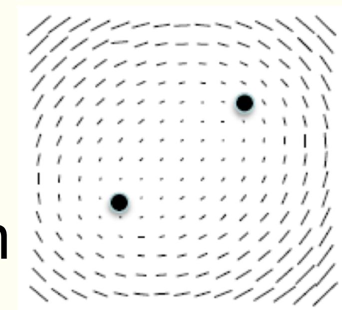
The Aberration Fields of Optical Systems **Without** Rotational Symmetry

- In the 1970s Prof. Shack (UofAz), working from a Star Plate from a recently commissioned telescope on Kitt Peak, an insight from Dick Buchroeder (OSC '77), and a lost vector operation, vector multiplication, discovered **Nodal Aberration Theory**



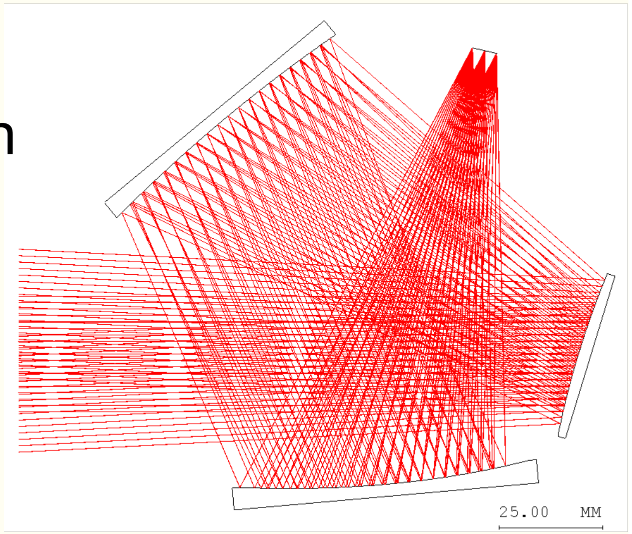
- His key result, which explained the Star Plate anomaly, was the equation for binodal astigmatism

- From here, Thompson (OSC '80) went on to derive the Nodal Aberration Fields for all of the 3rd and 5th order aberrations in Tilted and Decentered optical systems comprised of Rotationally Symmetric surfaces, or, off-axis sections of these surfaces (see JOSA A)

- We are now expanding the theory to include freeform optics

A first Truly Non-Symmetric Optical System

- F/1.9, 10° FFOV Low Cost LWIR Imager
  - Micro-Bolometer
    - 320x240 pixel resolution, 25µm pitch
    - Uncooled
      - Does not need accessible exit pupil
    - Requires fast system F/#
      - Drives up spherical volume of system

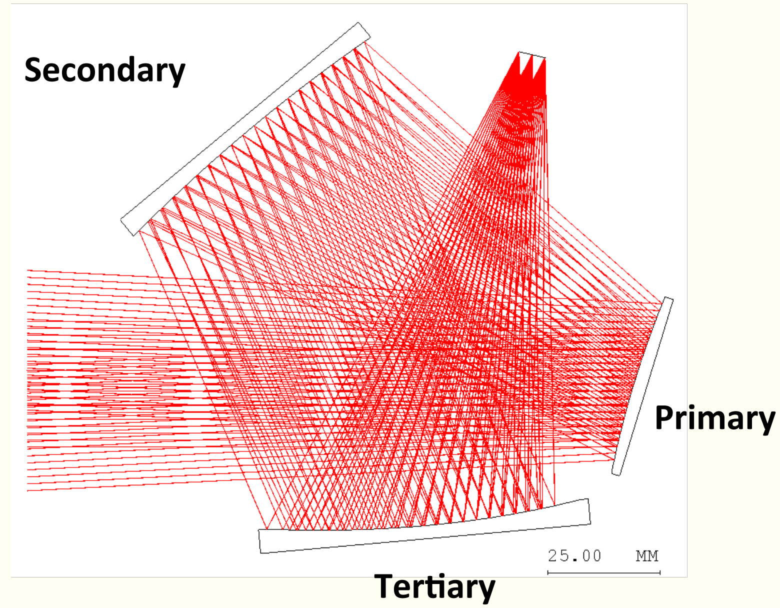


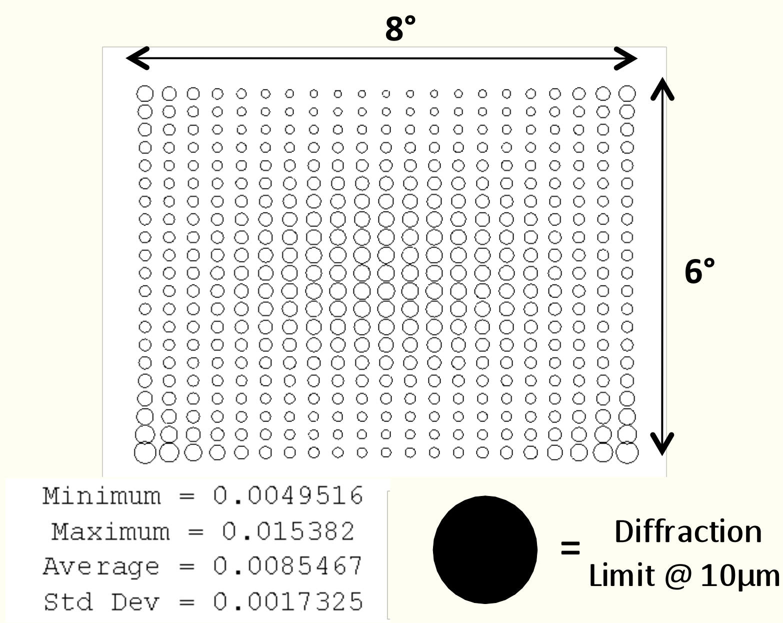
  - Compact Geometry
    - Large input port in small spherical volume
    - Unobscured

Optimized Design

- φ-polynomials are used for optimization in defined manner
  - For field constant correction
  - For field dependent correction

- Possible to reach solution
  - RMS WFE at λ = 10 μm less than $\lambda/50$ over 10° FFOV

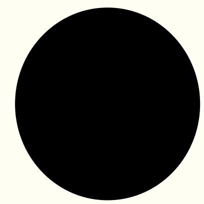




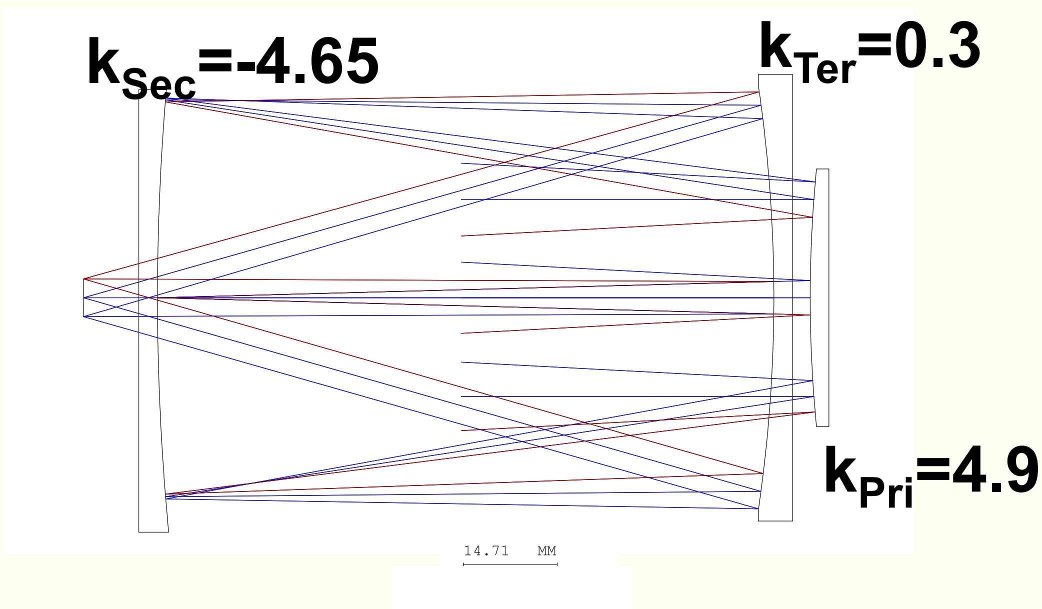
Fuerschbach et al
Opt. Exp. 19(22) (2011)

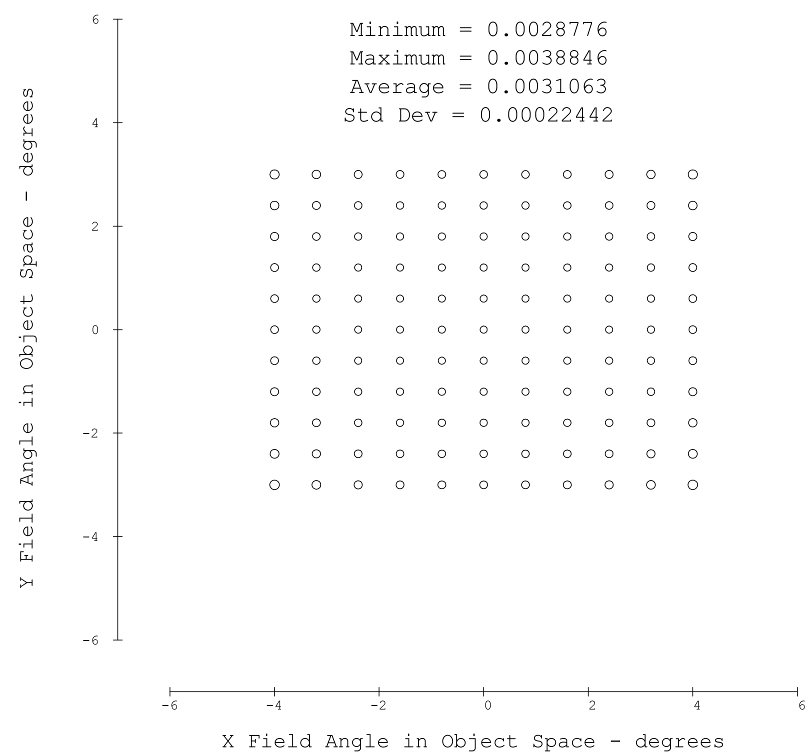
Start with On Axis Solution

- NPP Solution
  - RMS wavefront error less than < λ/250 over 10° FFOV
  - Obscured



= Diffraction Limit @ 10µm

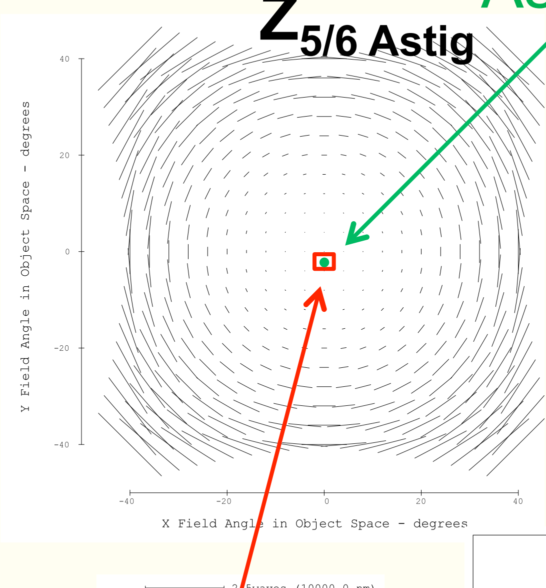


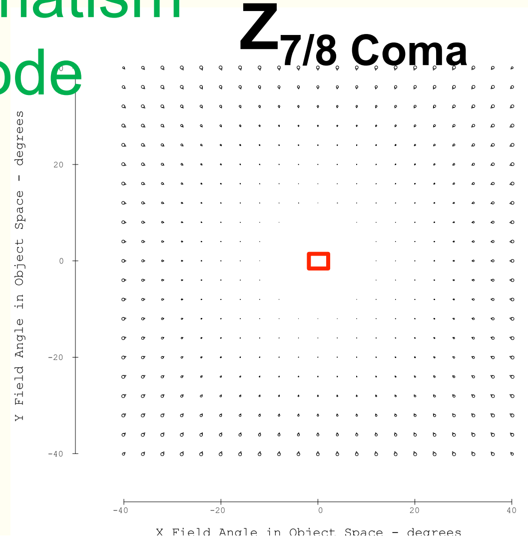


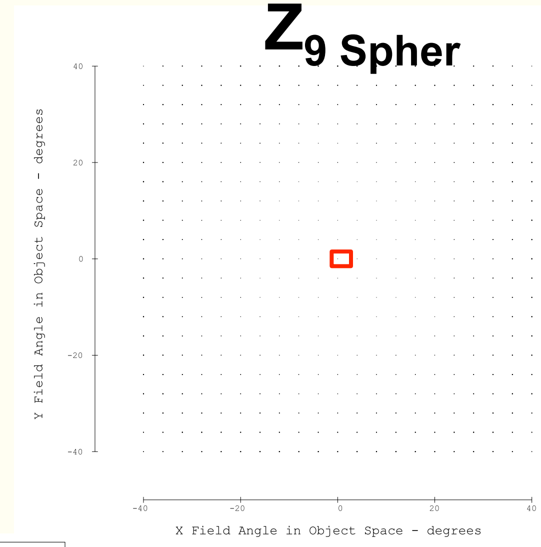
Aberration Contributions

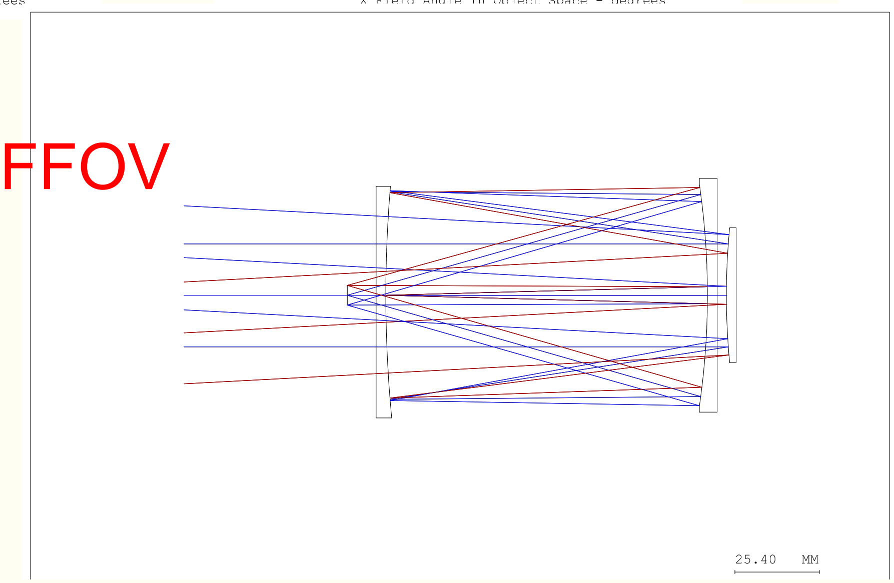
= Diffraction Limit @ 10µm

From On-Axis,
Tilt the Surfaces & Watch the Aberrations



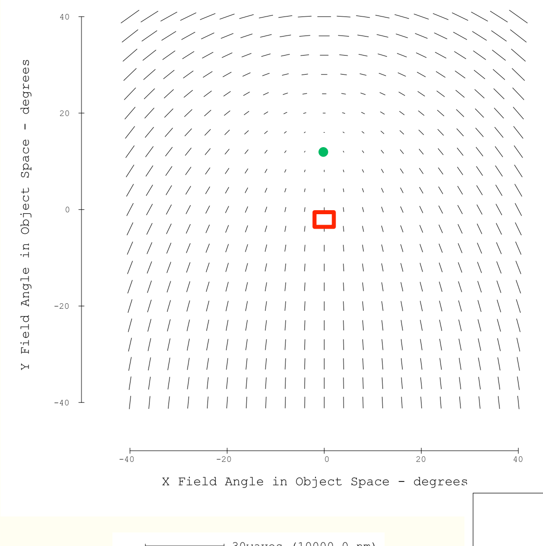




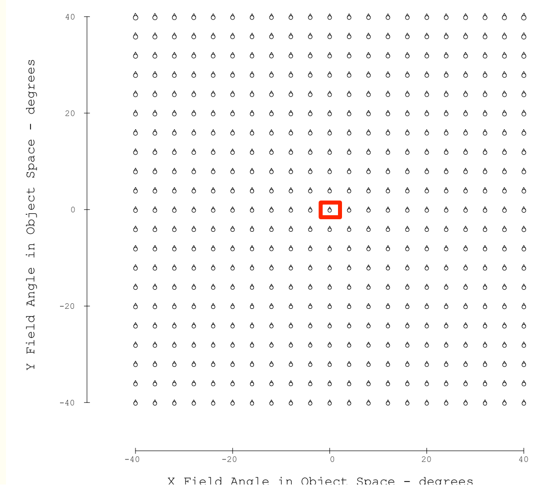


~25% Tilt

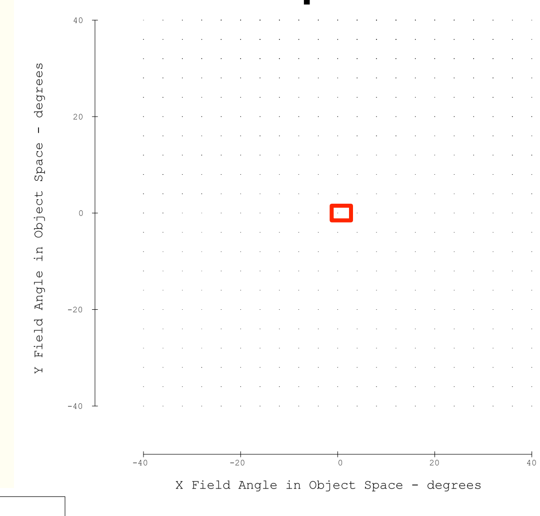
$Z_{5/6}$ Astig

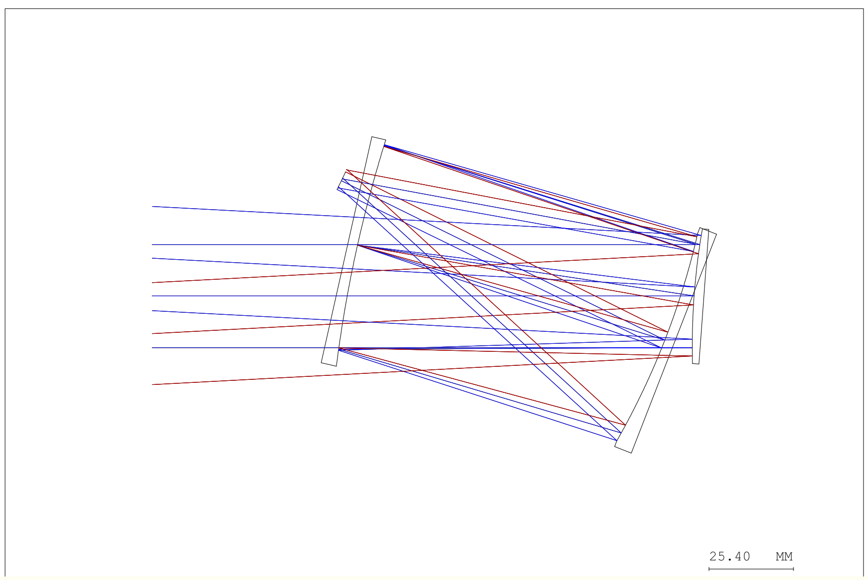


$Z_{7/8}$ Coma



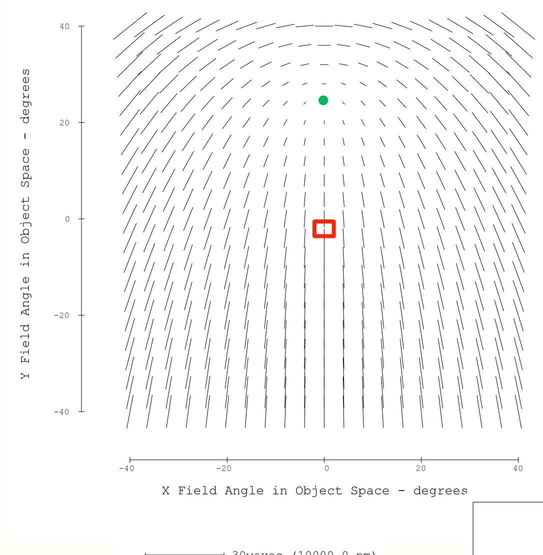
Z_9 Spher



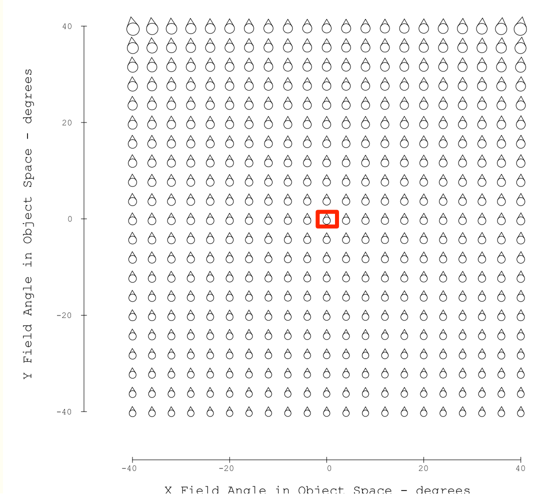


~50% Tilt

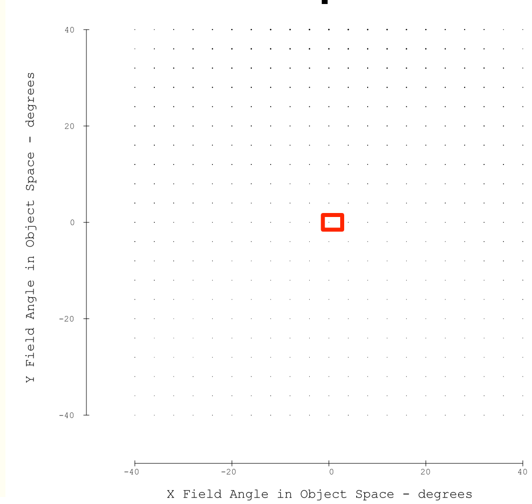
$Z_{5/6}$ Astig

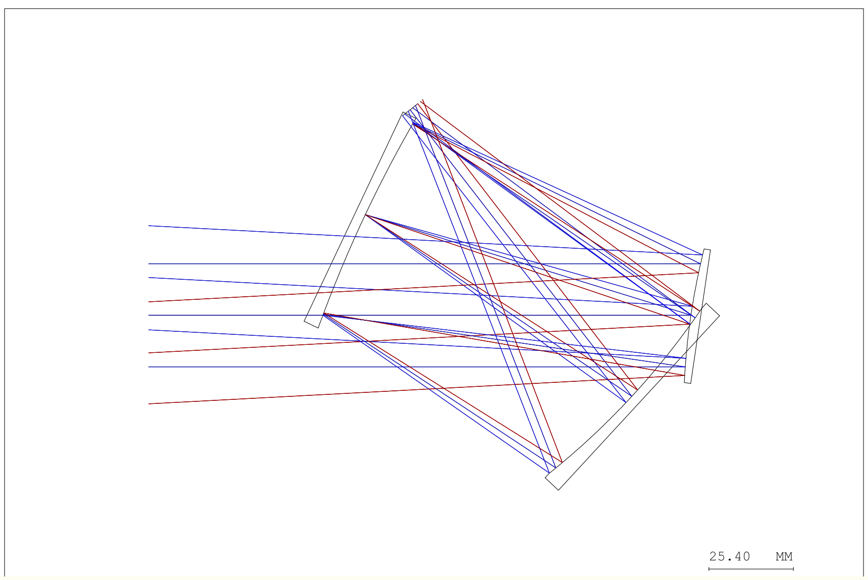


$Z_{7/8}$ Coma



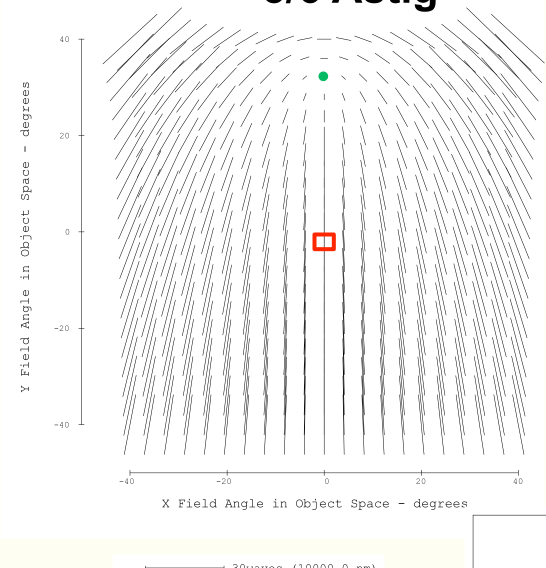
Z_9 Spher



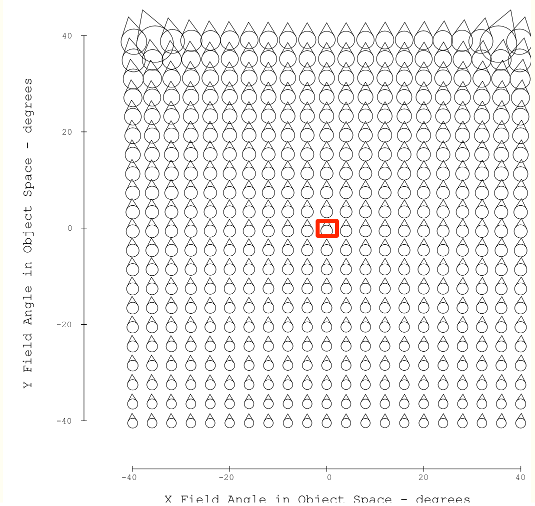


~75% Tilt

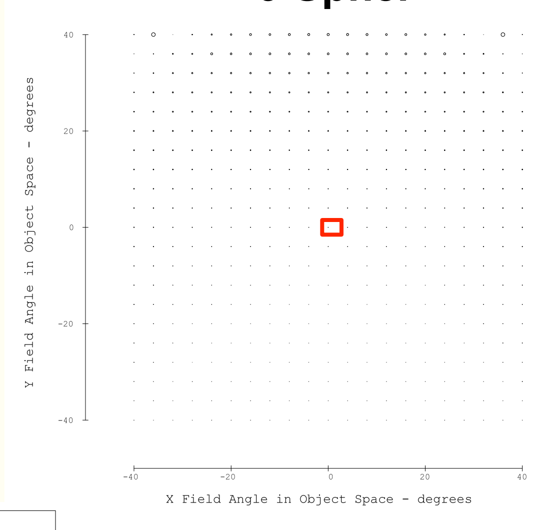
$Z_{5/6}$ **Astig**

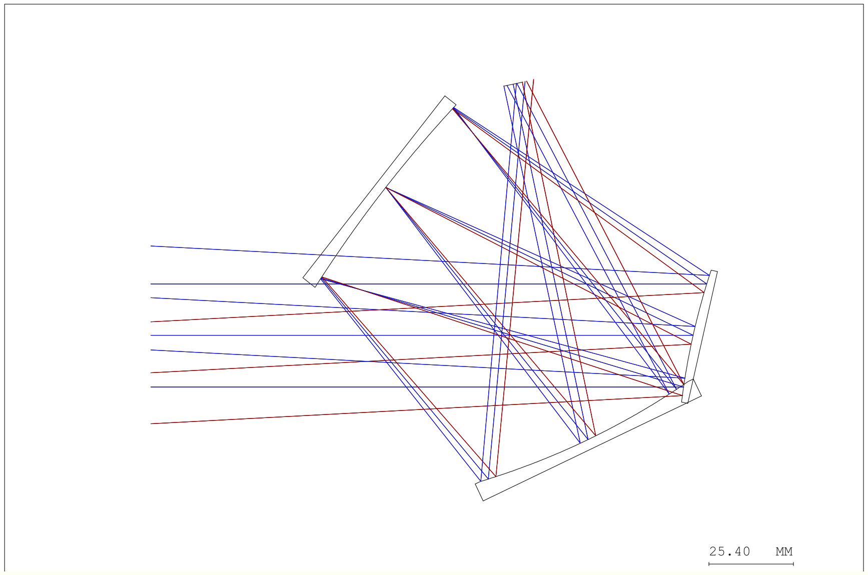


$Z_{7/8}$ **Coma**



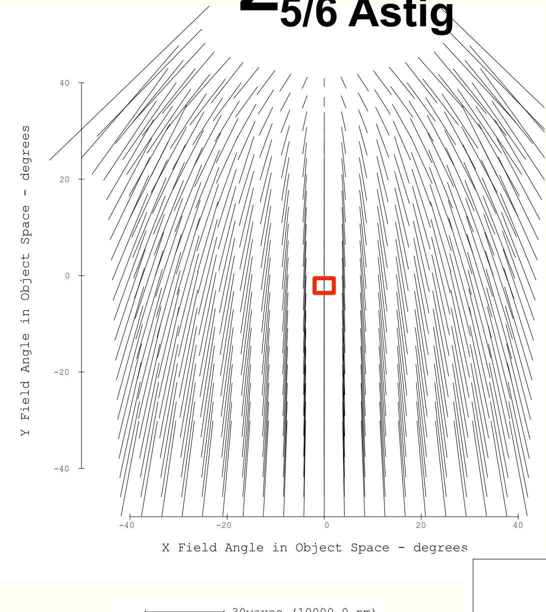
Z_9 **Spher**



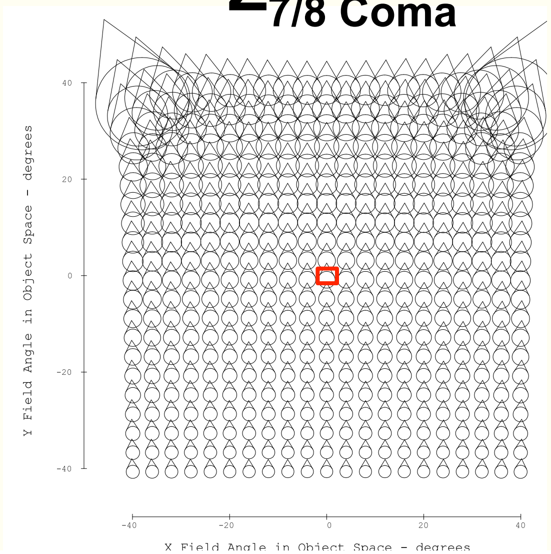


~100% Tilt

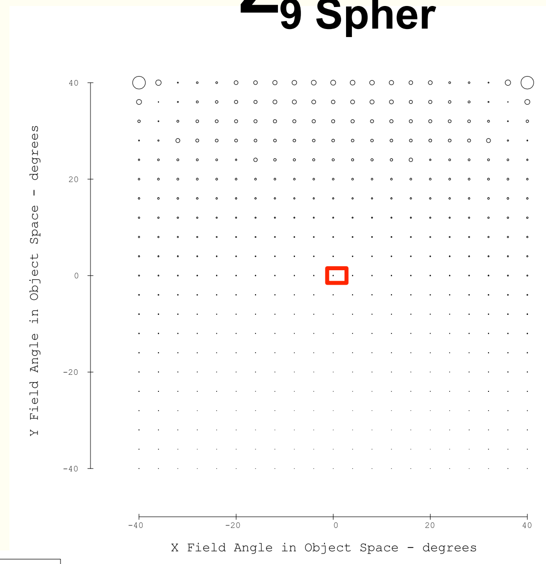
$Z_{5/6}$ Astig

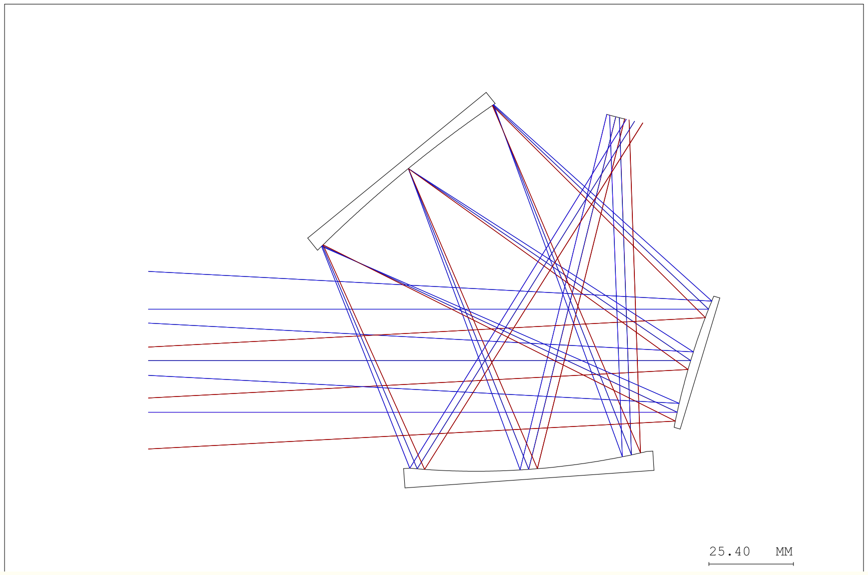


$Z_{7/8}$ Coma

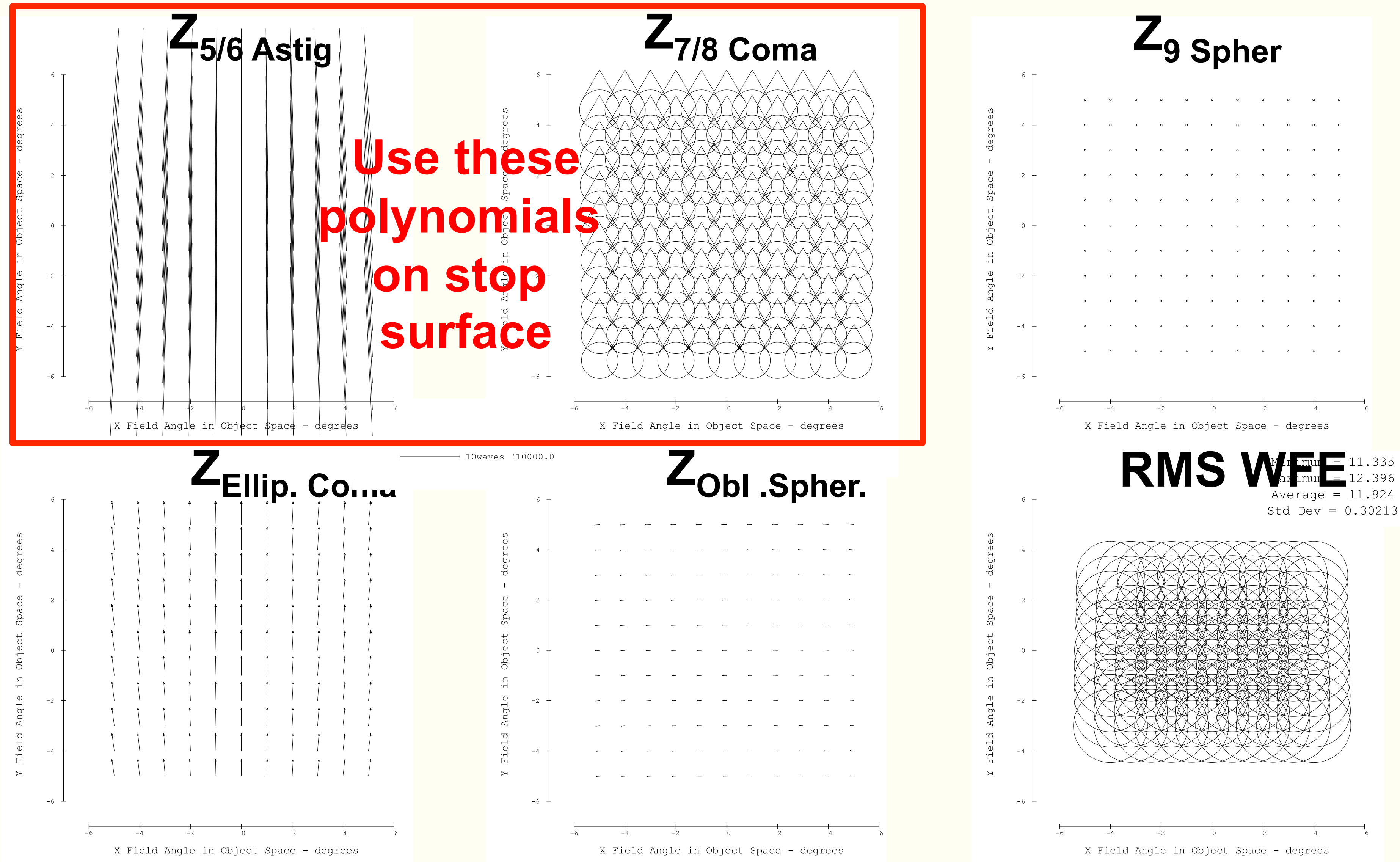


Z_9 Spher



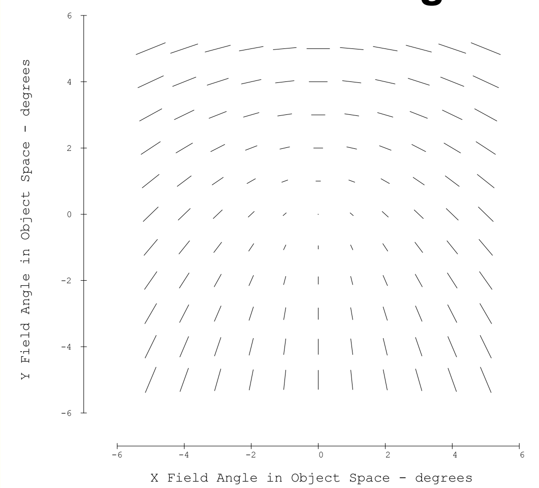


Within the FOV only



Optimized Design

$Z_{5/6\ \text{Astig}}$



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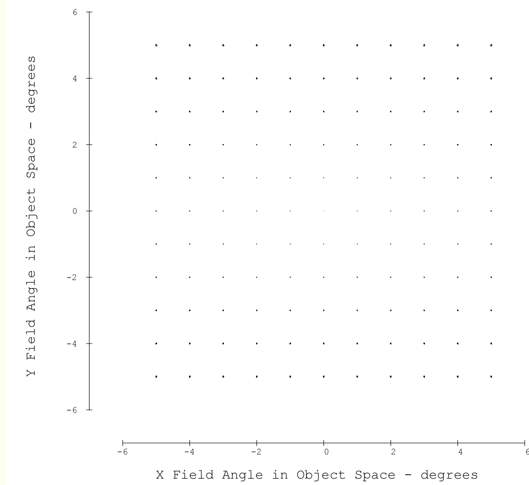
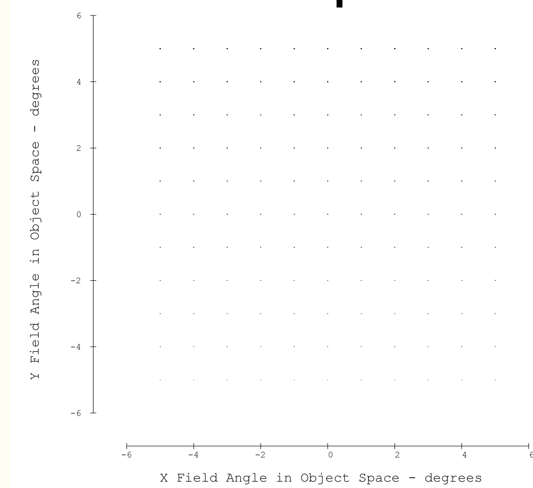


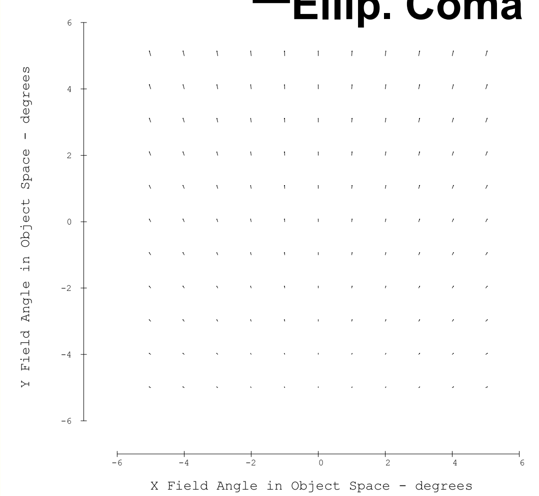
$Z_{9\ \text{Spher}}$



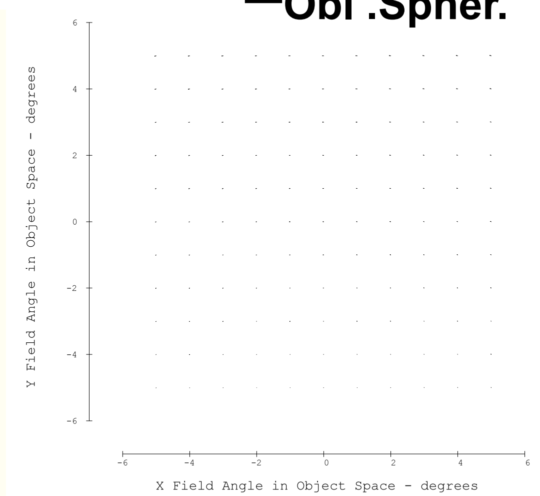
Std Dev = 0.2417

10waves (10000.0

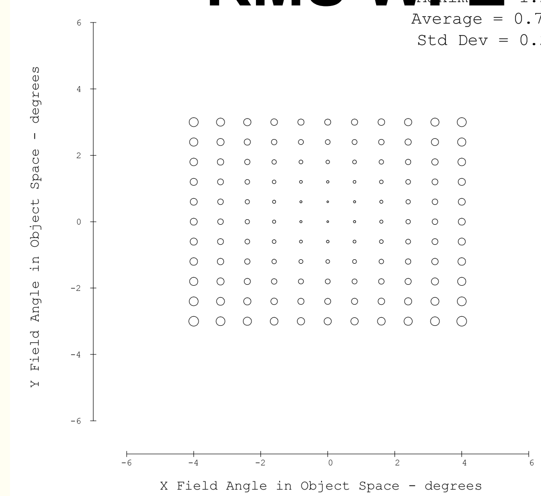
$Z_{\text{Ellip. Coma}}$



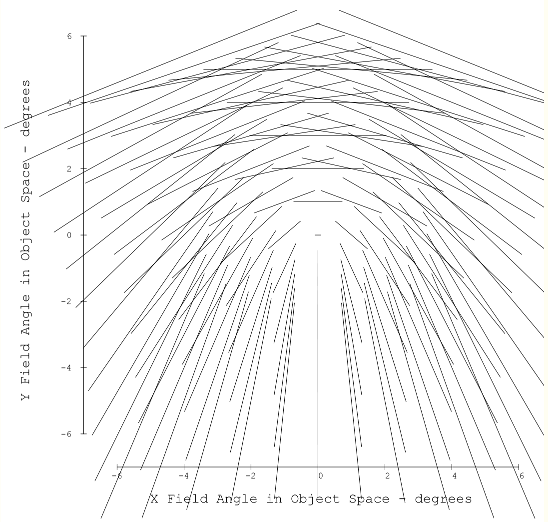
$Z_{\text{Obl .Spher.}}$



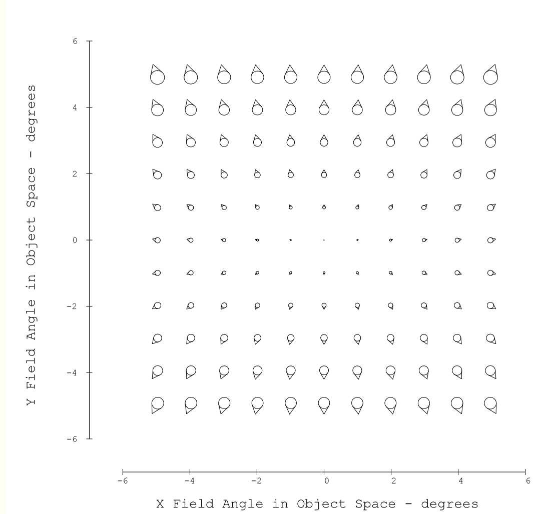
RMS WFE



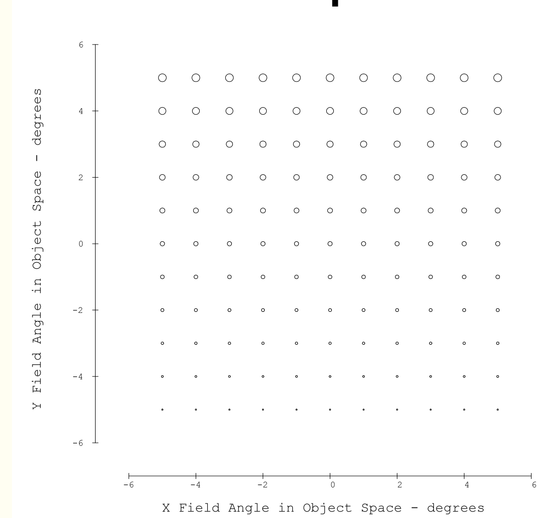
$Z_{5/6}$ Astig



$Z_{7/8}$ Coma

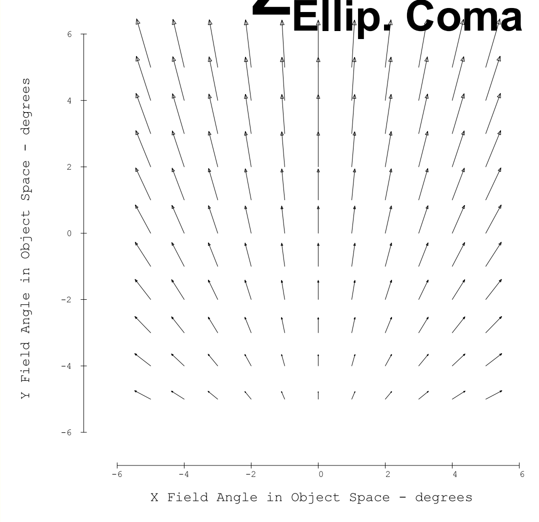


Z_{9} Spher

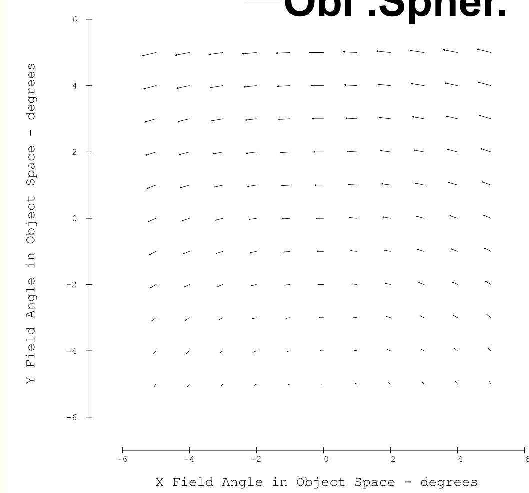


1waves (10000.0 nm)

$Z_{\text{Ellip. Coma}}$

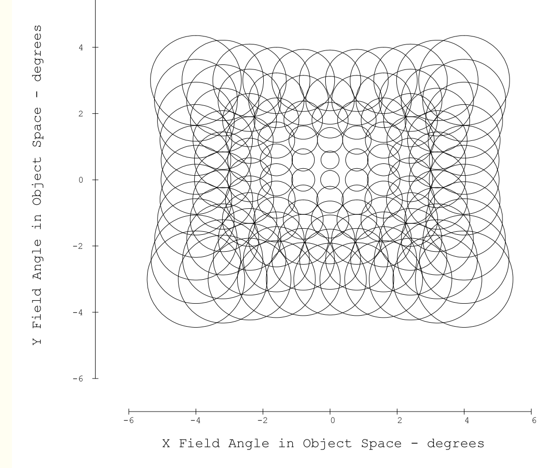


$Z_{\text{Obl .Spher.}}$

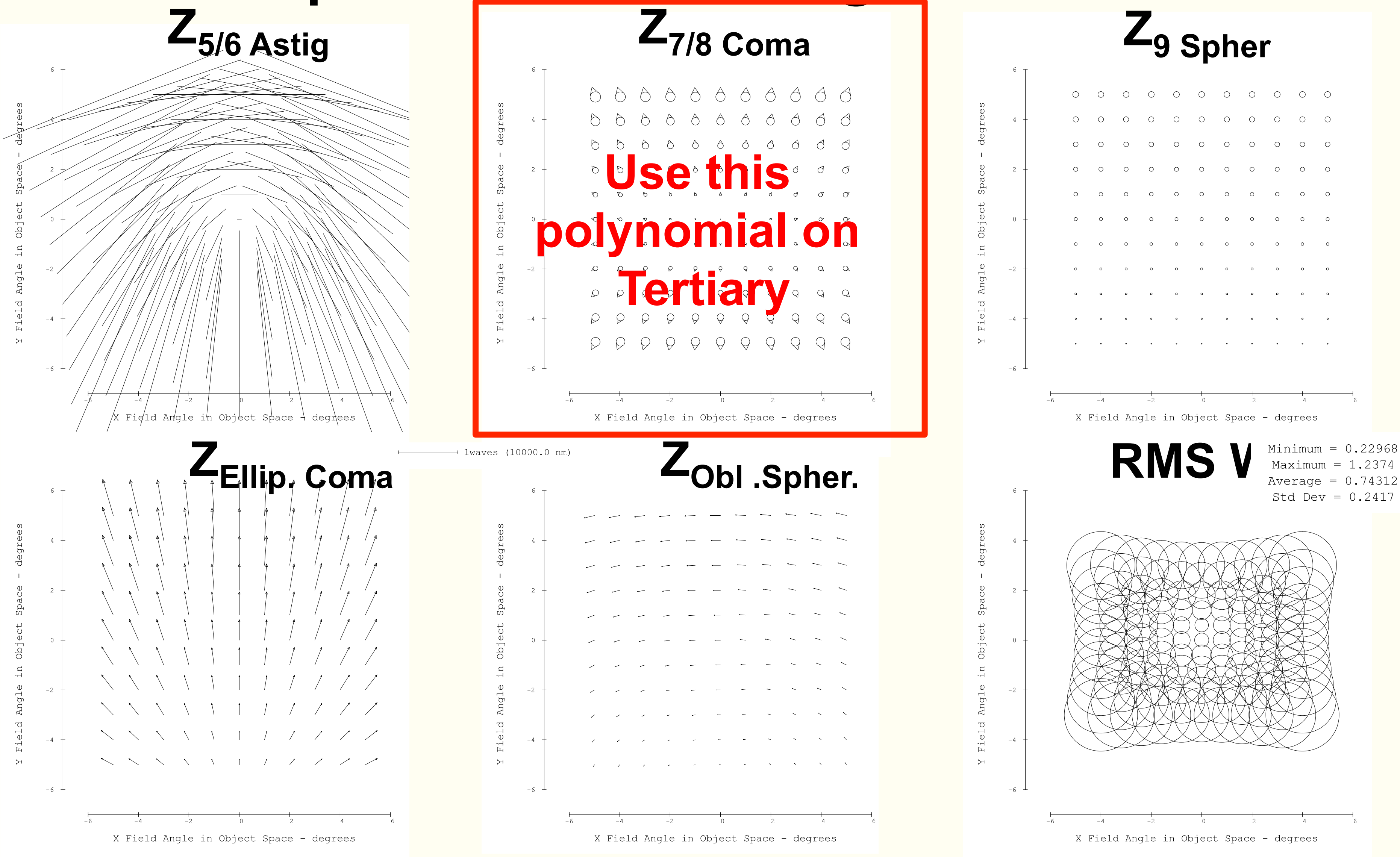


RMS W

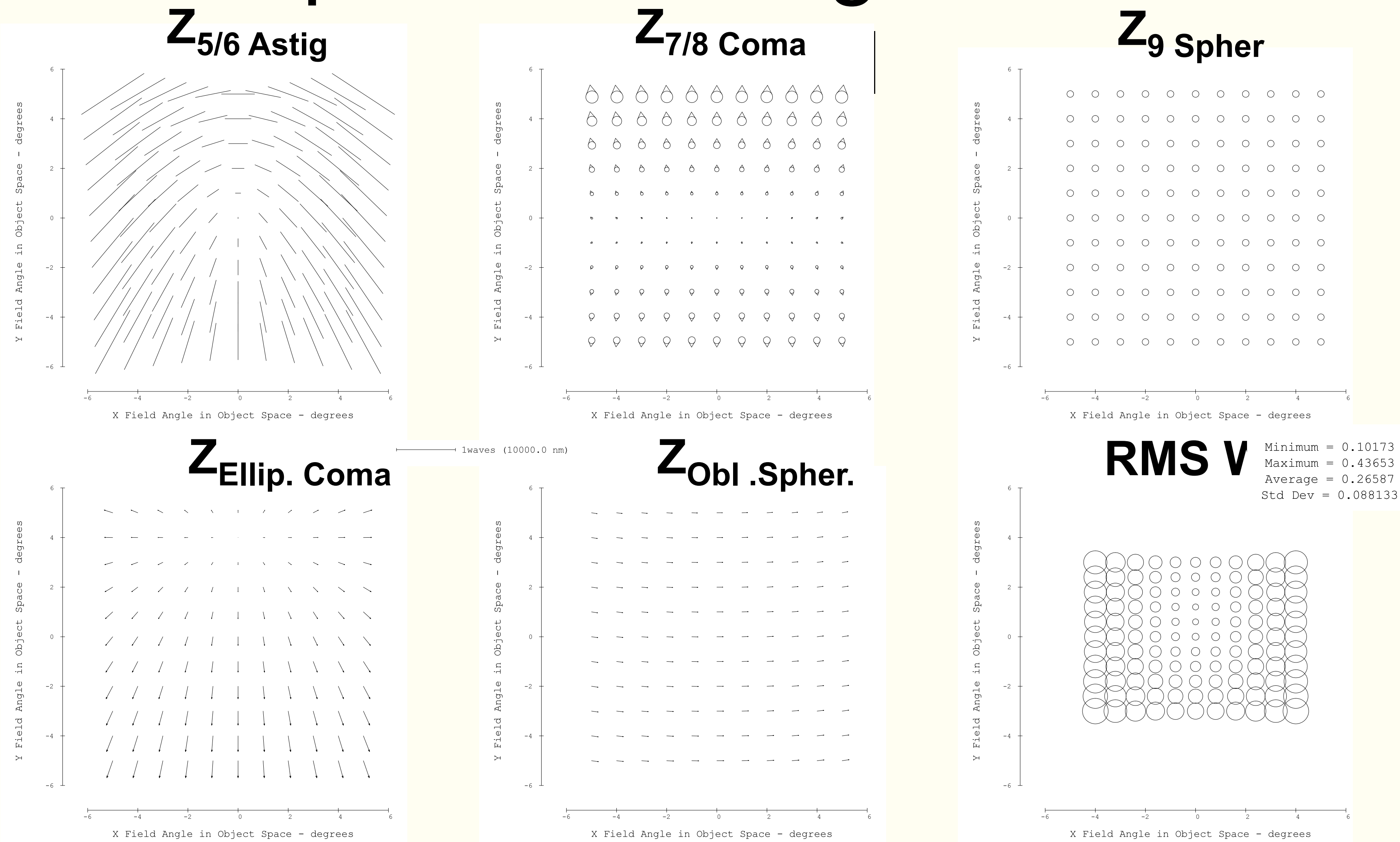
Minimum = 0.22968
Maximum = 1.2374
Average = 0.74312
Std Dev = 0.2417



Optimized Design with



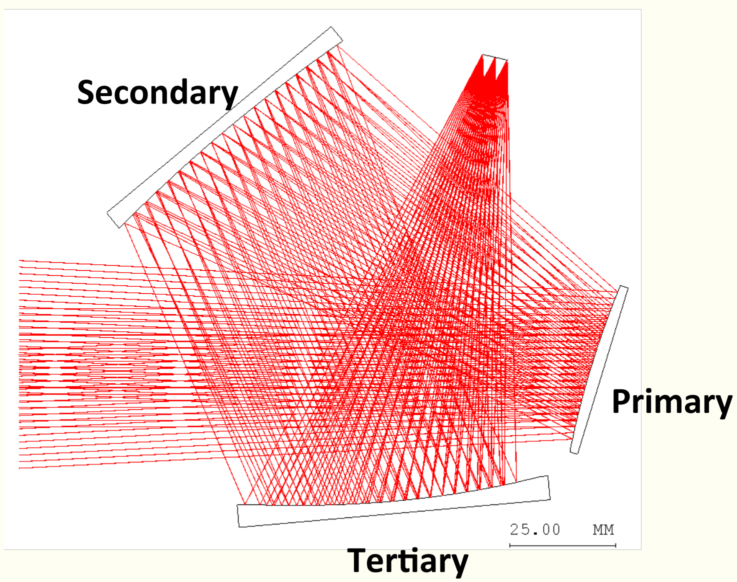
Optimized Design with

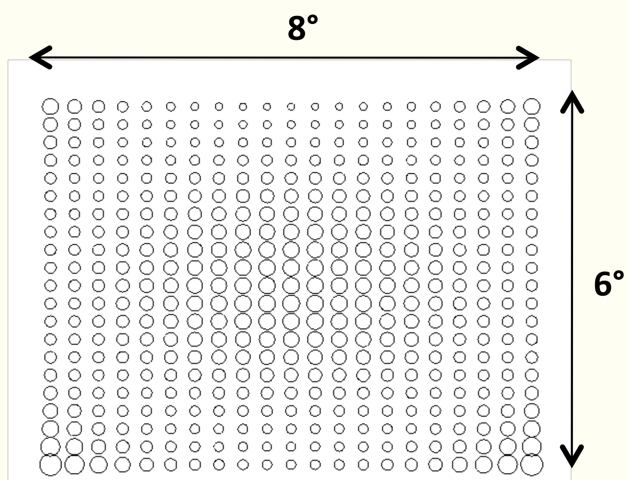


Final Optimized Solution

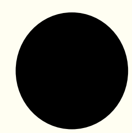
With further implementation of design using demonstrated strategies:

- Reach solution with RMS wavefront error at a λ = 10 µm of less than $\lambda/50$ over 10° FFOV





Minimum = 0.0049516
Maximum = 0.015382
Average = 0.0085467
Std Dev = 0.0017325

 = Diffraction Limit @ 10µm