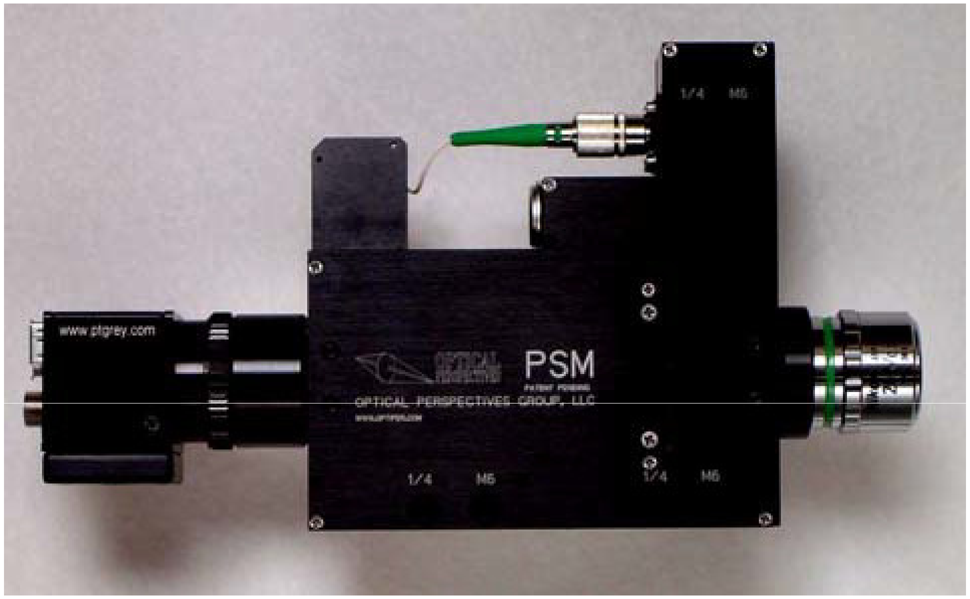
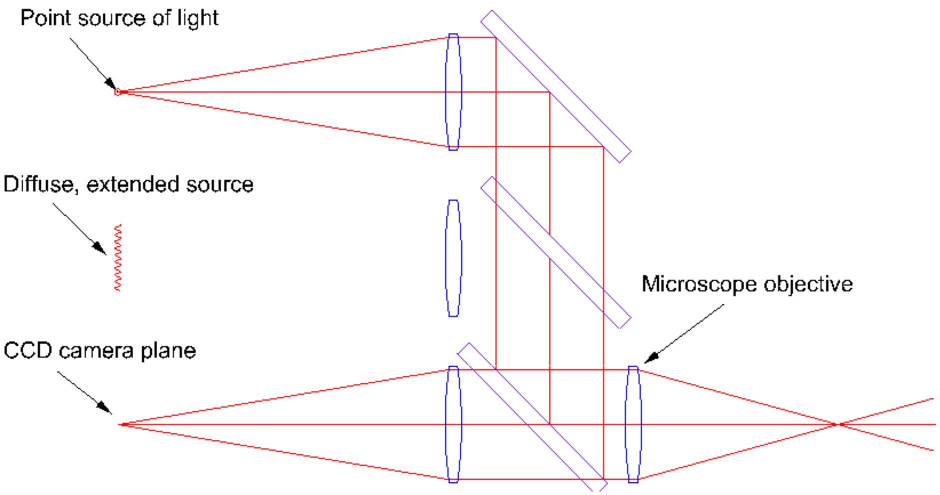
PSM – Point Source Microscope

- Traditional use for over 100 years to precisely measurement the radius of curvature of optical surfaces
- Use on coordinate measuring machine to precisely locate optical elements via centers of curvature
- Use with a precision rotary table to center optics in a lens barrel
- Use as a Star test device to find the optical axis of symmetric and off-axis parabolas in autocollimation
- Use to reverse engineer lenses by measuring radii and optical thickness and back focus
  - Can determine all 4 paraxial lens parameters, R1, R2, ct and index n
- Use as an autocollimator to determine wedge in windows, and parallelism of prism faces
- Use Cat's eye reflection to find focus on flawless (non-scattering) transparent surfaces
- Use Cat's eye reflection to find spacings between lenses in lens assemblies

Courtesy of Bob Parks

Commercial PSM Device
PSM in autostigmatic microscope mode

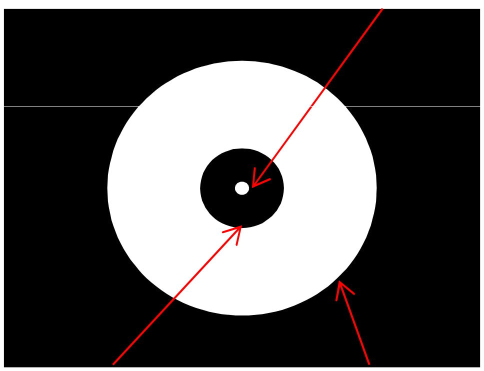




Courtesy of Bob Parks

W2-AM – Reticle based alignment tool

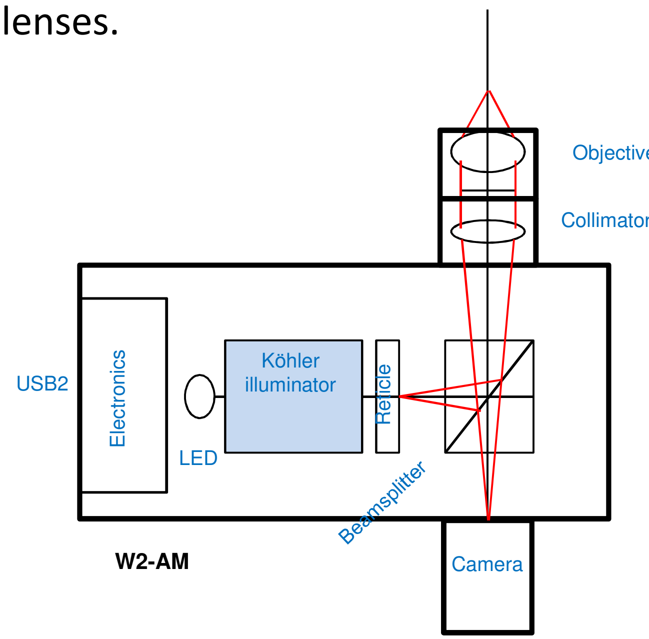
An LED based, Köhler illumination system back illuminates a chrome-on-glass reticle. The reticle acts as a field-stop for the imaging system and is conjugate to the camera. The reticle provides a large, easy to find “blob” to guide initial alignment to facilitate rapid location of the target. The obscuration provides further guidance to the operator to find the PSF or point image.



The collimating lens is external to the housing making it possible for the operator to adjust focus as well as to install alternative collimating lenses, even custom lenses.

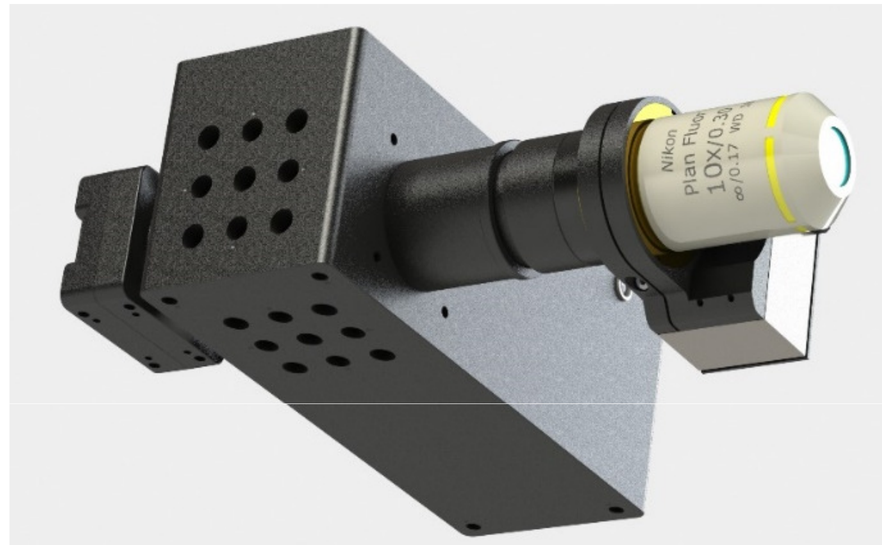
Built-in electronics with a USB2 interface provide power and control of the 4-channel digital current sources.

W2-AM can be built with sources from the UV through SWIR wavelengths.



W2-AM-PR – *Phase Retrieval*

- Once system is aligned the PR option allows one to measure the system wavefront with the same device.
- The measurement provides low-order Zernike coefficients that control focus, decenter, tilt, spacing and mounting errors.



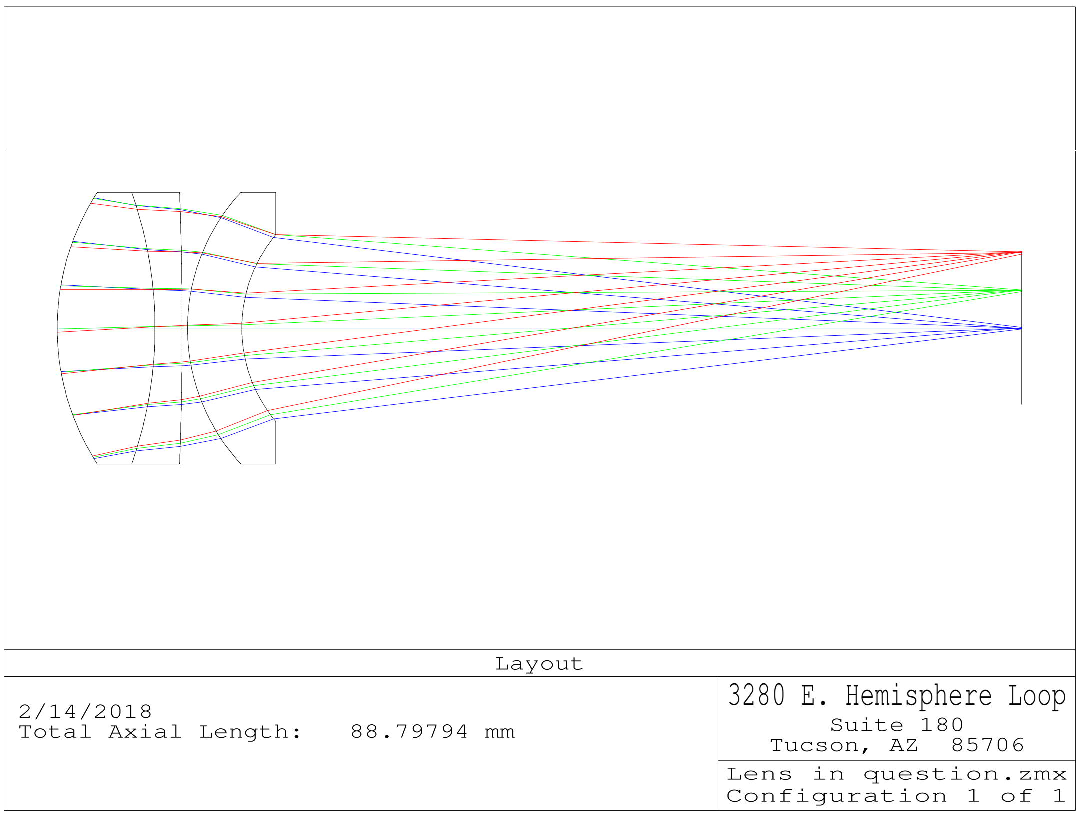
→ You don't always need an interferometer

Courtesy of Bill Kuhn

PR system adds a closed-loop piezo stage to shift the objective along the optical axis. The amount of defocus in the wavefront is doubled due to the shift of the source location and the image plane in opposite directions. The piezo stage is appropriate for fast optical systems. Slower systems can use a stage to drive the entire instrument.

Real World Problem

- RCI was asked to investigate why a specific lens assembly appeared to be focusing too short



Initial Results

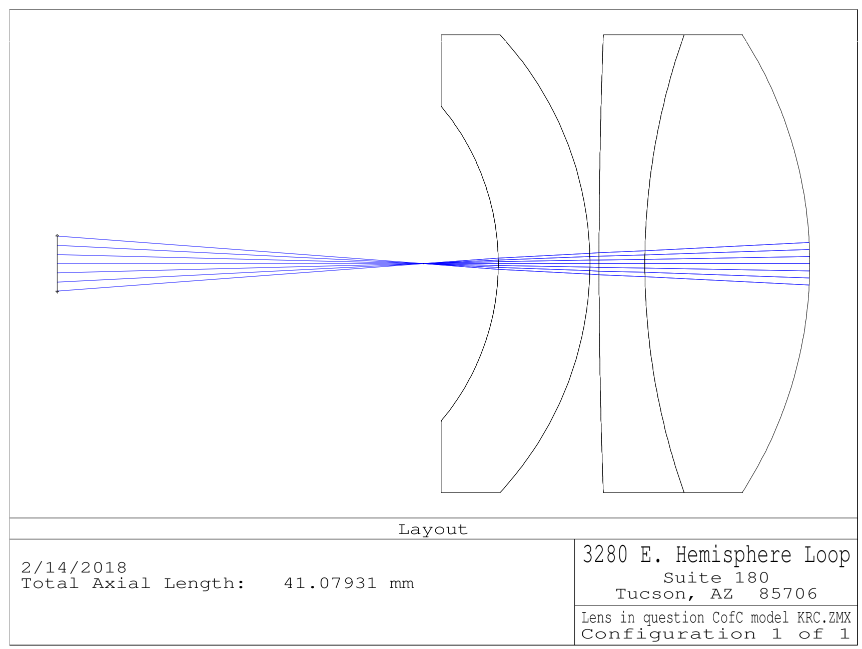
- RCI tested the unit with a collimator which produced a collimated beam to fill the pupil of the lens (~24mm diameter).
- It was found that the unit was focusing at a distance of ~48 mm from the rear lens surface which is significantly shorter than the design distance of 71.8 mm.
- RCI then measured other lens parameters to determine where the problem may lie (easy to do in the test setup)

Results (cont.)

- Measured Data
  - 0.000
  - 0.450
  - 2.960
  - 3.455
  - 9.890
- Zemax Model
  - 0.000
  - 0.500
  - 3.000
  - ?
  - 13.345

Results (cont.)

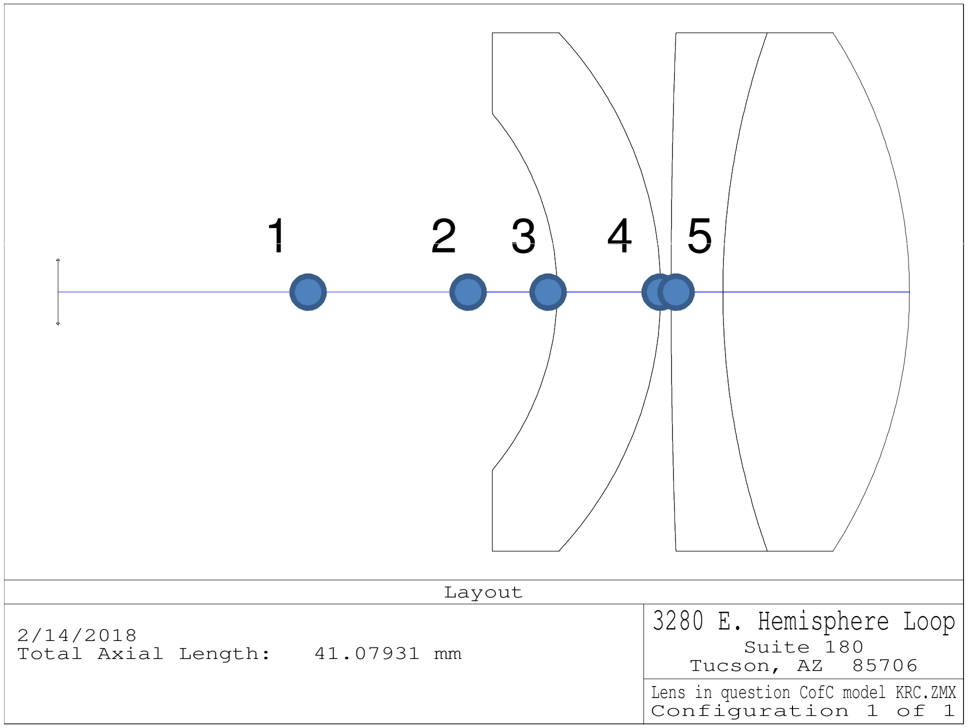
- RCI examined the locations of the centers of curvature of certain lens surface, as well as the locations of certain lens vertices



Results (cont.)

Five locations were measured:

1 – Double CofC
2 – Single CofC
3 – Single Vertex
4 – Single Vertex
5 – Single vertex



Results (cont.)

Calculated Position

- 1 – -13.388
- 2 – -4.079 *
- 3 – 0.000
- 4 – 2.547
- 5 – 2.920

Measured Position

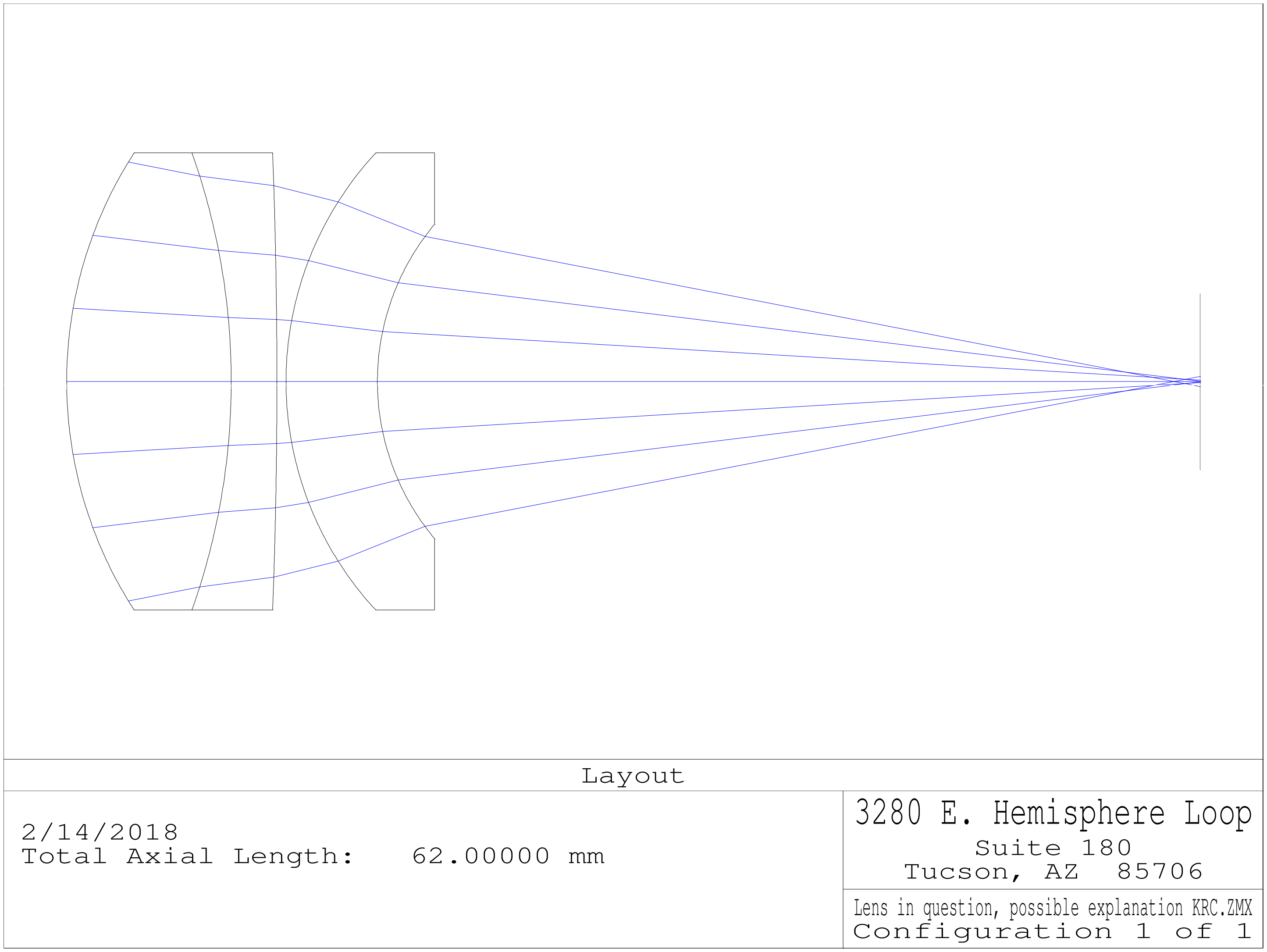
- 1 – -13.345
- 2 – -3.454 *
- 3 – 0.000
- 4 – 2.510
- 5 – 2.960

* These two values are significantly different indicating that the doublet has an error associated with it. Other numbers differ by only ~ 40 microns, so seem correct

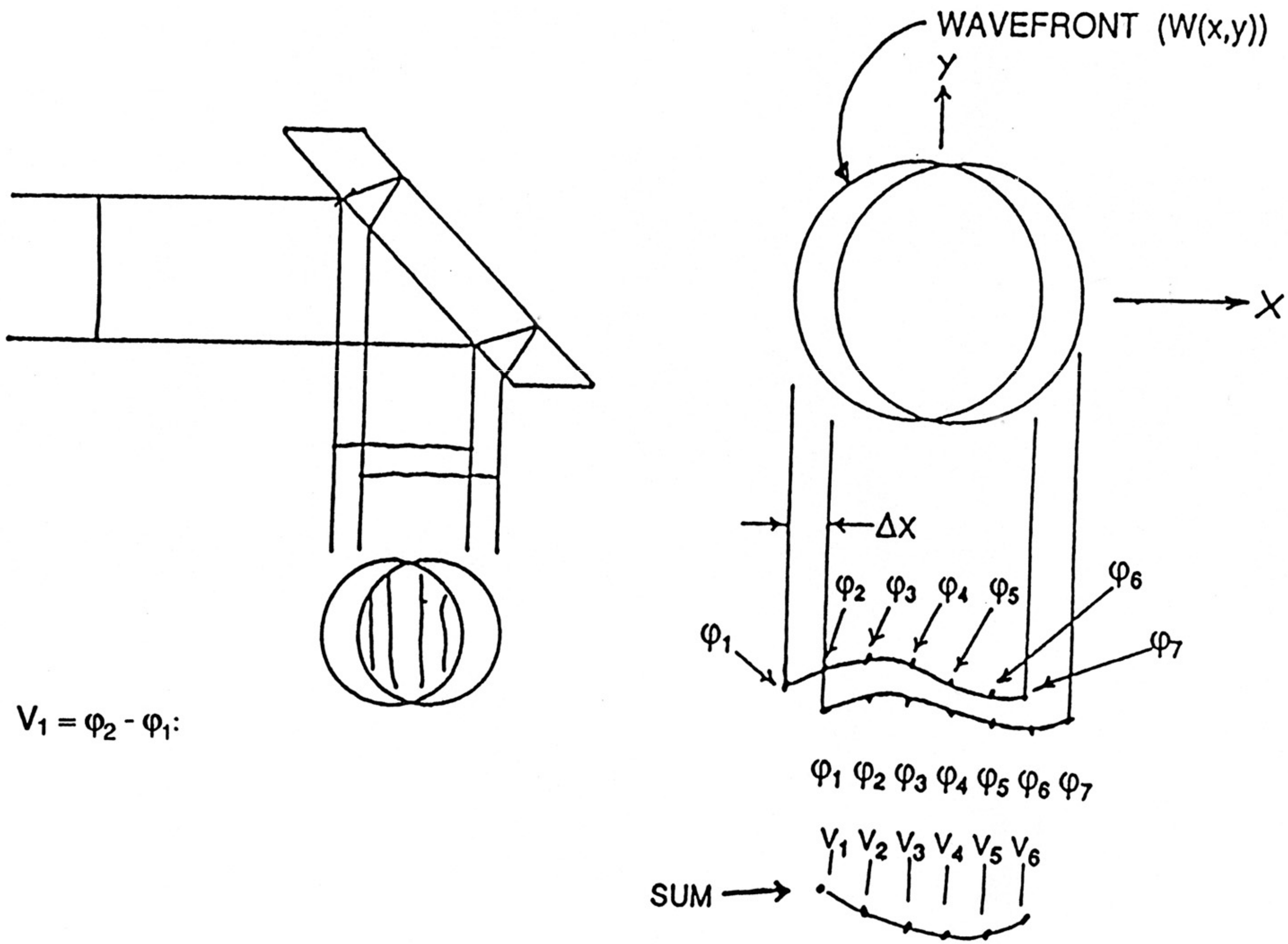
Conclusions

- Back focal distance estimated to be about 48 mm, not the desired 71.70 mm
- Significant spherical aberration was also noted at the image location, consistent with there being something wrong with the lens assembly
- Measurements made of CofC and vertex positions indicate something wrong with the doublet and not the singlet
- Assuming the radii and CT's of the lenses are correct, a possible explanation is that the first lens is made from S-FPL51, not S-FPL53 (as per the design).
- Putting this into the model makes the calculated #2 position -3.597 mm, which is fairly close to the measured value of -3.455 mm (as demonstrated on next slide).
- Additionally, the spherical aberration noticed is in the same direction as the model.

Modeled error (S-FPL51 Lens 1)



Lateral Shear Interferometer



Lateral Shear Interferometer

From the previous page we see:

$\phi_1 = \phi\ (x_1,y_1)$ and $\phi_2 = \phi(x_2,y_2)$

But Y = constant (looking at a slice in the x-direction)

Therefore, $y_1 = y_2$ and $x_2 = x_1 + \Delta x$

Therefore

$$\phi_2 = \phi_1\ (x + \Delta x,y)$$

At point v1 we observe the phase difference of all the sheared wavefront:

$v_1 = \phi_2 - \phi_1 = \phi_1\ (x+\Delta x,y) - \phi_1\ (x,y)$

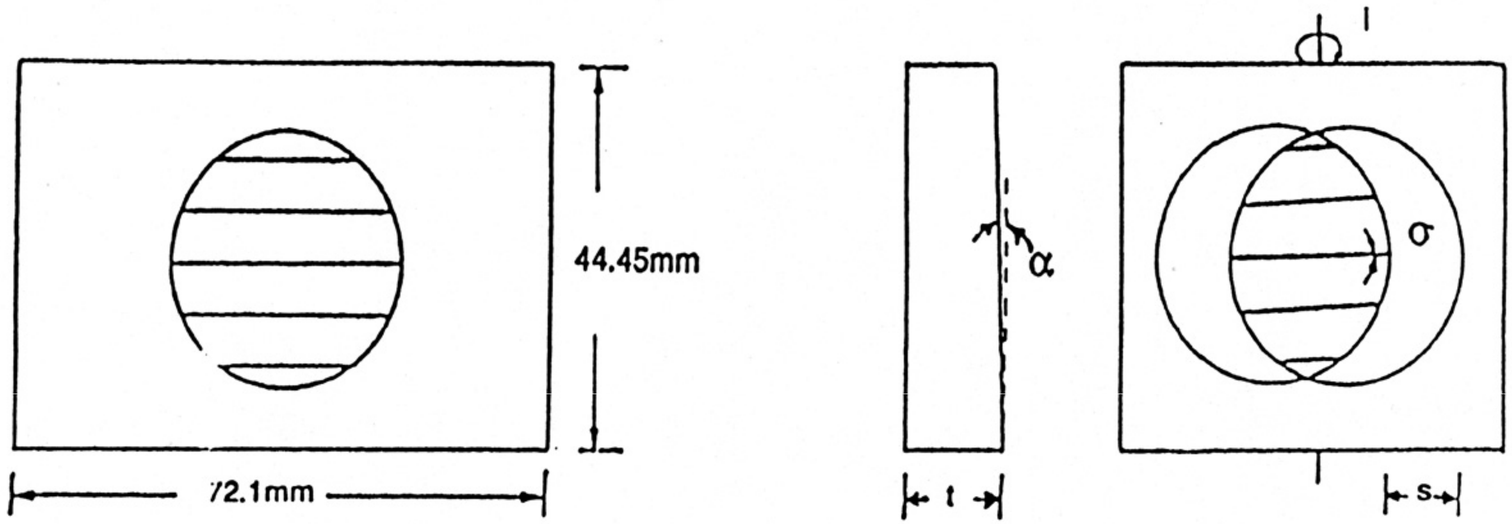
Let $\Delta x \varnothing 0$ and let s be the actual shear distance

Then the condition for seeing a fringe is:

$$\left[\frac{\Phi_1(x+\Delta x,y)-\Phi_1(x,y)}{\Delta x}\right]\Delta S = N\lambda$$

But the fraction is the definition of a derivative! Thus, the output wavefront from a shearing interferometer is the derivative of the input wavefront

Shear Plate Example



Material	= BK-7
Plate Thickness (t)	= 13.4 mm
Wedge Angle (α)	= 50 μrad
Angle of Incidence (i)	= 45 degrees
Lateral Shear (s)	= 10 mm
Fringe Tilt (σ)	= 2.8º at λ/10 defocus
Wedge in X Direction	= 0 ± 2 μrad

Interferometry

Estimating Wavefront Error

Rule #1 A fringe is a wave of wavefront error - always

+ 2 for surface information

+ 2 for double pass

in transmission: OPD = (n-1)T!!!

Rule #2 Something must move to determine proper orientation

a. Focus and note change OR

b. Move reference arm - note direction of motion OR

c. "Squeeze" to determine wedge direction

Rule #3 Always use fiducials when diagnosing non-rotationally symmetric errors

Rule #4 Piston, tilt, focus and (usually) coma are always removable

Rule #5 Always look at bullseye fringes

Rule #6 Always, at least once, come in from the edge of the surface or pupil with a finger, ruler, etc. to insure that no clipping (vignetting) occurs

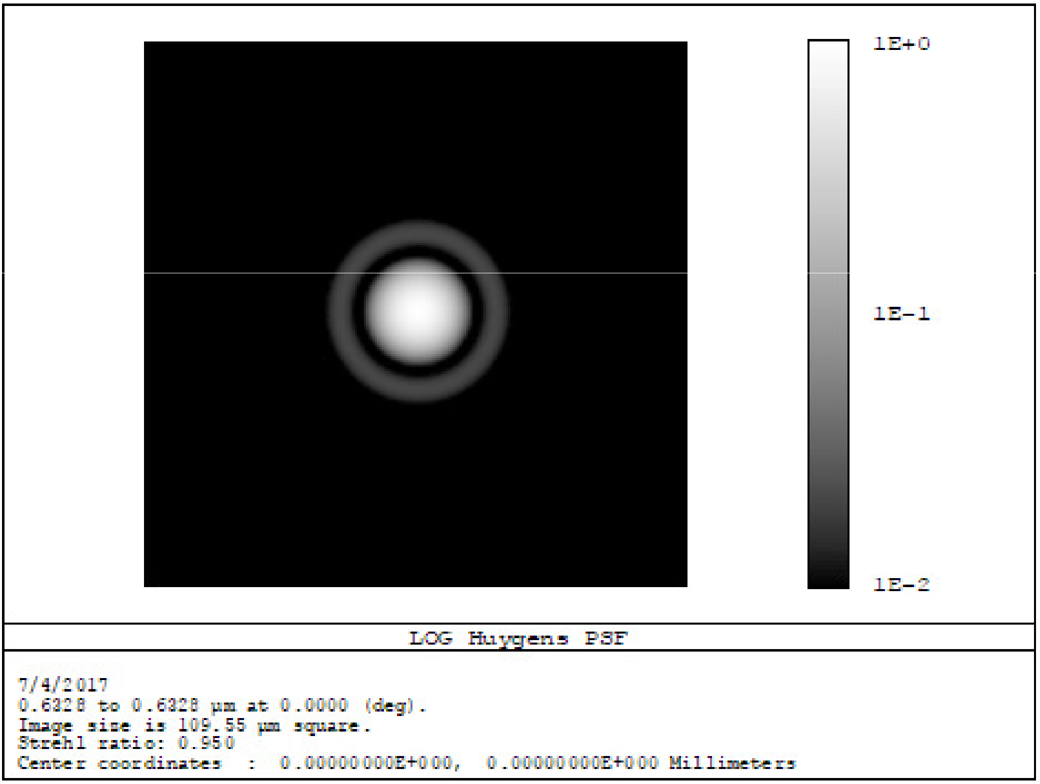
The Star Test

Features

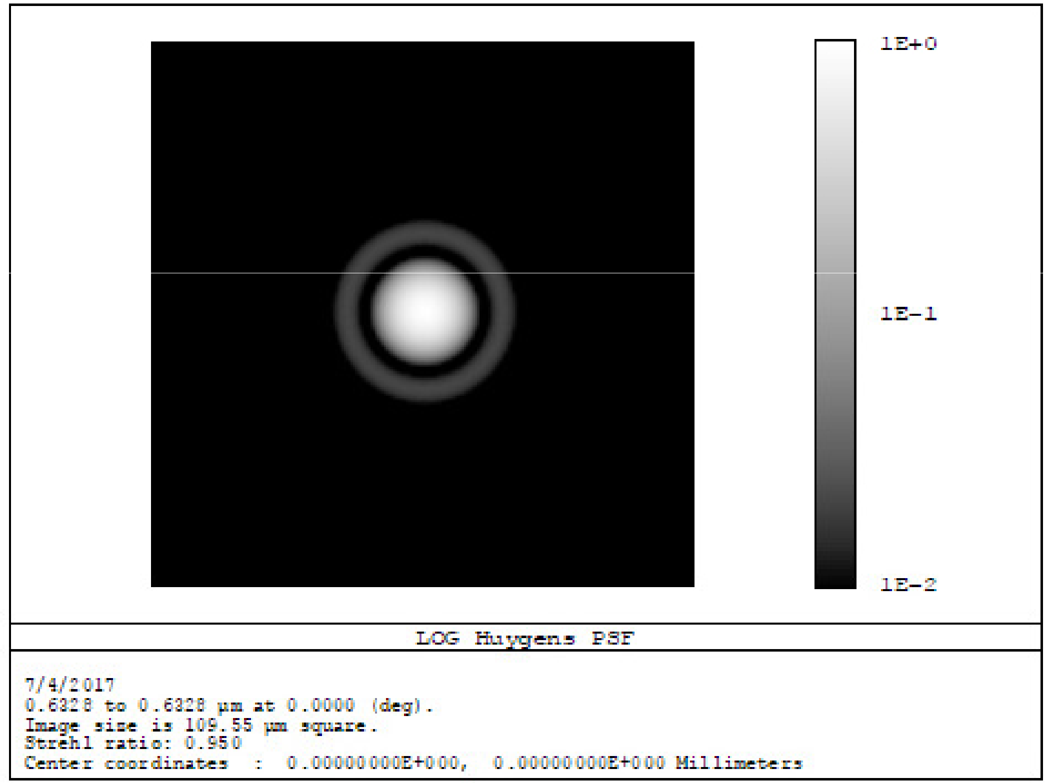
- Sensitive - Can detect λ/10 or better (see Hartmann photos)
- Good for qualitative verification - instant visual recognition
- Quick and inexpensive - laser or white light
- Above features apply to both diffraction limited systems and geometric blur limited systems

No Aberration, λ/8 focus changes

Inside Focus

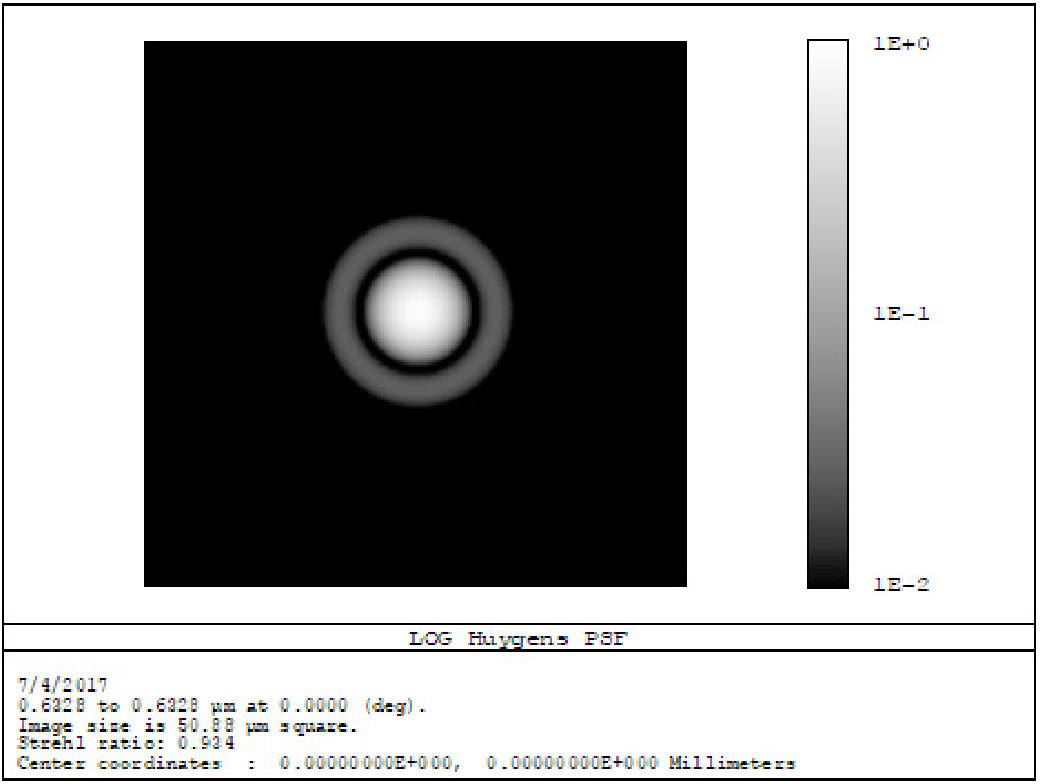


Outside Focus

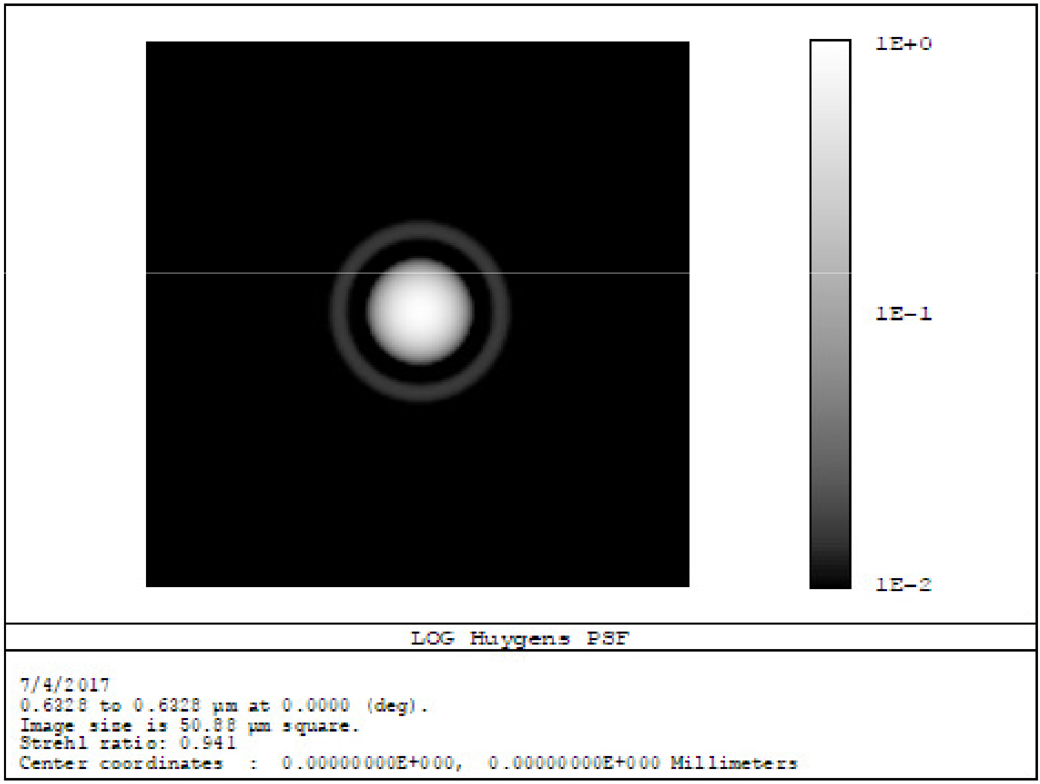


λ/10 Spherical Aberration Sensitivity

Inside focus 25 microns

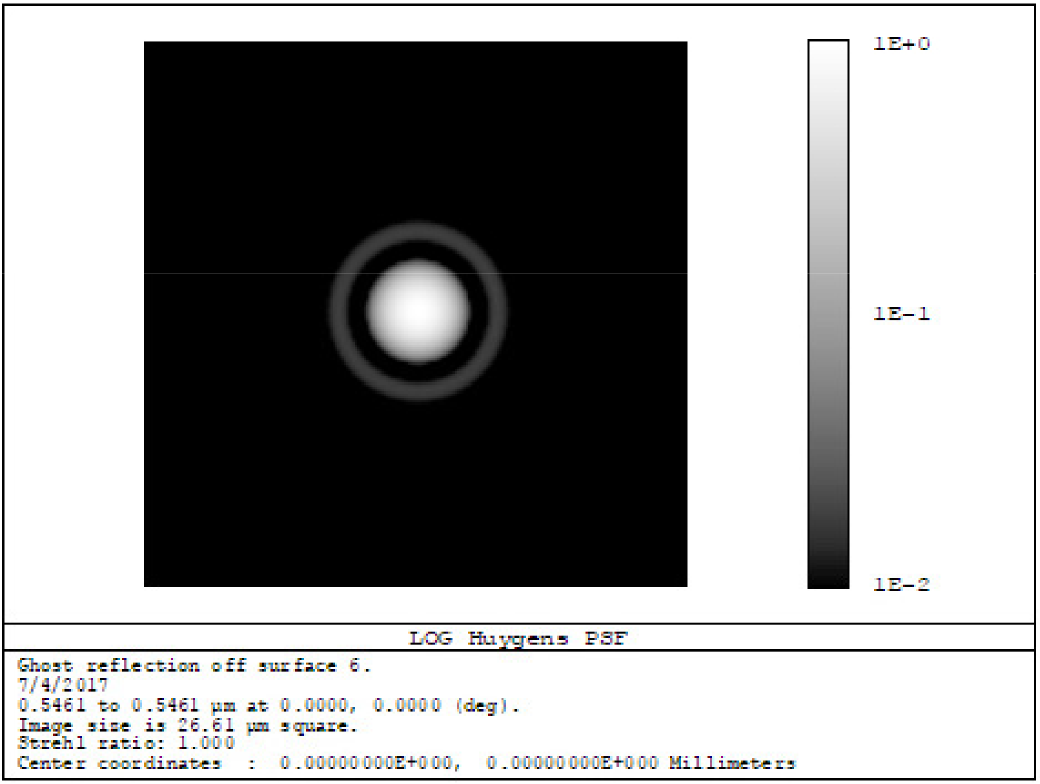


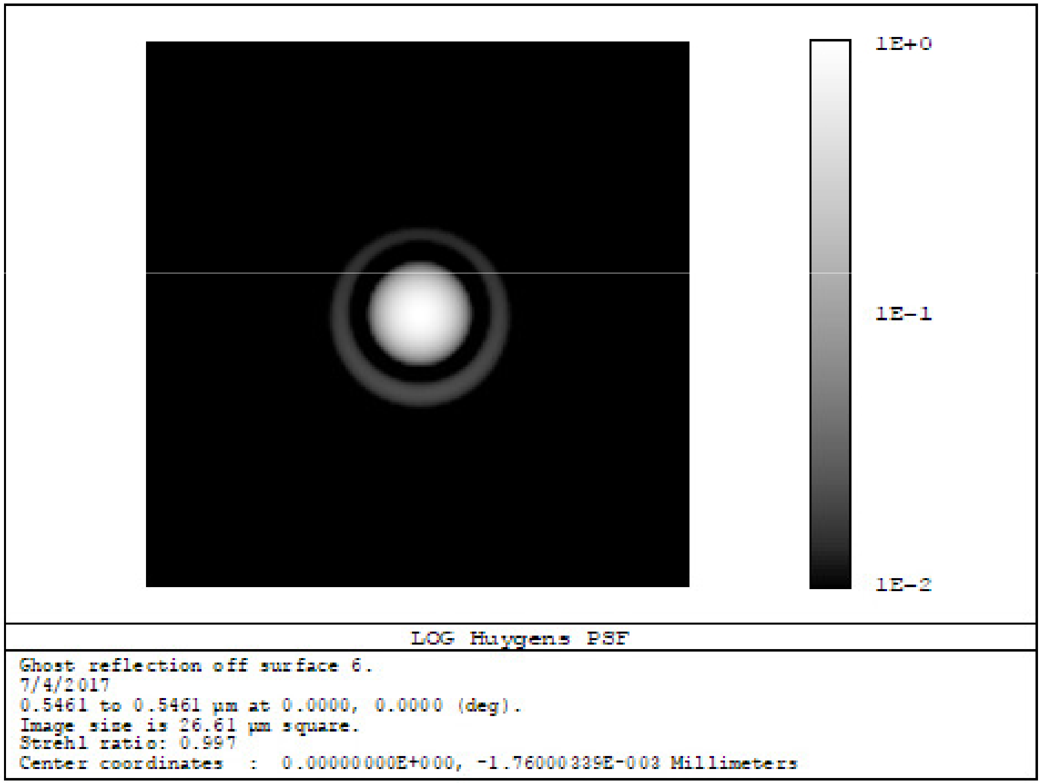
Outside focus 25 microns



Coma Sensitivity

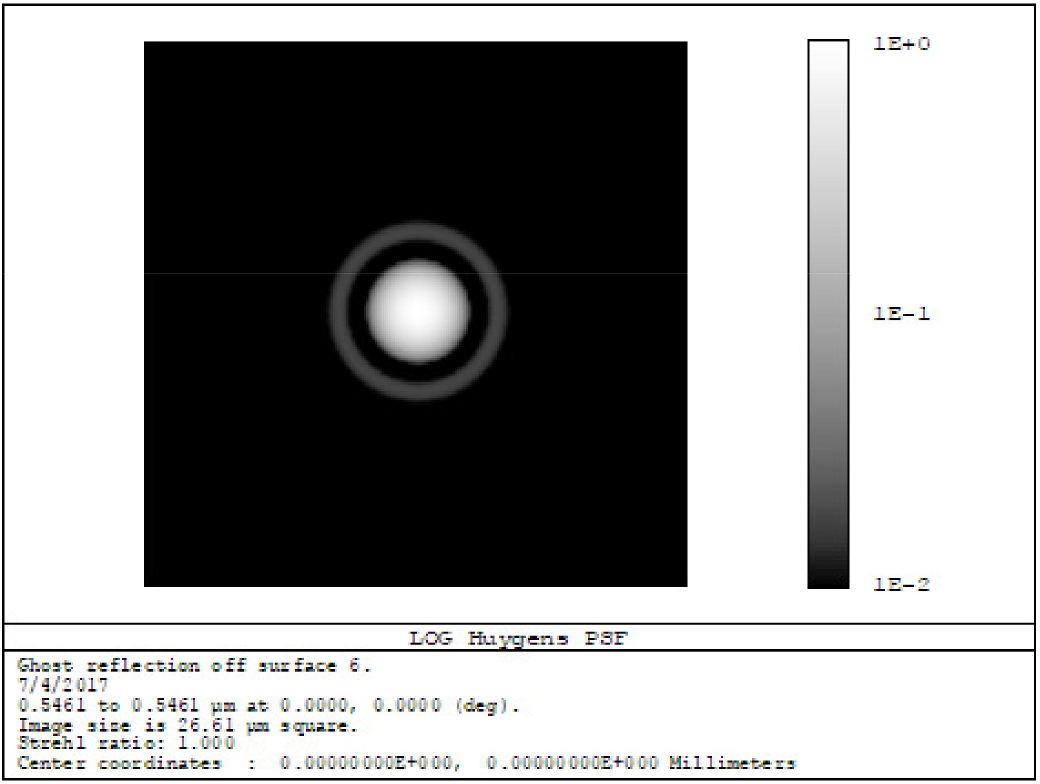
Coma Free	λ/10 Coma



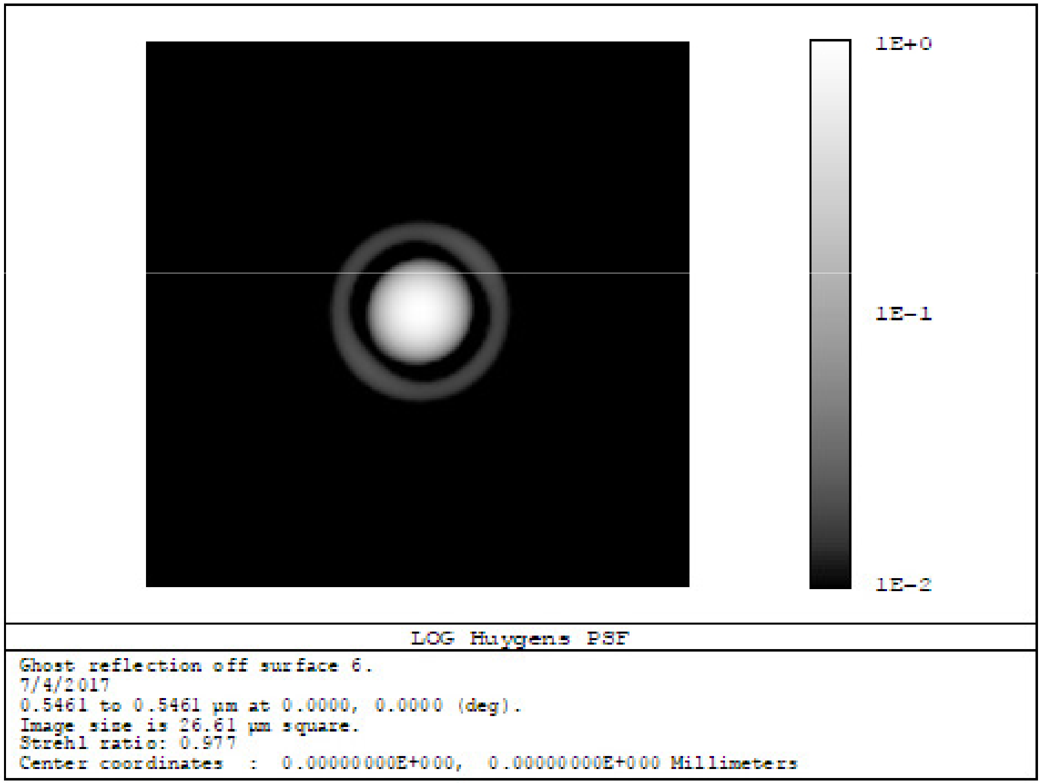


Astigmatism Sensitivity

Astigmatism Free



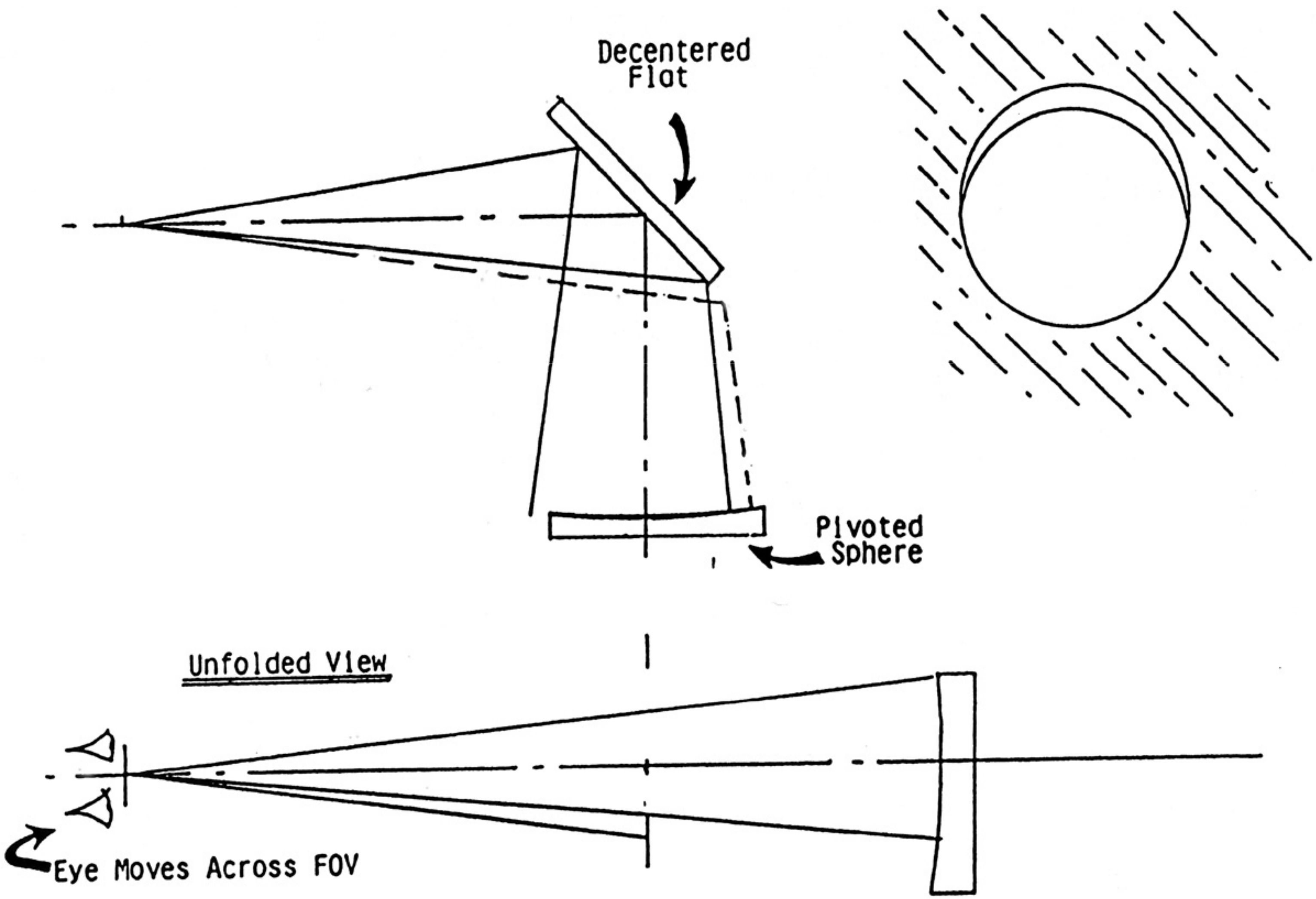
λ/10 Astigmatism



Checking for Vignetting

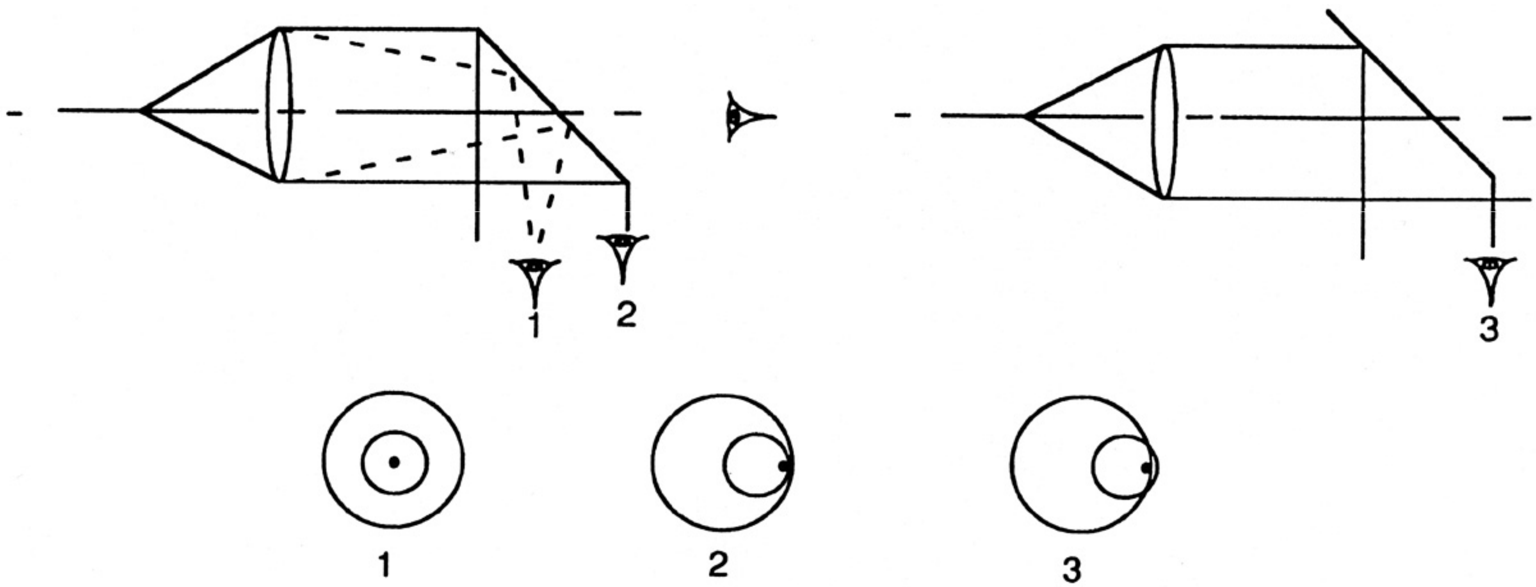
- Why we usually think of misalignment as an introduction of aberration
- It is possible to be misaligned and have a good image
- A good example is a fold mirror that is decentered, or a spherical mirror rotated about its center of curvature
- By placing the observer's eye at the focus, it is often easy to diagnose a vignetting problem
- In order to fully determine vignetting problems, the eye should be moved around the periphery of FOV
- Vignetting causes a loss of light through the optical system
- Even small amounts of vignetting in I.R. systems can be a disaster because the detector might see warm hardware
- Sometimes vignetting is deliberately introduced to reduce aberrations

Observing Vignetting



Visual Inspection of Vignetting

Examples: Visual inspection of a collimated beam with fold mirror

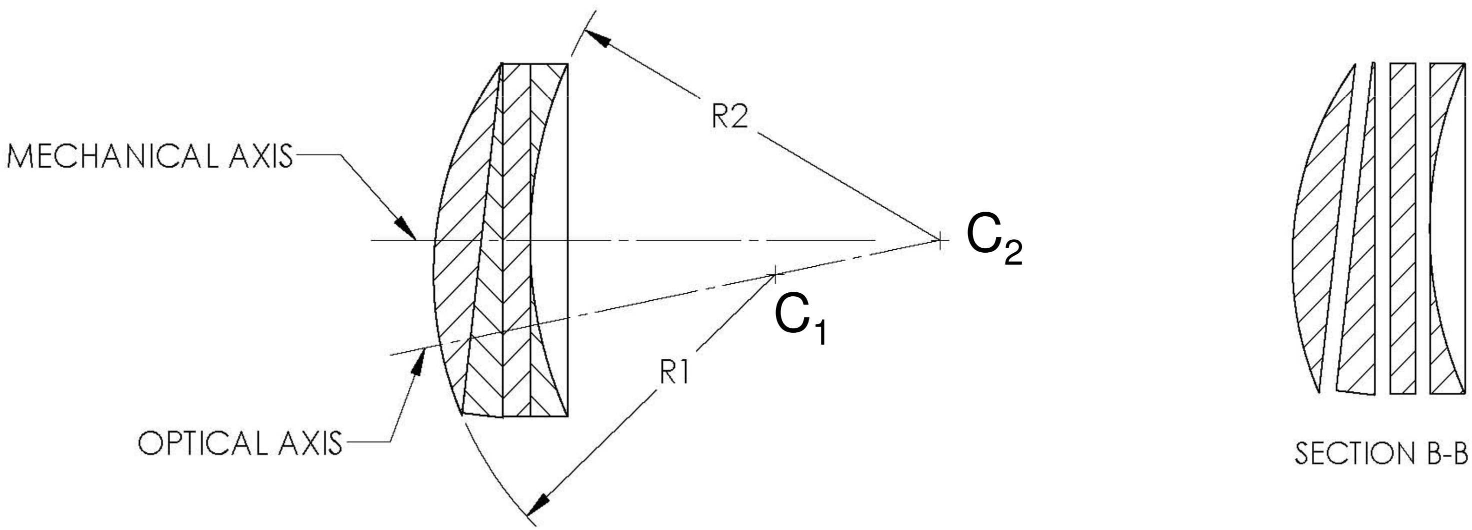


4.0 Classic Alignment Examples

- Alignment of lens elements
- The alignment of a Cassegrain telescope

Alignment of Lens Elements

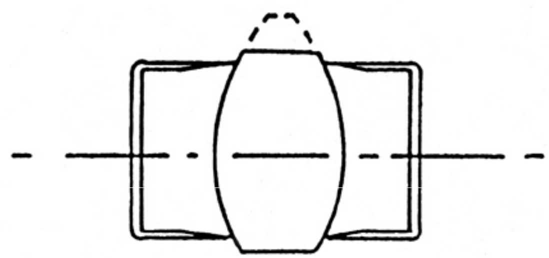
- All lenses have two optical surfaces, and the glass between them can be considered the mount!
- A lens can be thought of as having four sub-components:
  - Two plano convex (or concave) lenses:
  - A plane parallel plate and a wedge (mfg. error) , as shown:



- The line C_1 C_2 is the optical axis of the lens. The lens should be edged parallel to the axis.

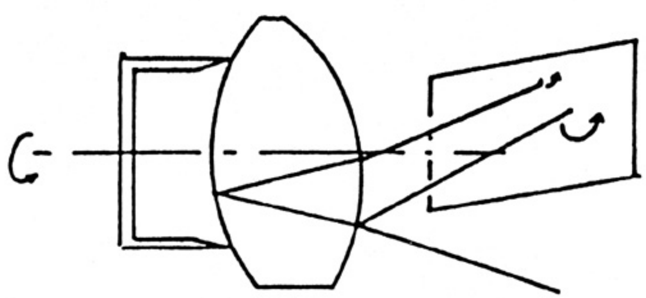
How to Superimpose the Optical and Mechanical Axes of a Lens

Determining this axis can be done automatically by squeezing the lens between two cups

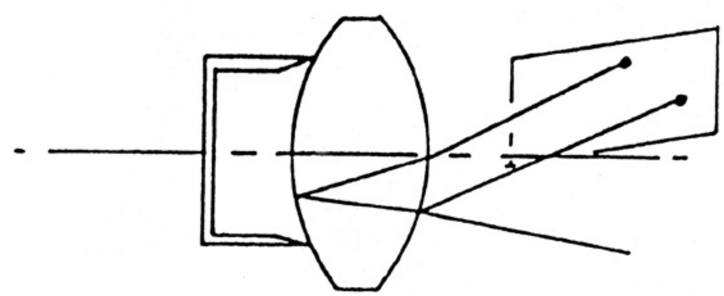


The lens is then reground between the cups

The lens can also be centered with one cup and a laser:

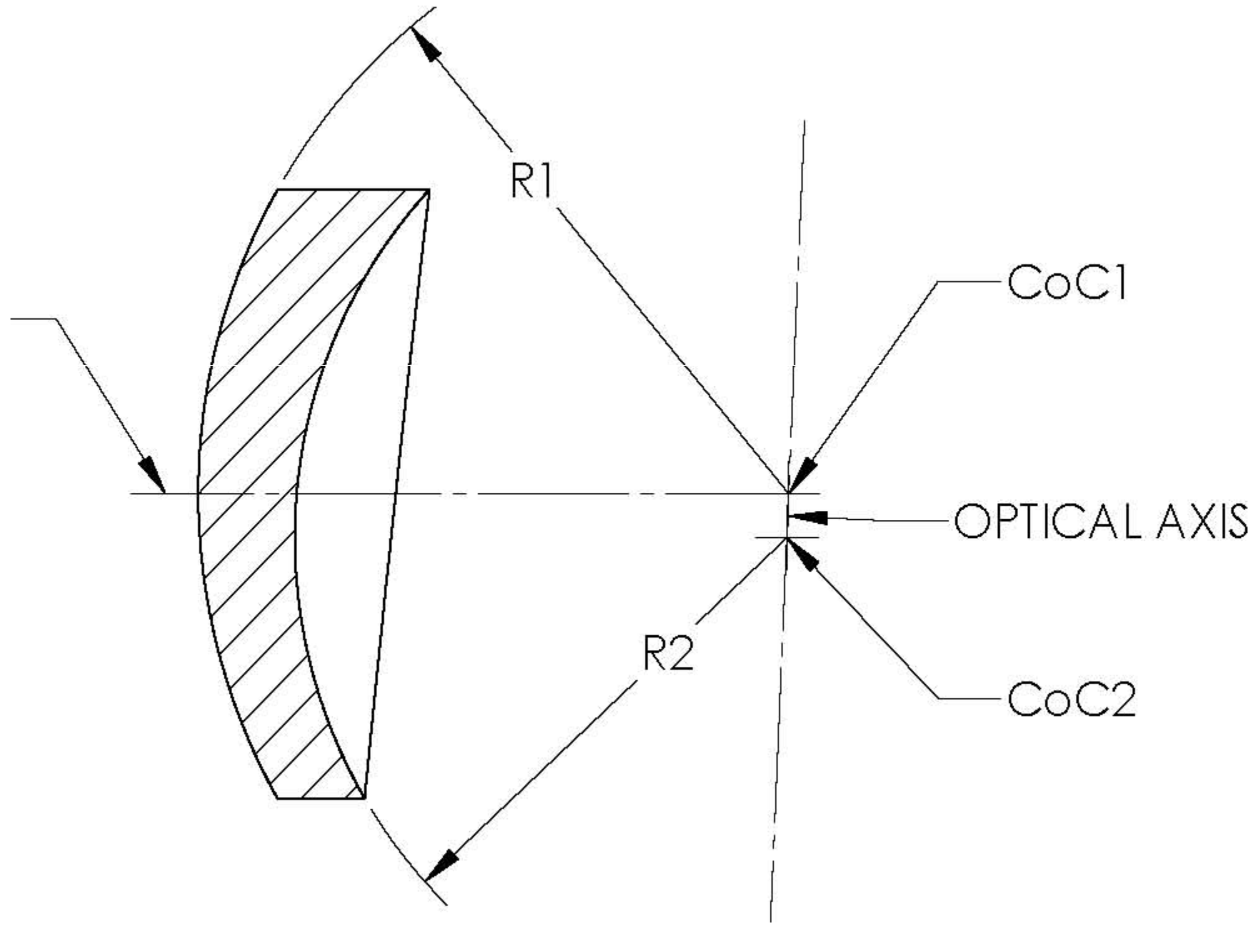


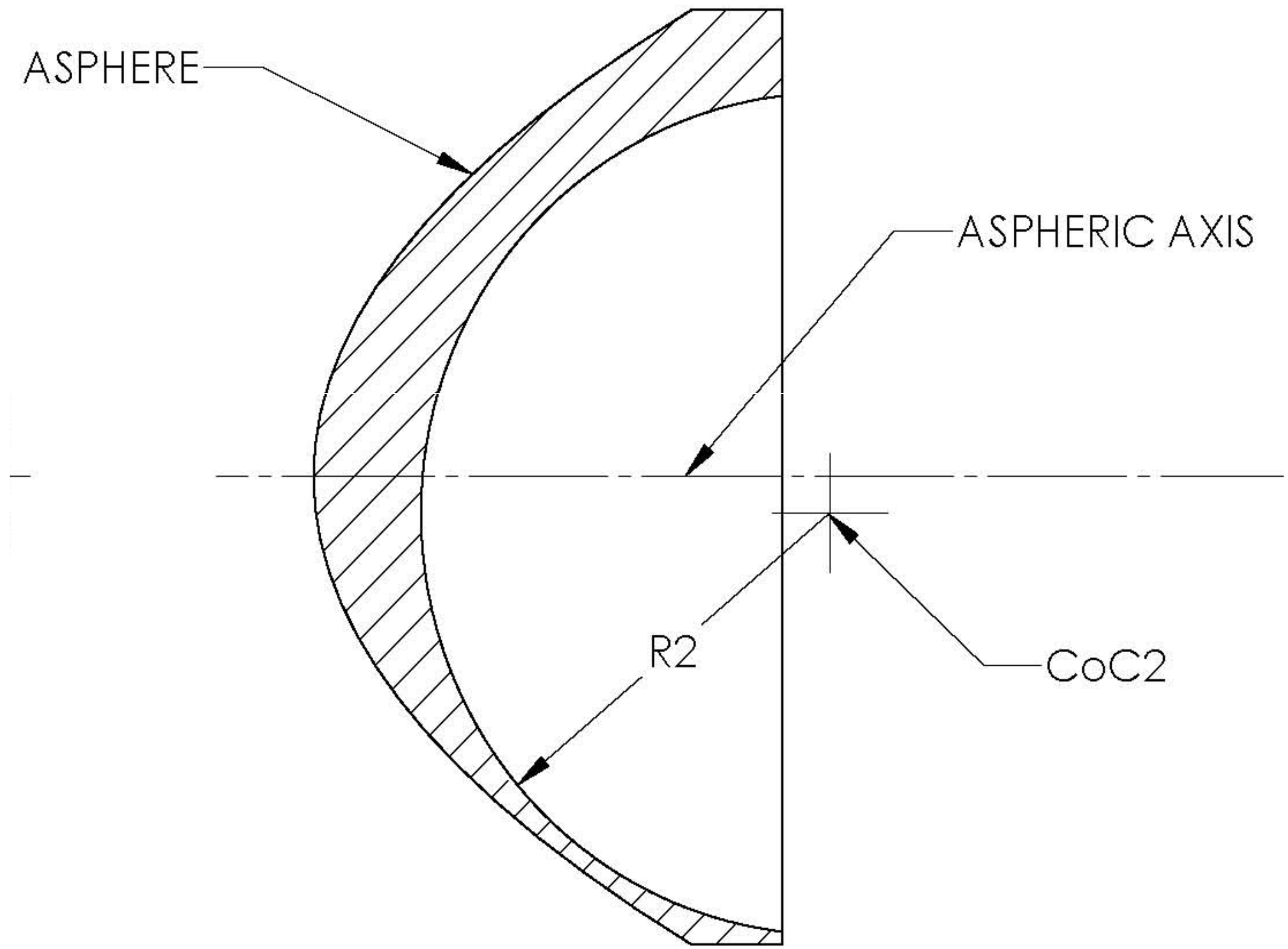
Not Aligned



Aligned

Concentric lens




ASPHERE
ASPHERIC AXIS
R2
CoC2

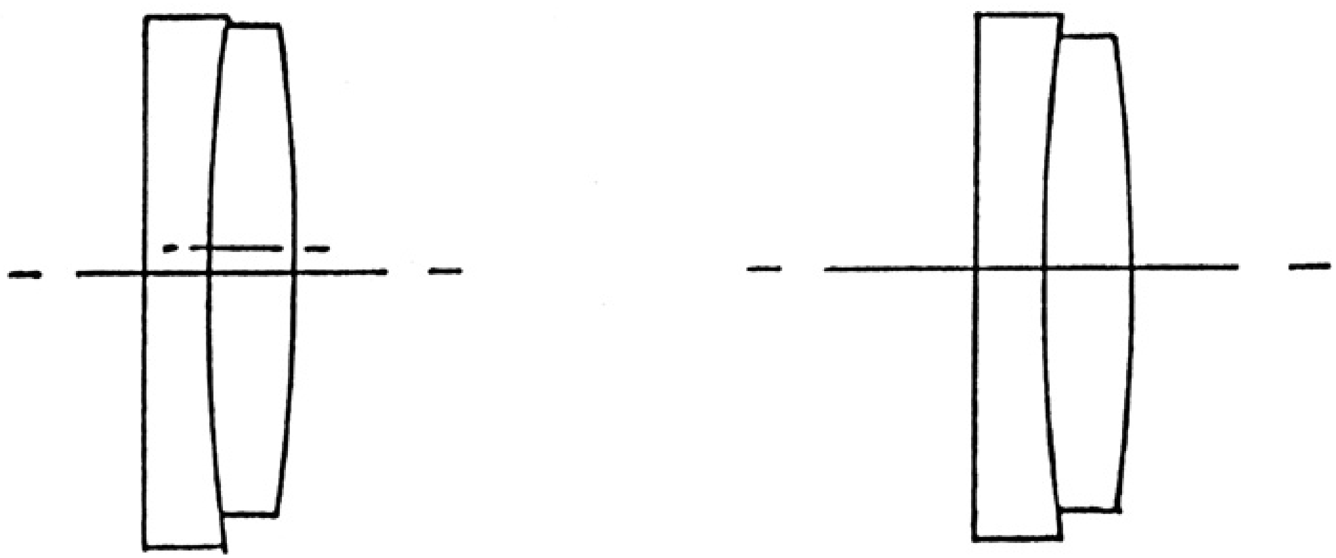
Removing Wedge from a Doublet

Method #1

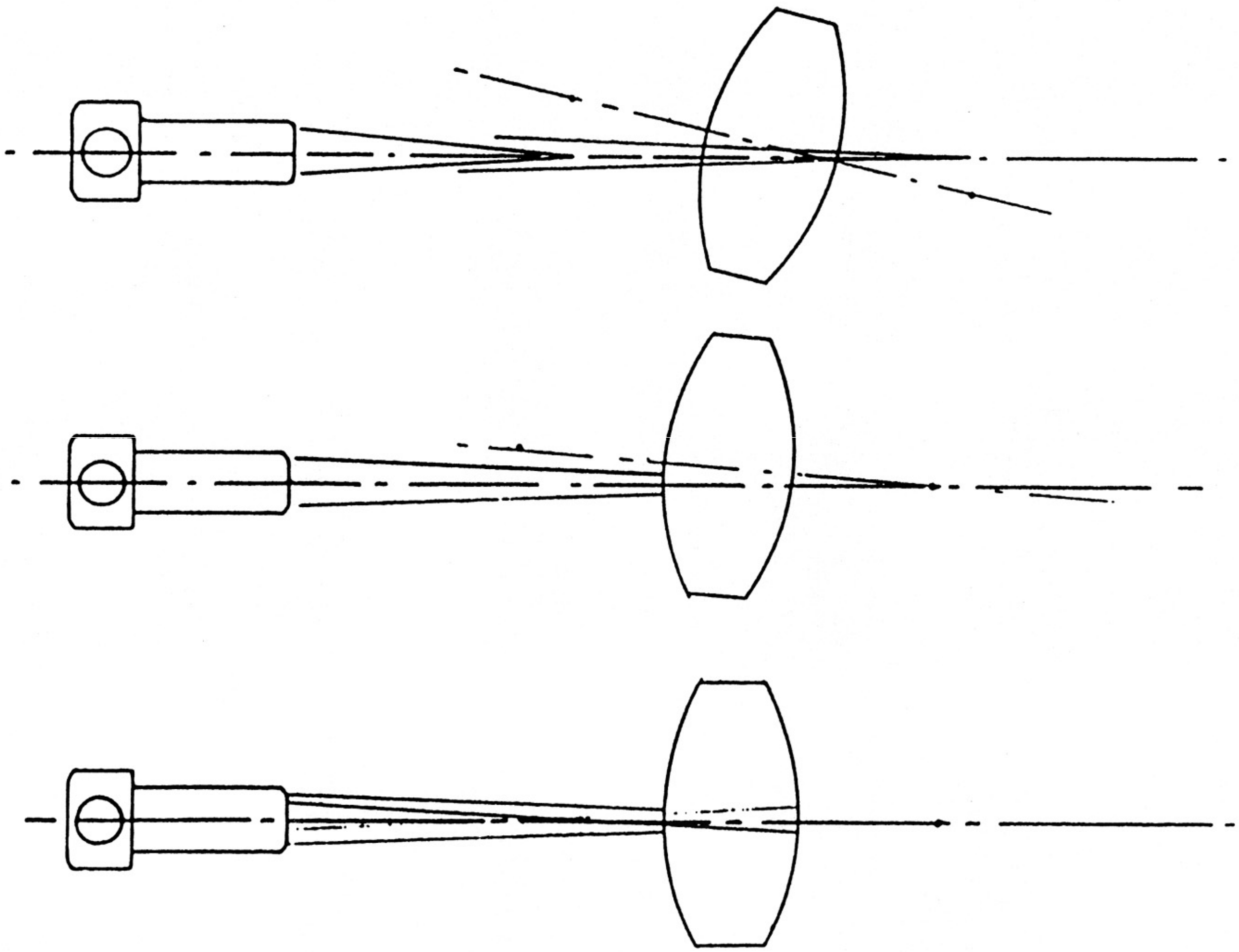
- Remove wedge from both lenses, center, cement, edge

Method #2

- Remove wedge from negative lens, use concave surface to remove wedge from positive lens. Leave negative lens oversize to allow for sliding of positive element. Cement. Edging not usually necessary or desirable

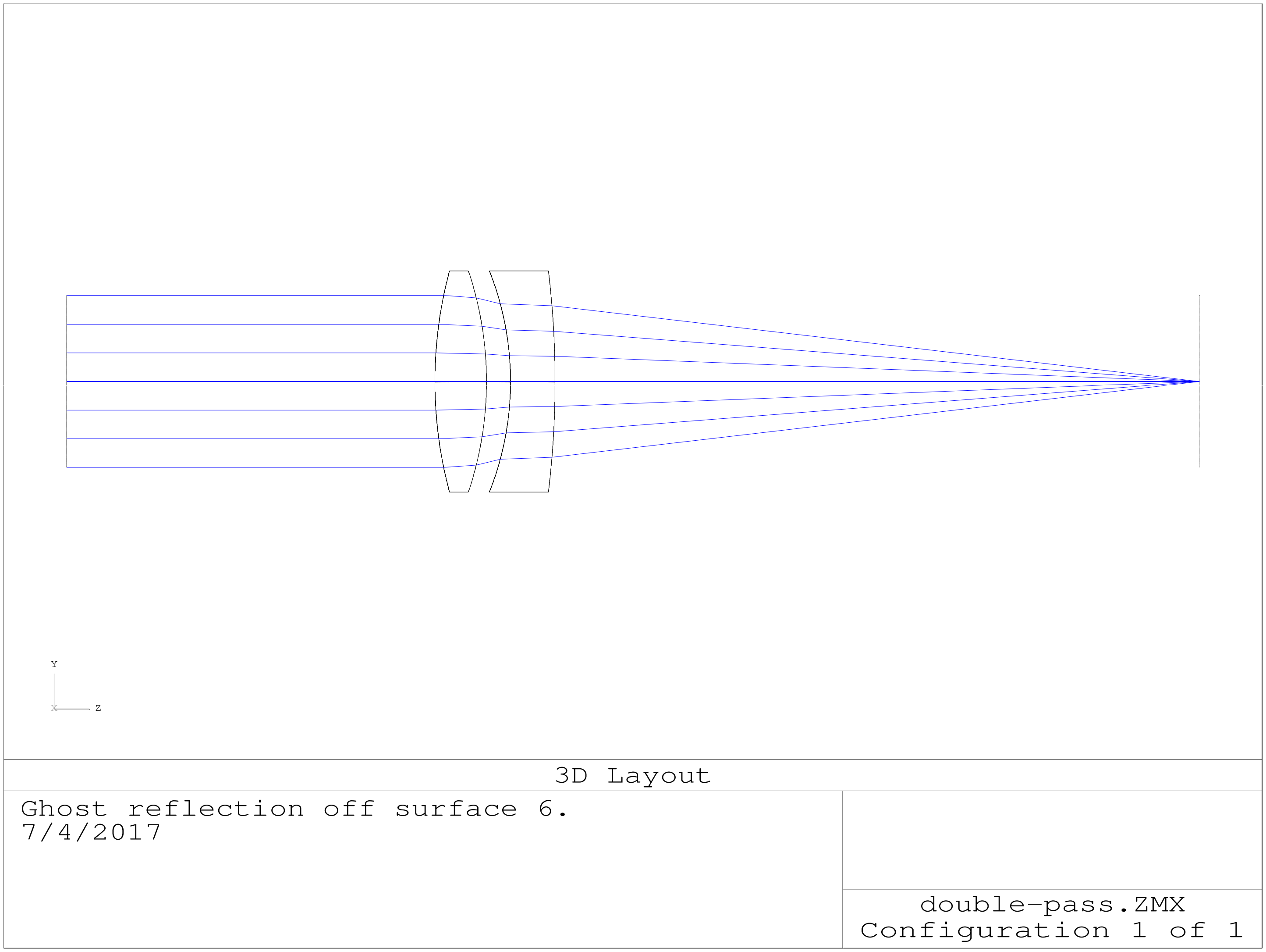


How to Align a Lens with an Alignment Telescope



Look for 4 reflections: 2 Auto-reflections & two (or one) retro-reflection(s)

Air-spaced Doublet Example



Air-spaced Doublet Example (cont)

- 8 reflections seen using an alignment telescope
- 4 vertex returns that don't move if the AT is tapped
- 4 center of curvature returns that do move if AT is tapped
  - -32.434 CC S4 7.970 VX S4
  - -10.195 CC S3 5.178 VX S3
  - -12.705 CC S2 2.864 VX S2
  - 34.724 CC S1 0.000 VX S1
- Align the AT to CC S1 and CC S4 for largest lever arm distance
- If CC S2 and/or CC S3 are not on AT axis, then lenses are tipped or wedged with respect to each other.