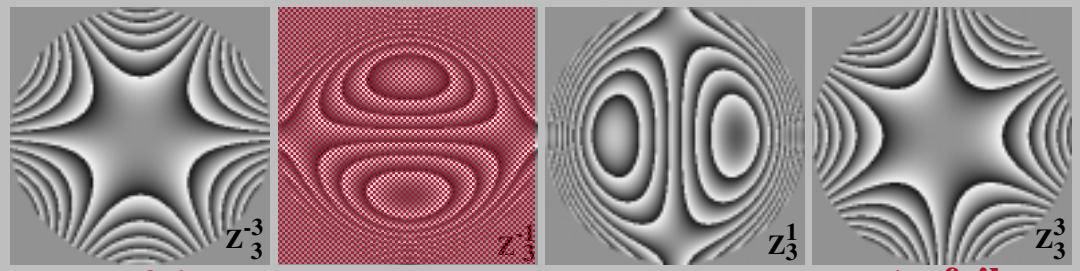


astigmatism defocus astigmatism

Lower Order Aberrations

3rd



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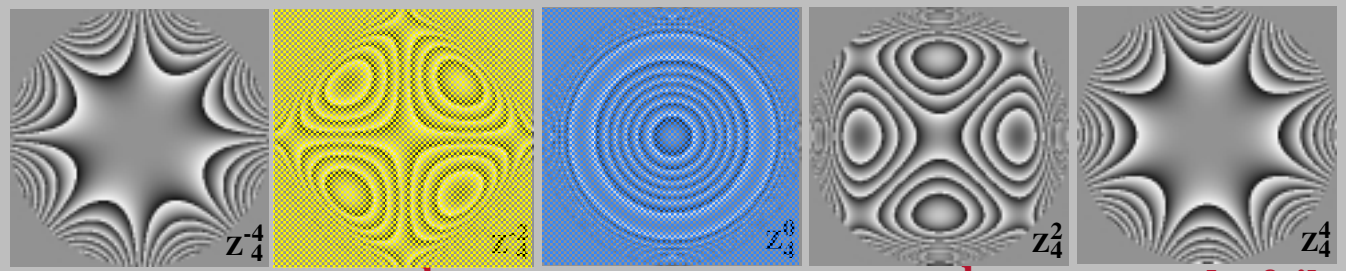
Higher Order Aberrations

4th



quadrafoil secondary astigmatism spherical secondary astigmatism quadrafoil

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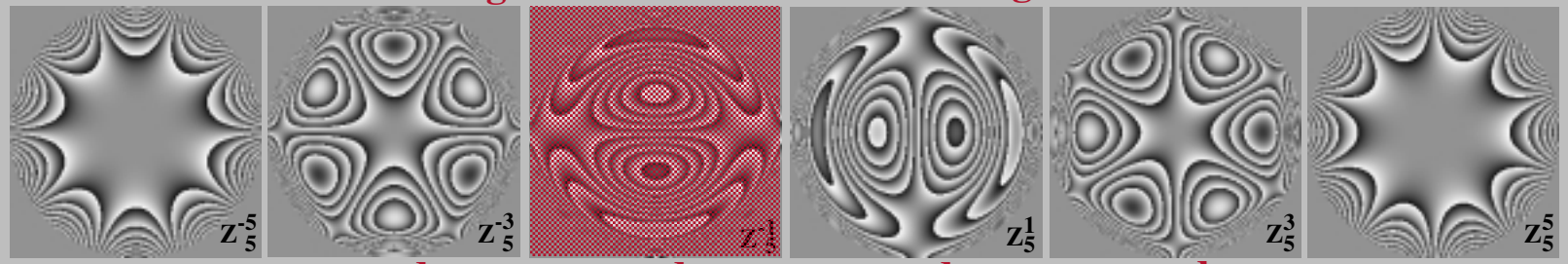
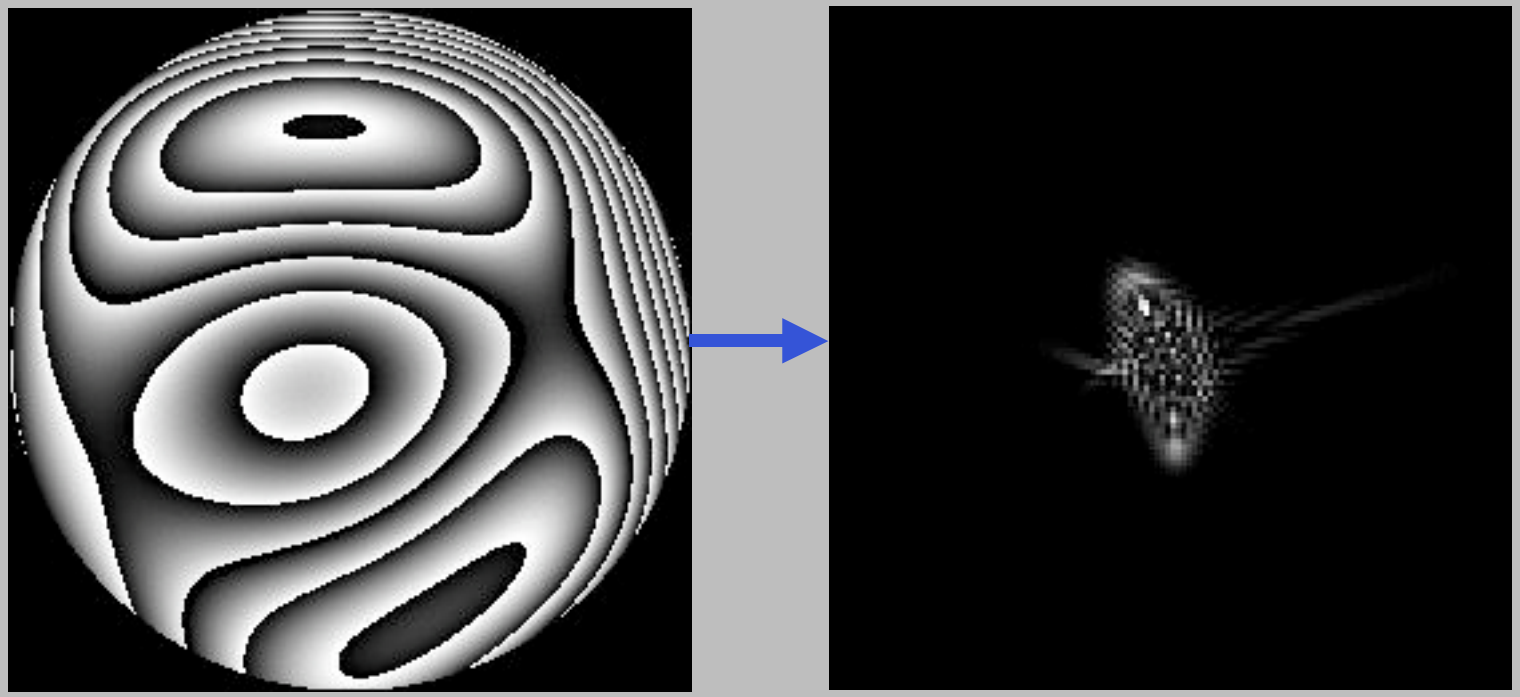


pentafoil secondary trefoil secondary coma secondary coma secondary trefoil pentafoil

There are strong interactions between Zernike Modes.

Therefore,
Decomposing the wave aberration into Zernike modes is not the best way to evaluate the subjective impact of the wave aberration

How Bad is This Wave Aberration?

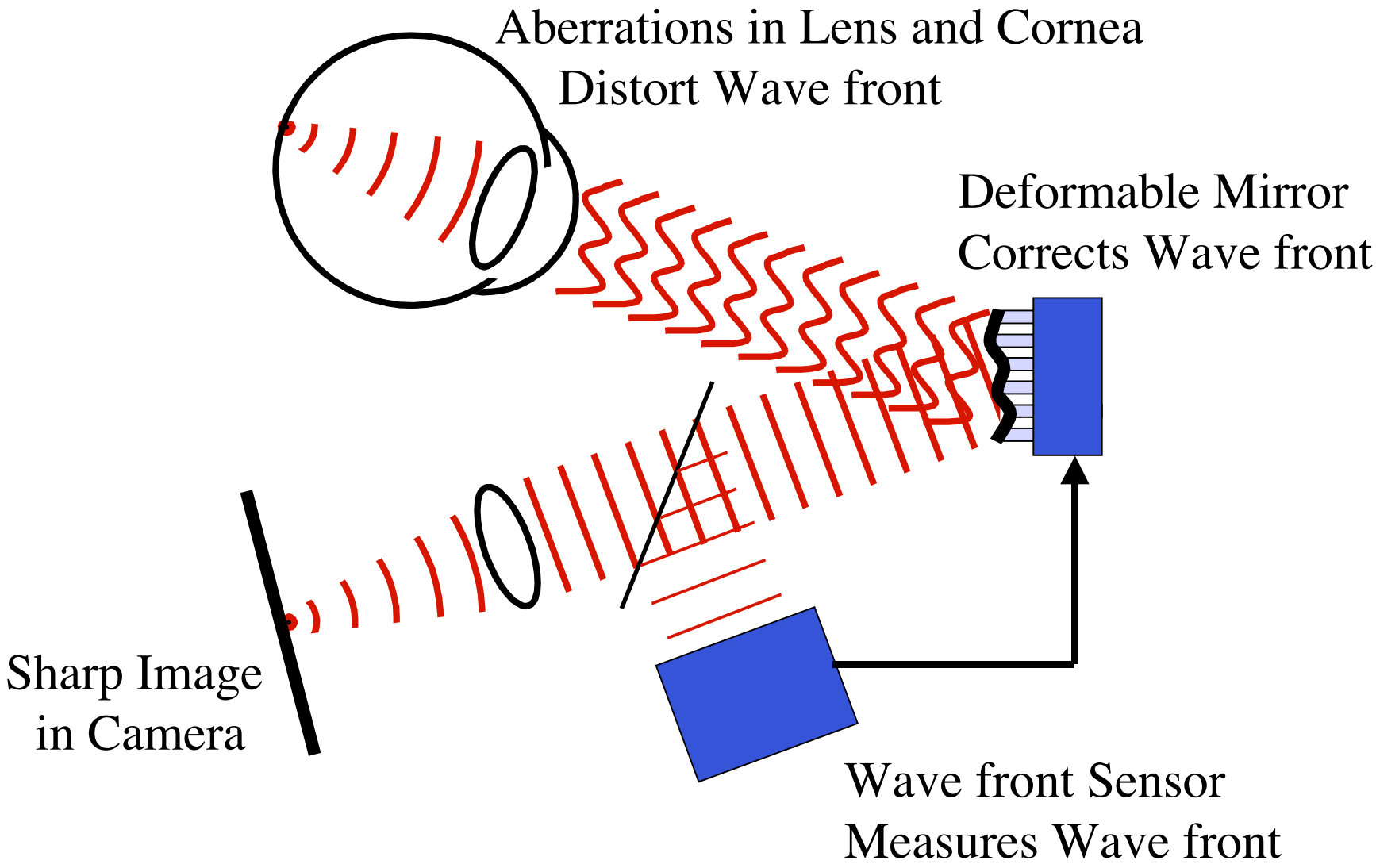


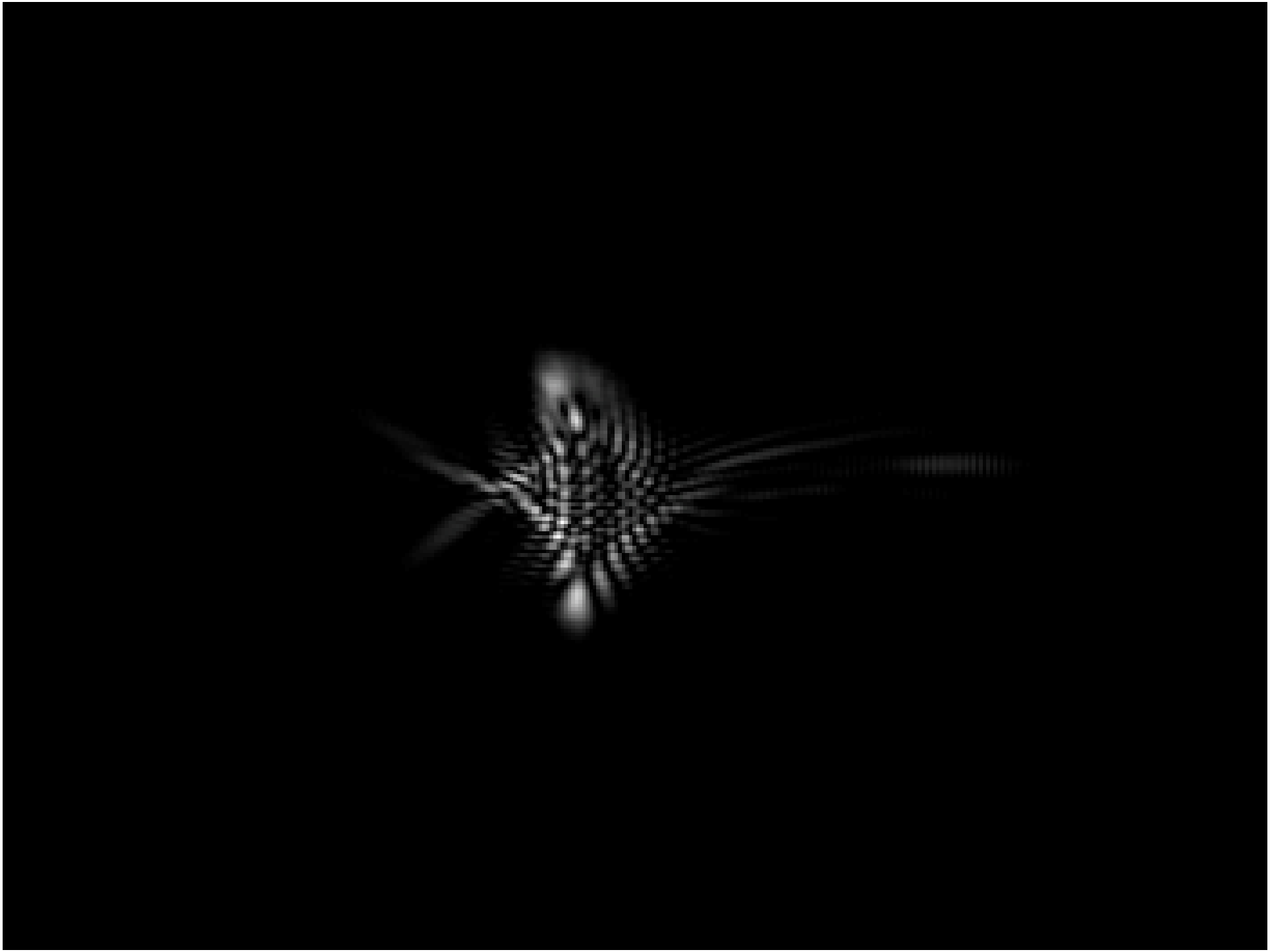
Wave Aberration

Point Spread Function

Use Retinal Image Quality, Not the Wave Aberration

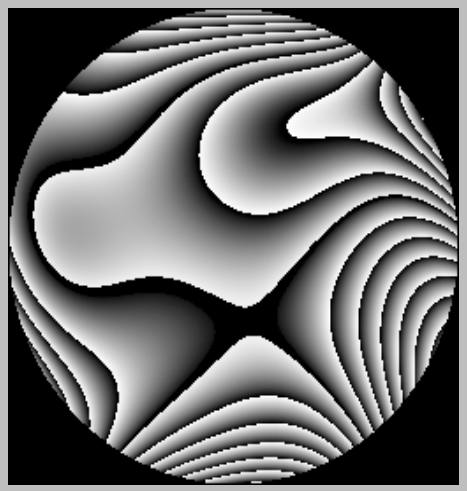
Principle of Adaptive Optics





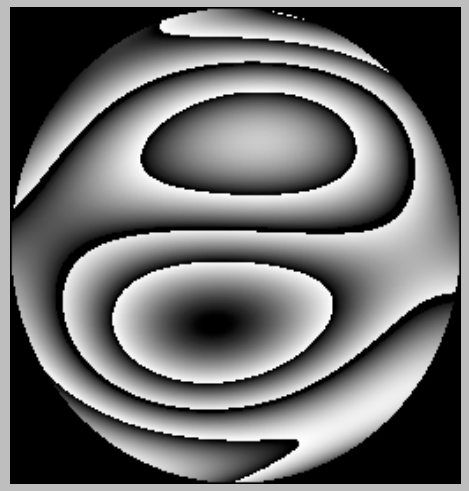
Adaptive Optics Can Create Wave Aberrations

(Subject: ND)

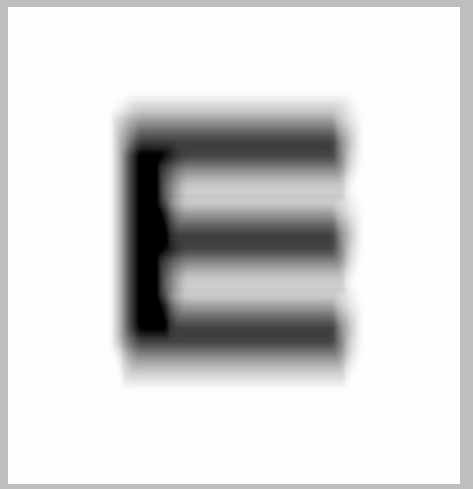


Wave Aberration

After AO correction

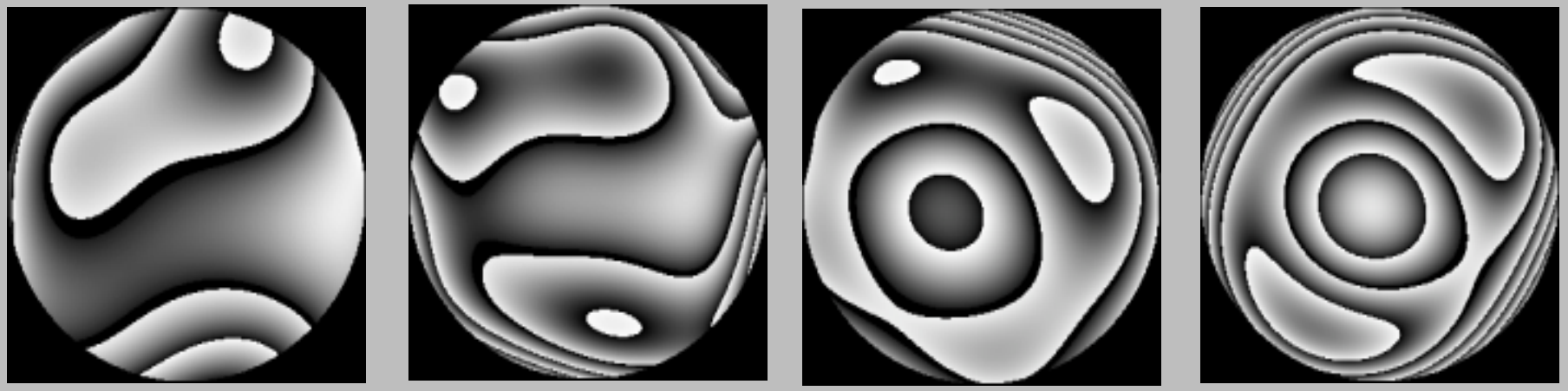


With coma added



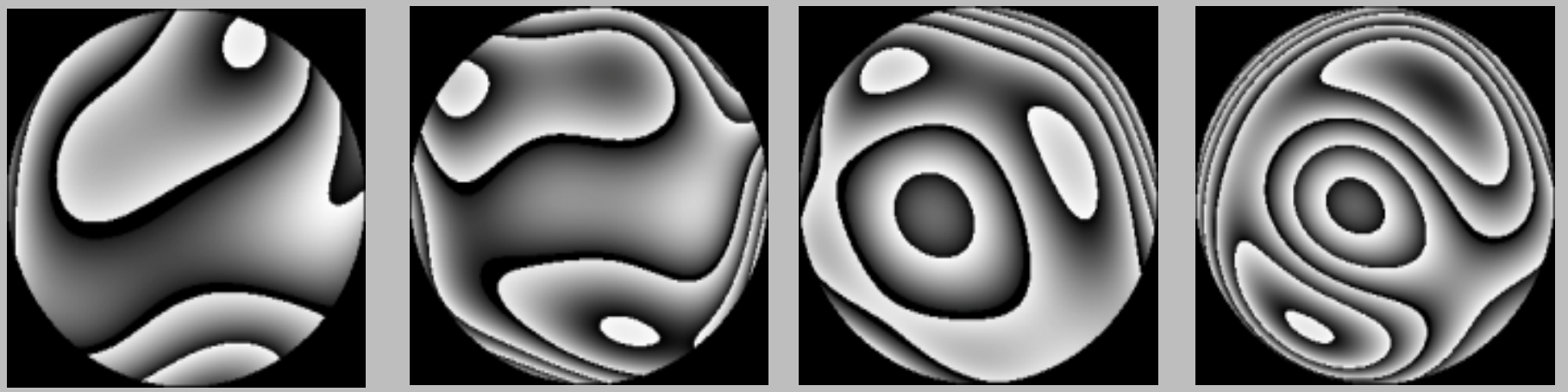
Convoluted retinal image

Wave aberrations from Lasik postOp patient

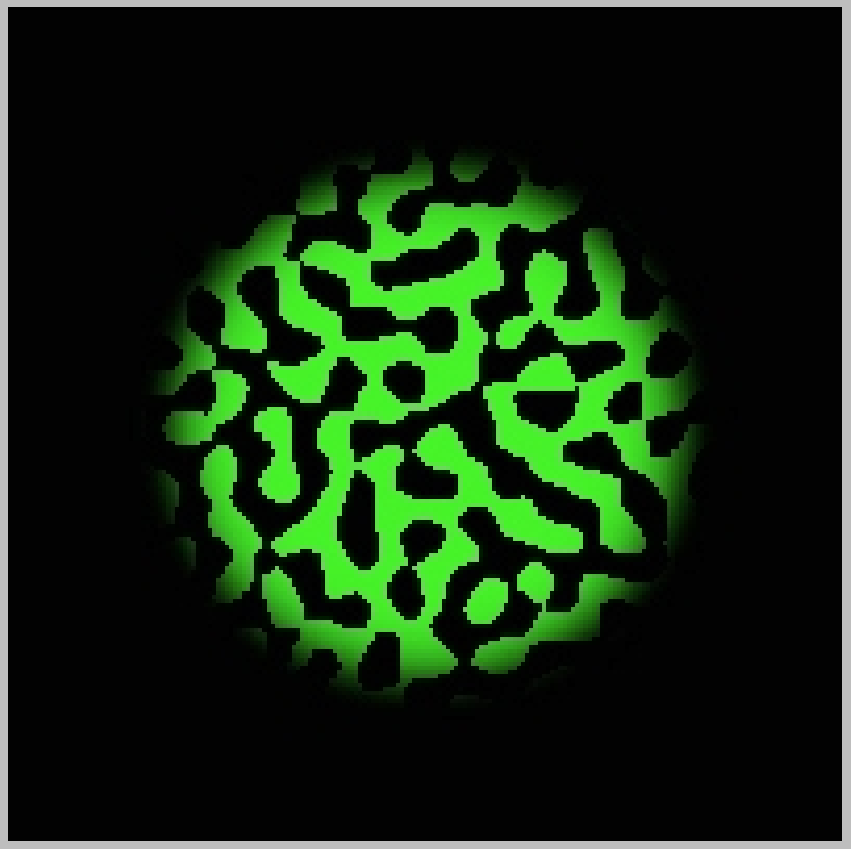


Wave aberrations created by adaptive optics

(With real eye, JP)



Blur Matching



550 nm, 1 deg, 6 mm pupil

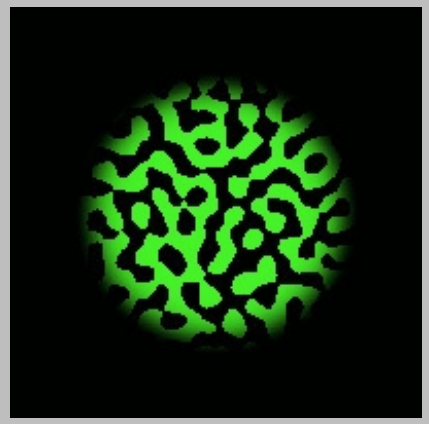
Binary Noise Stimulus

- Lots of Sharp Edges
- Edges At All Orientations
- Seen Through Adaptive Optics

Blur Matching of Patient Wave Aberrations

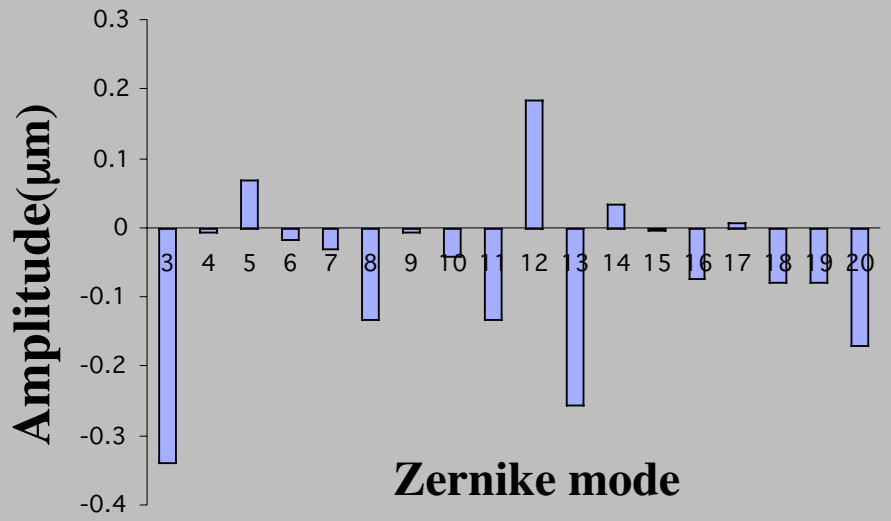
The subject adjusted the amplitude of defocus so that the subjective blur matched that of the patient wave aberration.

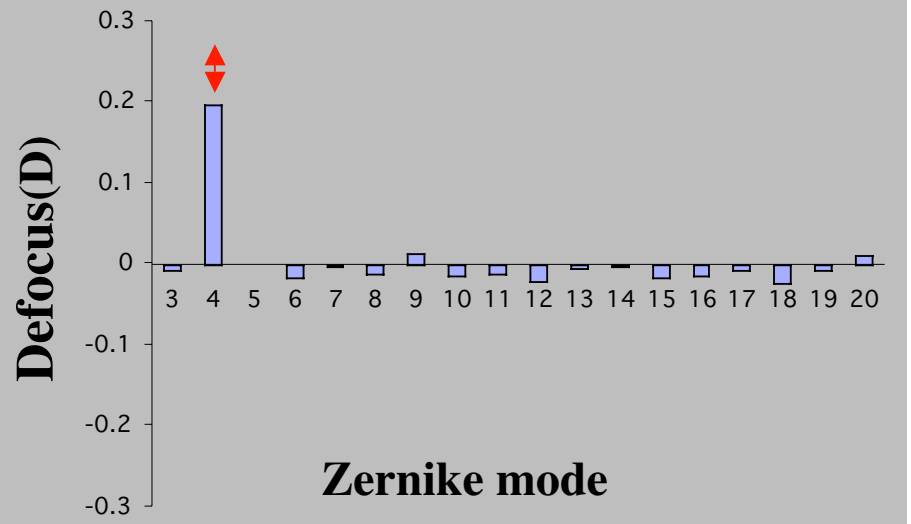
Patient wave aberration



Stimulus

Defocus





Blur Matching Controls for Neural Differences between Patients

Using Multiple Subjects Controls for Neural Adaptation

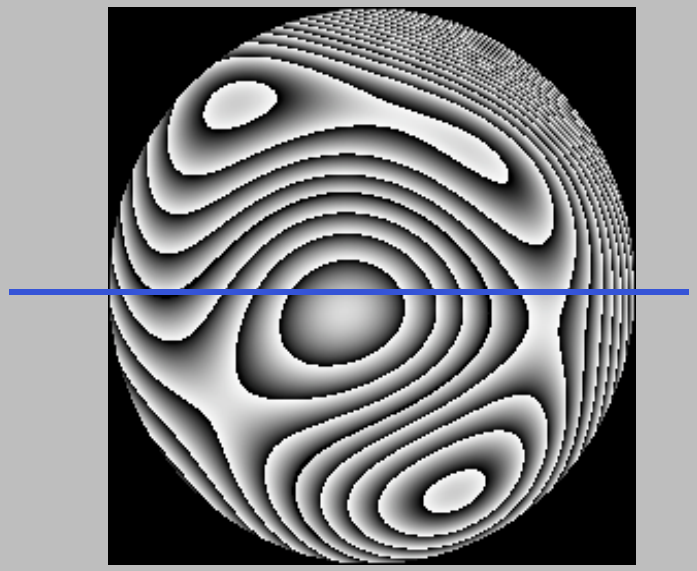
Acuity does not always capture the subjective quality of vision

Equal Acuity But Different Subjective Image Quality

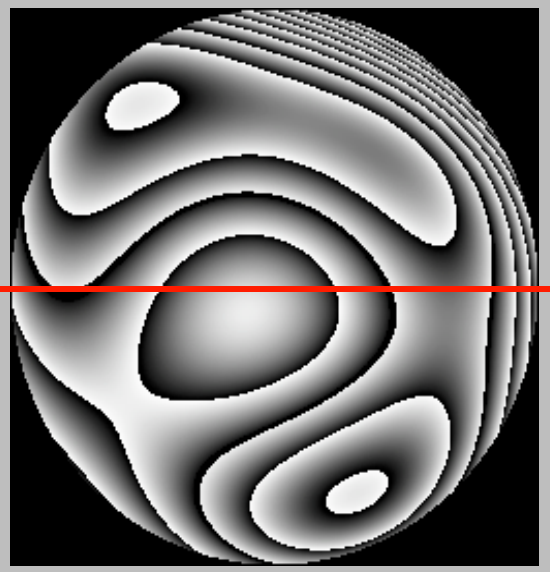
Compare Subject Matches with Matches Made Using Three Different Metrics

Wavefront RMS
Strehl Ratio
Neural Sharpness

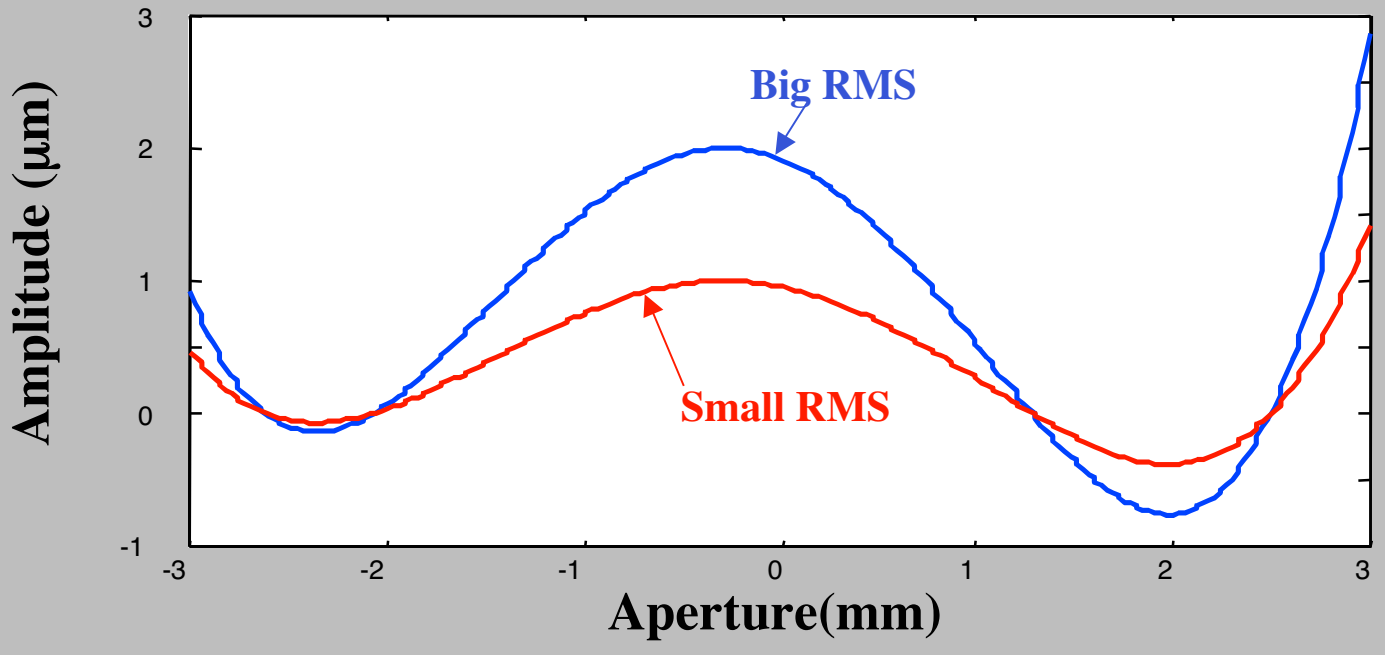
Wave Aberration RMS



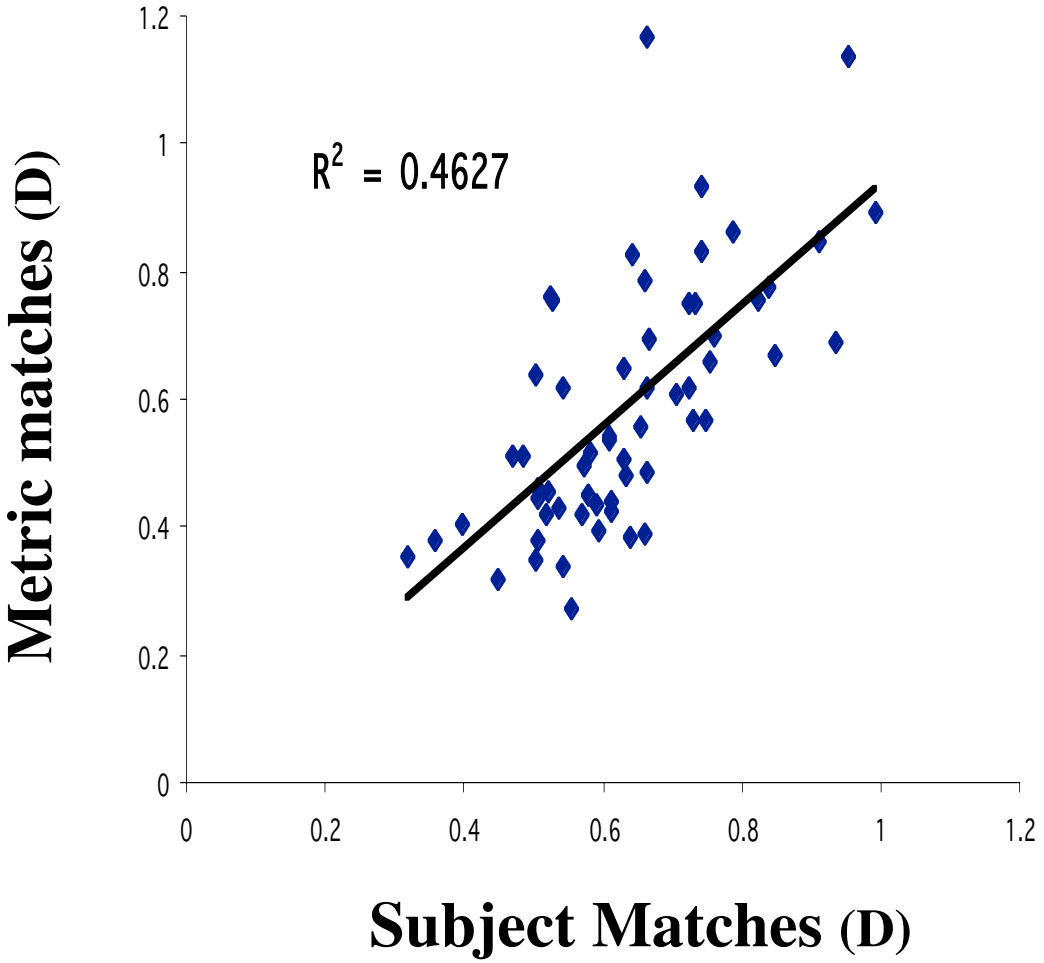
Big RMS



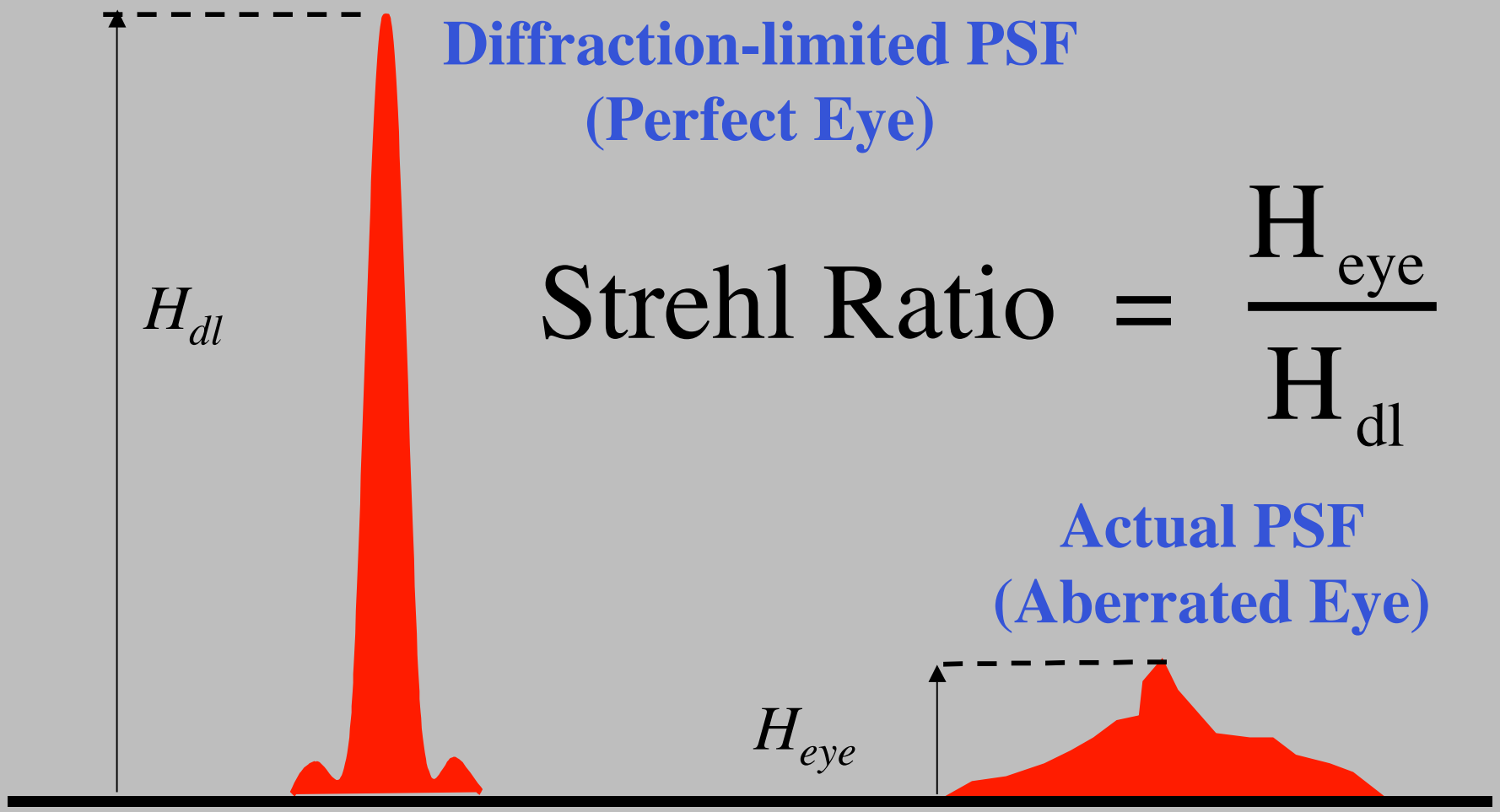
Small RMS



RMS Metric

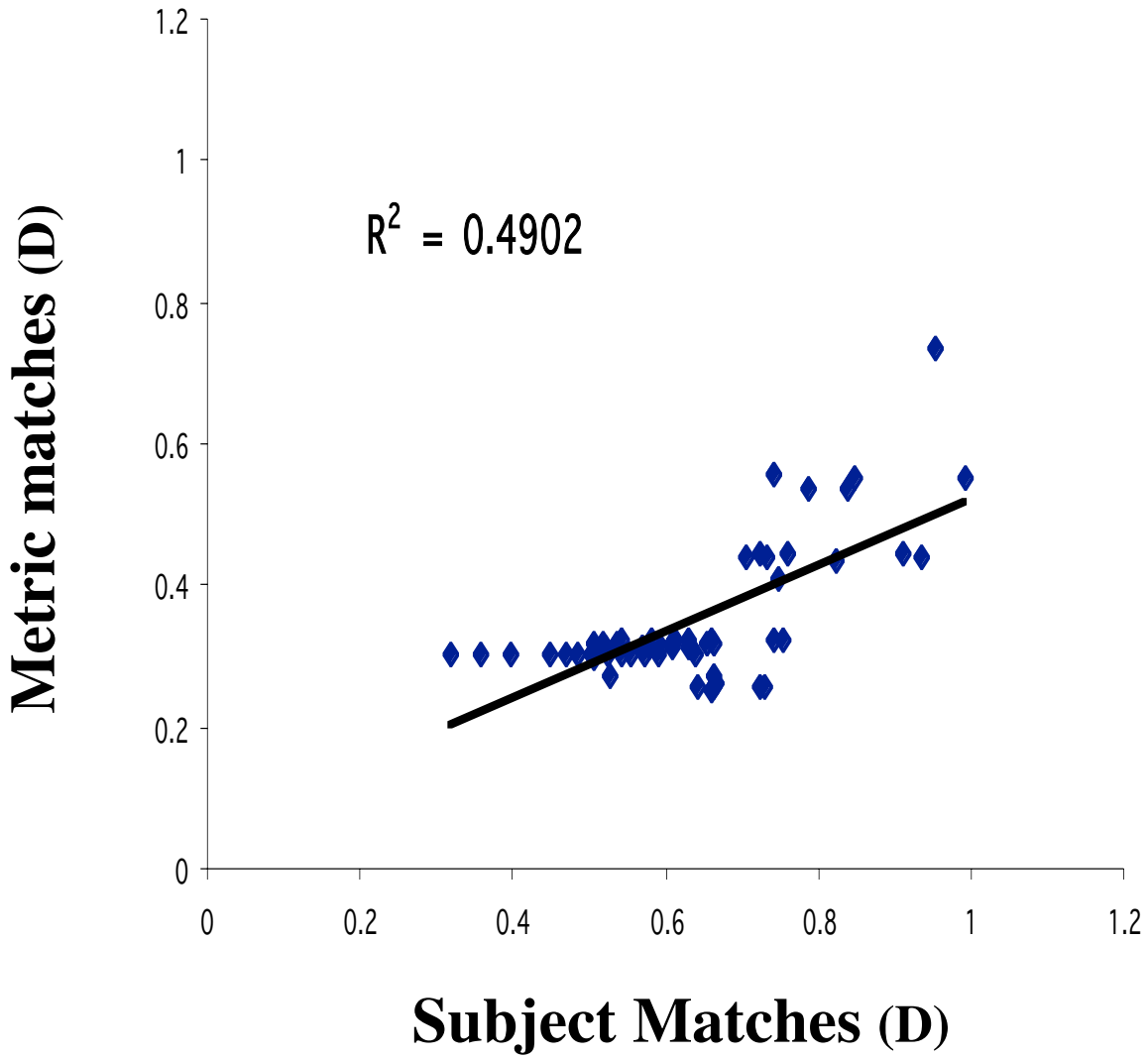


Strehl Ratio of Point Spread Function



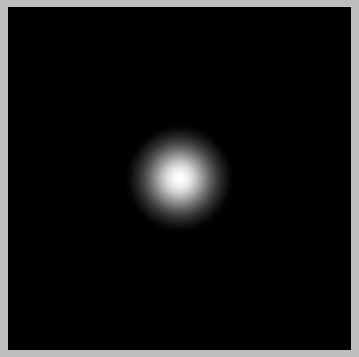
C. of Austin Roorda

Strehl Ratio Metric

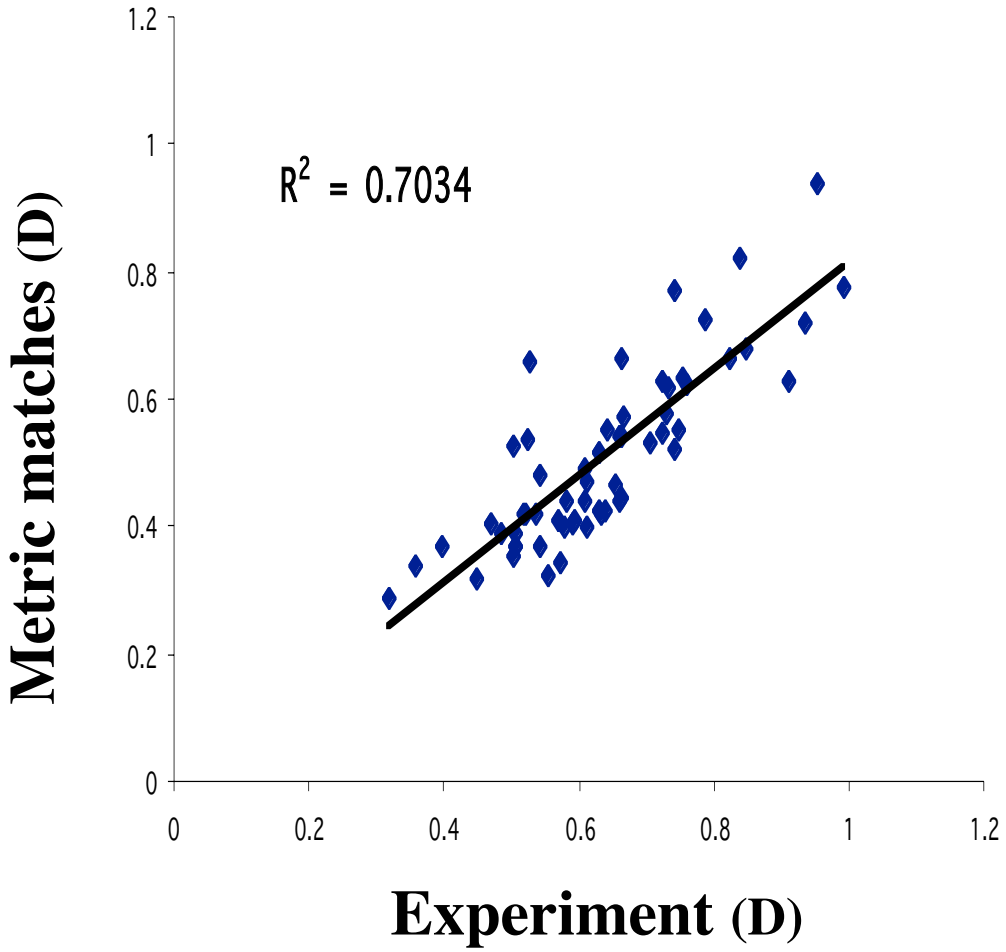


A Simple, Biologically-Plausible Metric for Subjective Image Quality

$$\sum \left(\text{Point Spread Function} \times \text{Gaussian Neural Blur } \sigma = 0.8' \right) = \text{Subjective Image Quality}$$

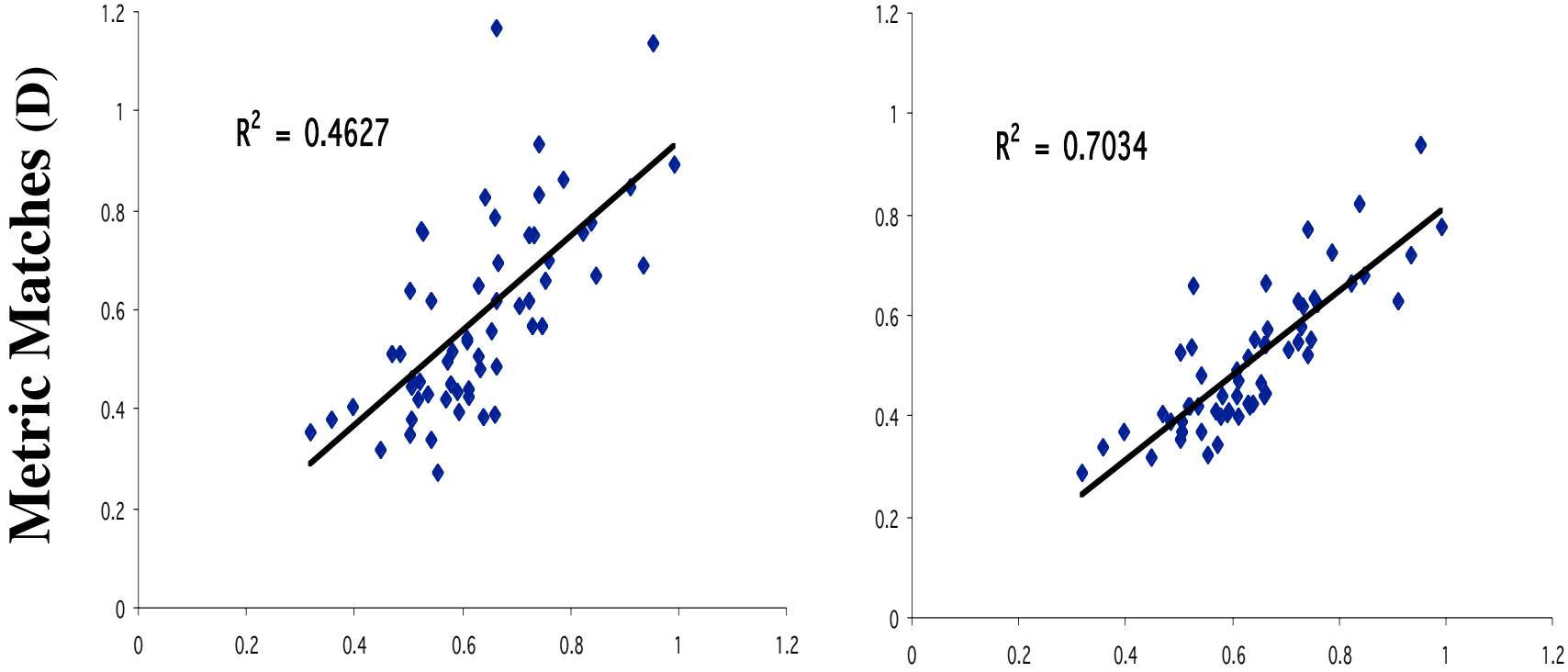


Neural Sharpness Metric



Wavefront RMS

Neural Sharpness



Collaboration to Identify the Optimum Image Quality Metric

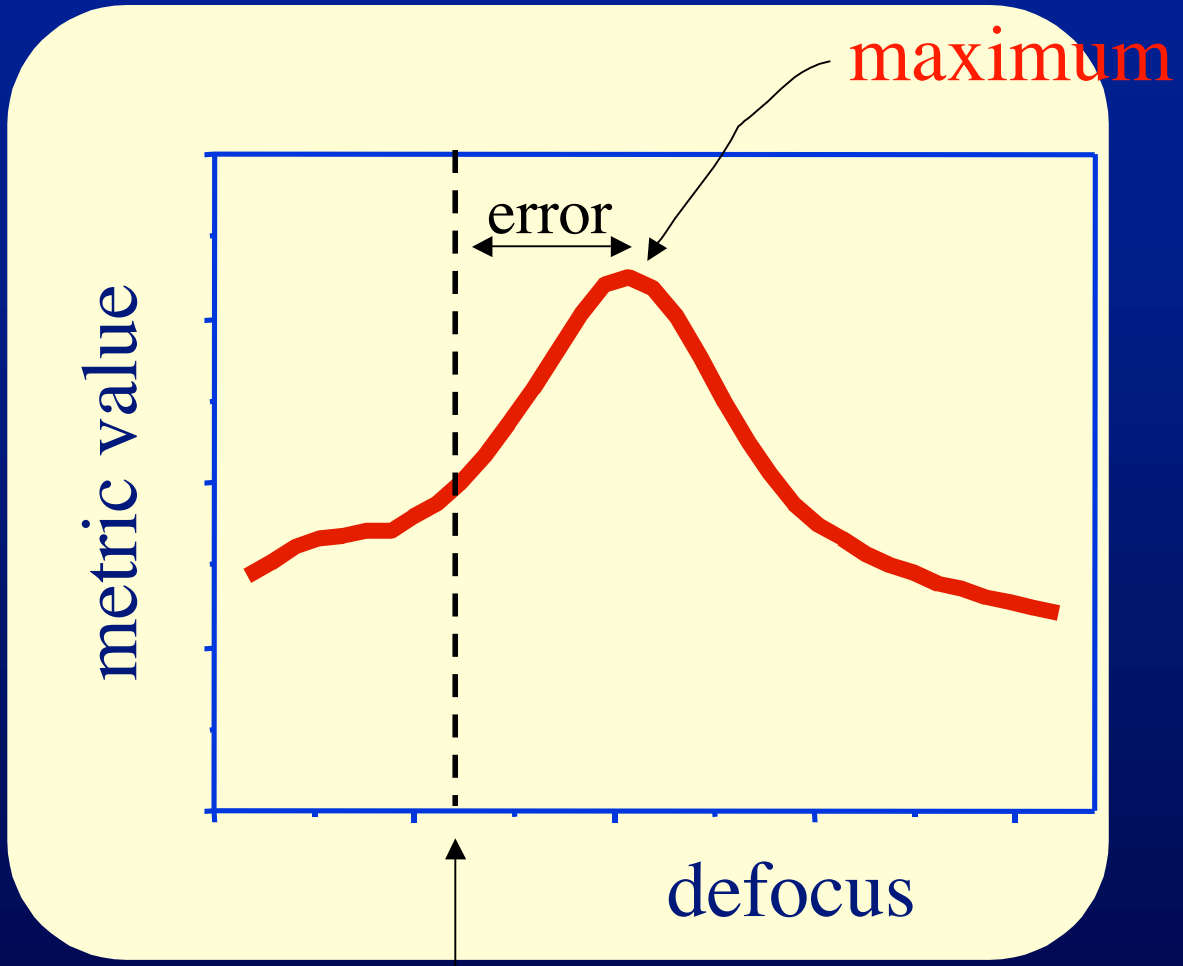
Ray Applegate, University of Houston:
Effectiveness of Image Quality Metrics in Predicting Visual Acuity with Convolution Simulations

David Williams, University of Rochester
Effectiveness of Image Metrics in predicting Subjective Image Quality with Adaptive Optics

Larry Thibos, Indiana University:
Effectiveness of Image Quality Metrics in Predicting Visual Acuity in the Population

Optimizing refraction with an image quality metric

search in 3-D space



Guirao and Williams (2003)

Conclusions

- Generating blur with adaptive optics leads to a robust metric for correcting vision.

- It is hard to estimate subjective blur from the wave aberration. Zernike Decomposition doesn't help much.

- The point spread function combined with a biologically plausible model of neural blur is better.

- Standards for optimizing correction from wavefront are in the works