The measurement of object distance for projected virtual objects using a scanning pentaprism and digital alignment telescope

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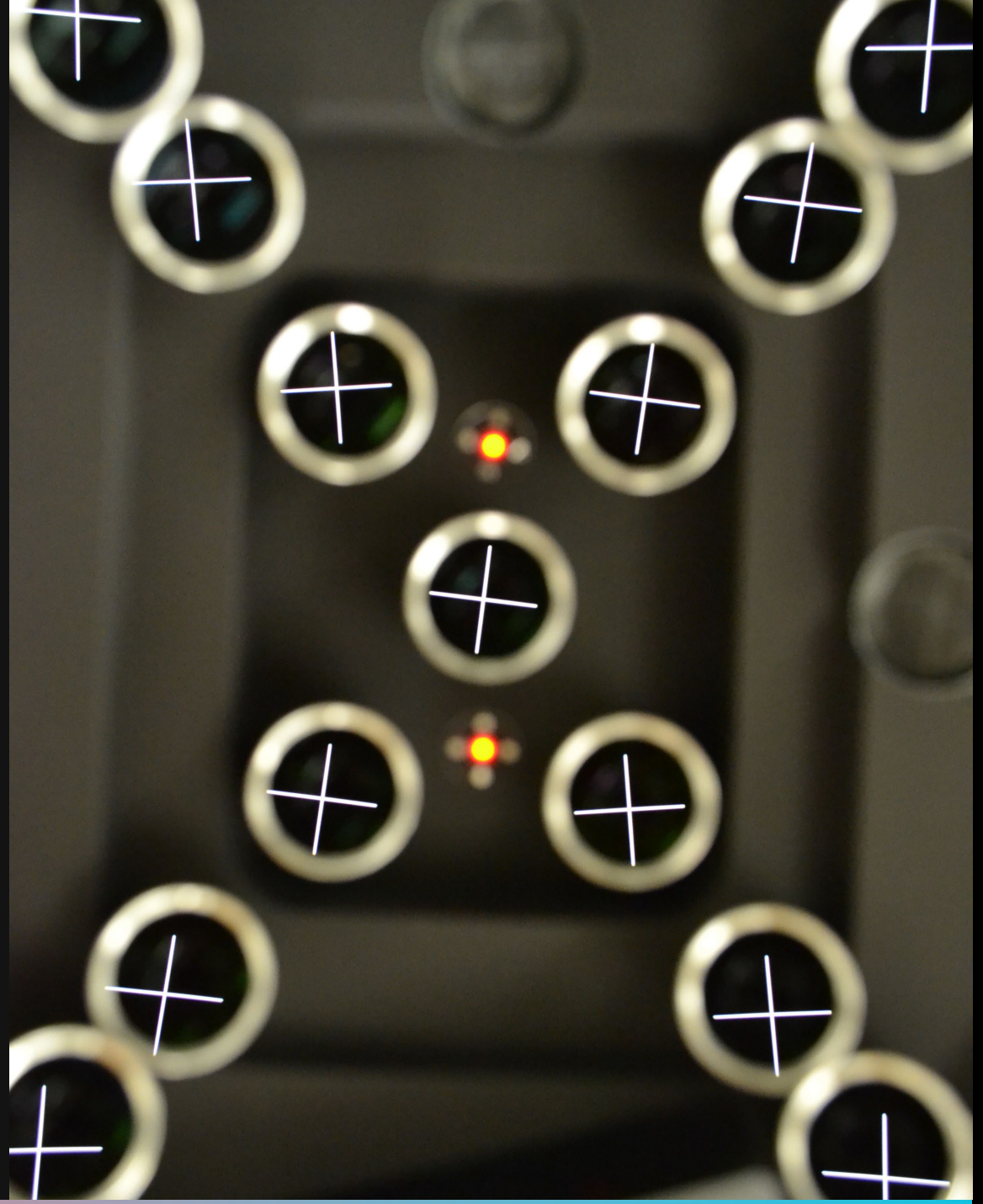


Optikos

An imager test scenario must be **consistent** with the use case.

How do we ensure

Conjugate Distance

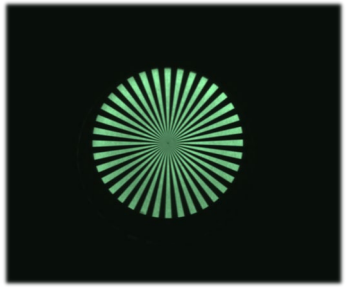
regardless of

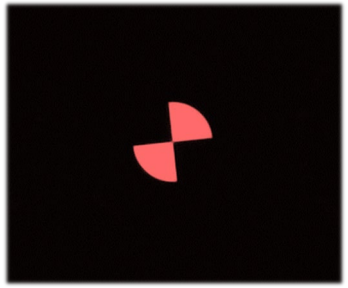
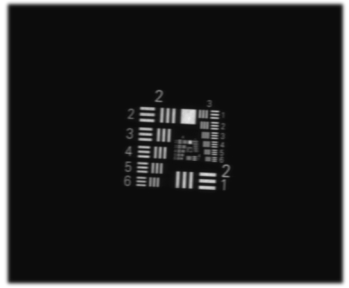
Aperture Size , Wavelength Spectrum

or

Target Shape

?



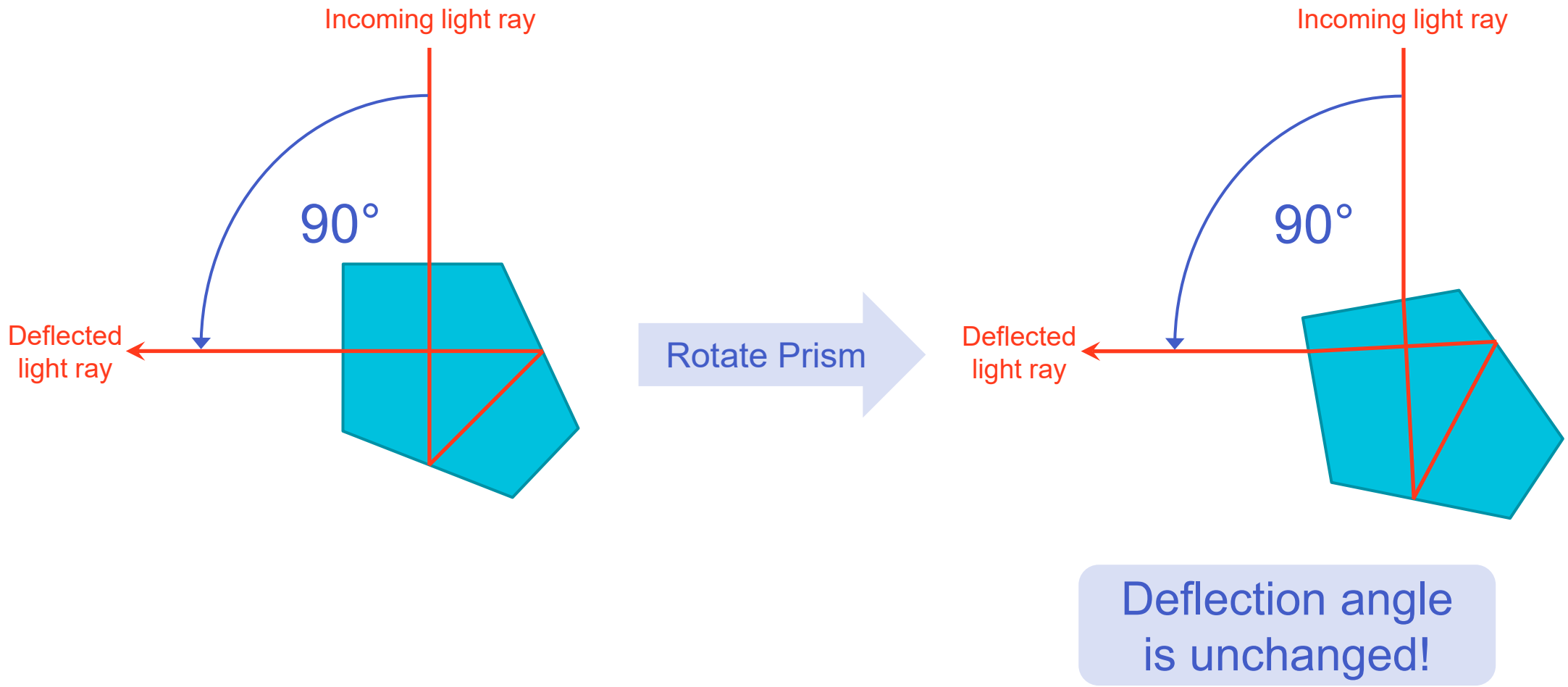



There are several methods for ensuring collimation…

	Restriction				
Method	Pinhole Source	Monochromatic Source	Instrument EFL >> Collimator EFL	Relay Optic > Collimator Aperture	Accommodating Features in Collimator
Laser Unequal Path Interferometer	✗	✗	✓	✗	✗
Calibrated Camera	✓	✓	✗	✗	✓
Shack-Hartmann Wavefront Sensor	✗	✓	✓	✗	✓
Shear Plate Interferometer	✗	✗	✓	✗	✓
Autocollimation	✓	✓	✓	✗	✗
Scanning Pentaprism	✓	✓	✓	✓	✓

The Scanning Pentaprism has the versatility we need.

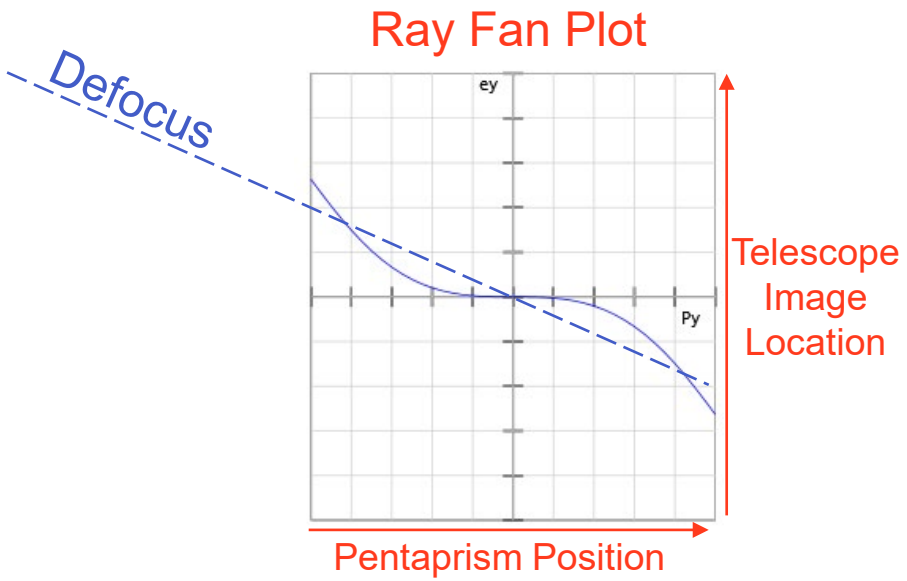
A pentaprism provides a constant deflection angle.



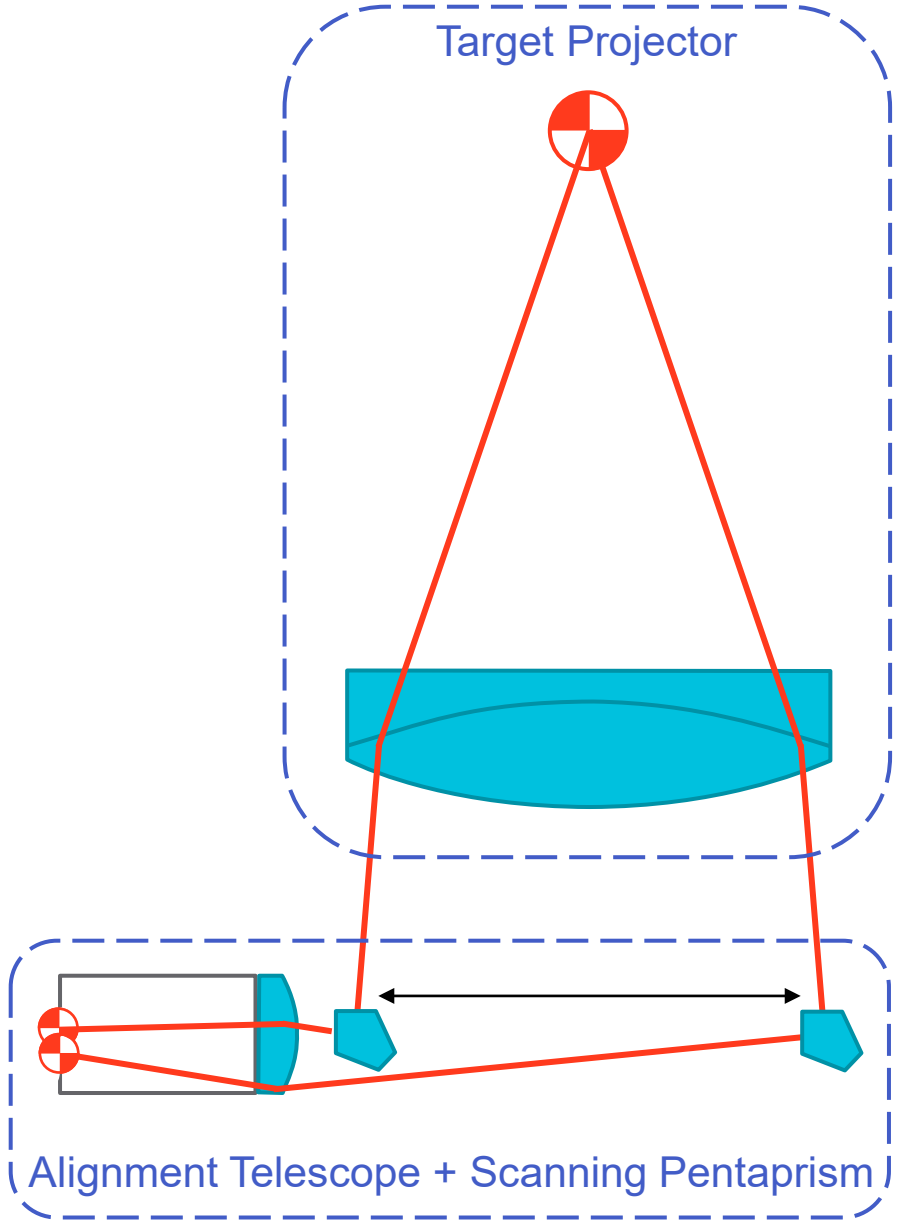
Deflection angle is unchanged!

The Scanning Pentaprism Approach

- Alignment telescope and collimator are rigidly affixed to each other.
  - Moving only the pentaprism drastically reduces straightness required of the linear guideway
- Location of the telescope image is proportional to angle of ray collected from target projector

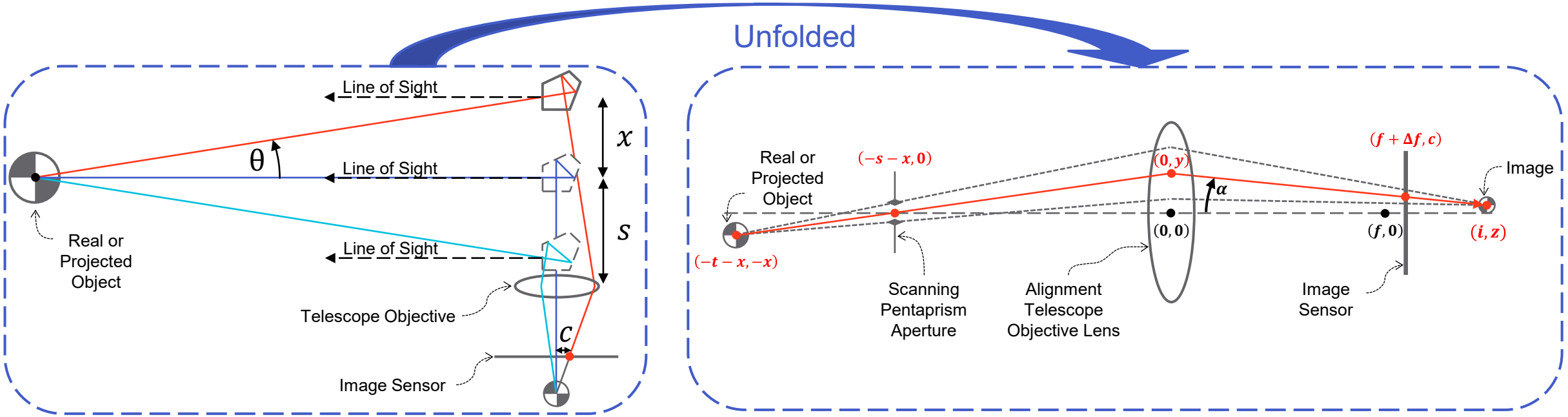


Produces



Geometrical Optics Analysis — See Manuscript

Pentaprism = Aperture Stop → Defines line of sight in object space



Known by design
- s — Nominal aperture spacing
- f — Telescope objective focal length

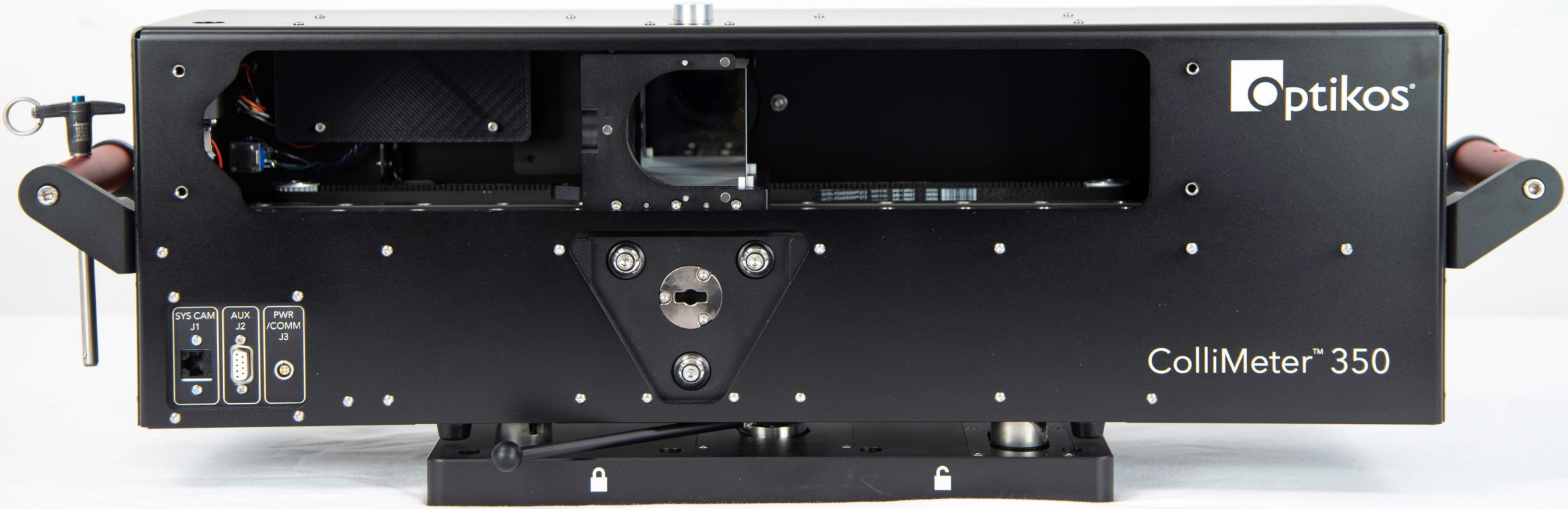
Monitored during operation
- x — Pentaprism position
- c — Chief ray height on sensor

Quantity to be calculated
- t — Object distance

- $y = \frac{x(t+x)}{t-s} - x$ — Chief ray height at telescope objective
- $z = \frac{x}{\frac{(t+x)}{f} - 1}$ — Image location
- $\tan\alpha = \frac{z-y}{i}$ — Chief ray angle in image space
- $c = z - (i - f - \Delta f)\tan\alpha$ — Chief ray height on image sensor

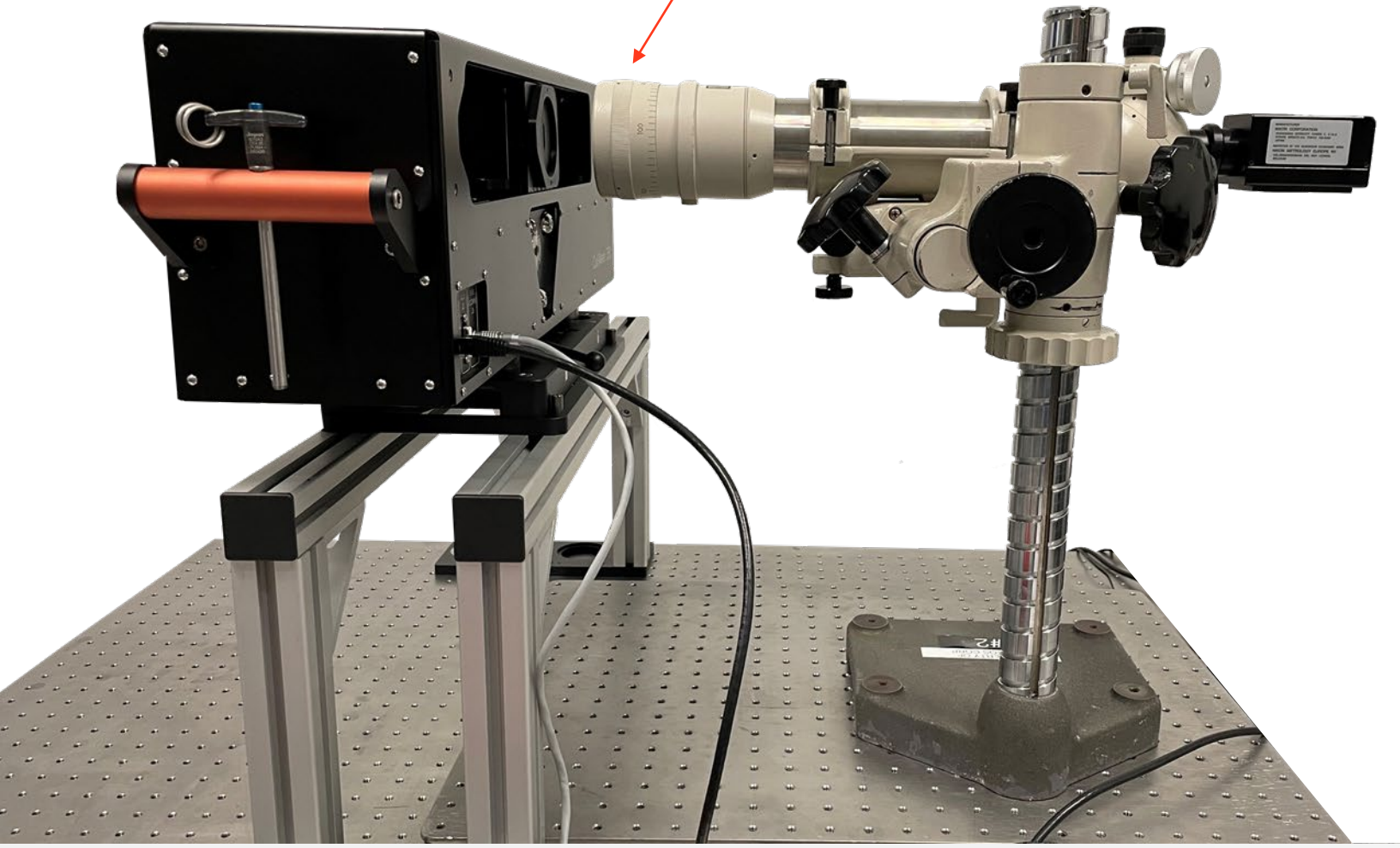
The Scanning Pentaprism Demonstrator

Scan Range	Weight	Pixel Subtense	Full Field of View	Spectral Range
350 mm	16.9 kg	2 arcsec	1.38°	300-1000nm



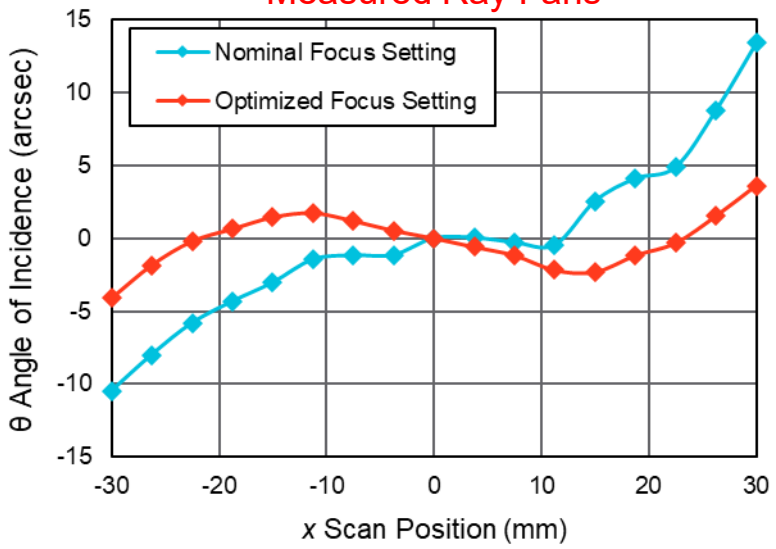
Compensating Spherical Aberration

Focus Setting Adjustment



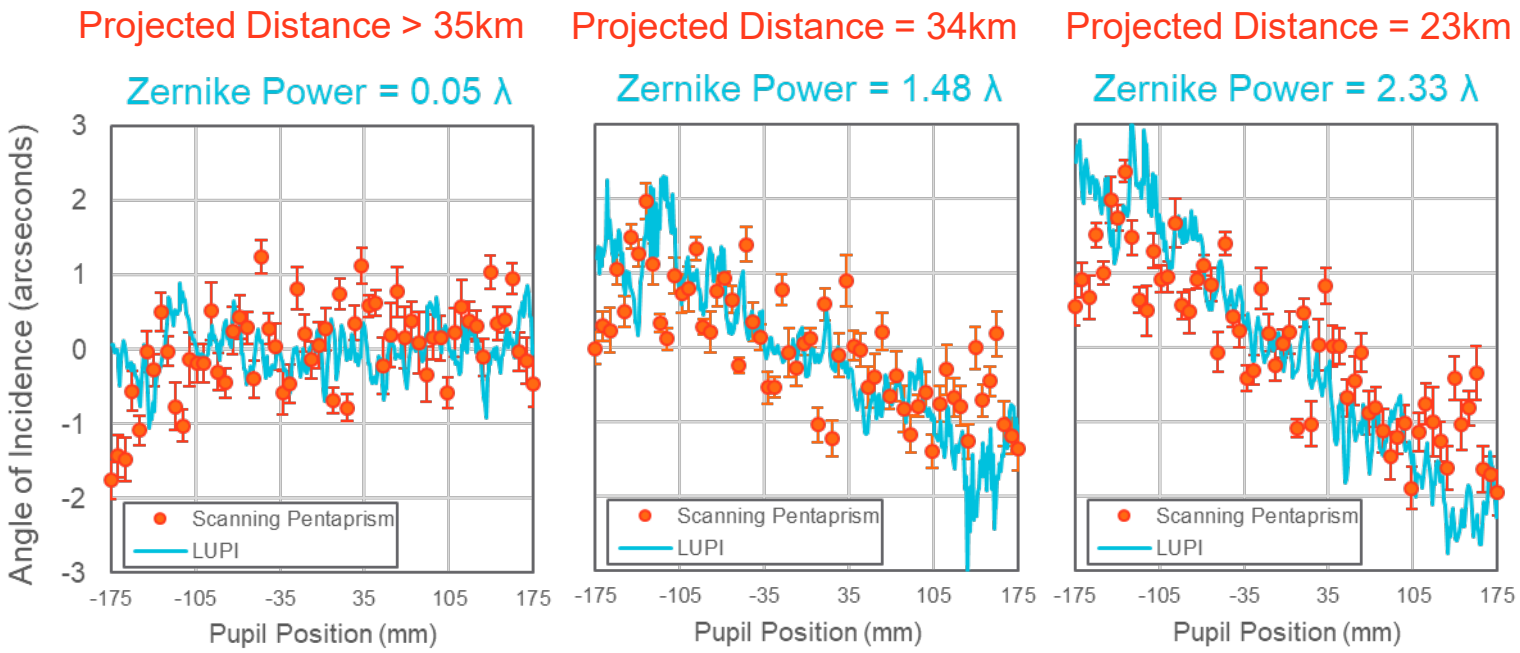
Autocollimator Crosshair in Live Video

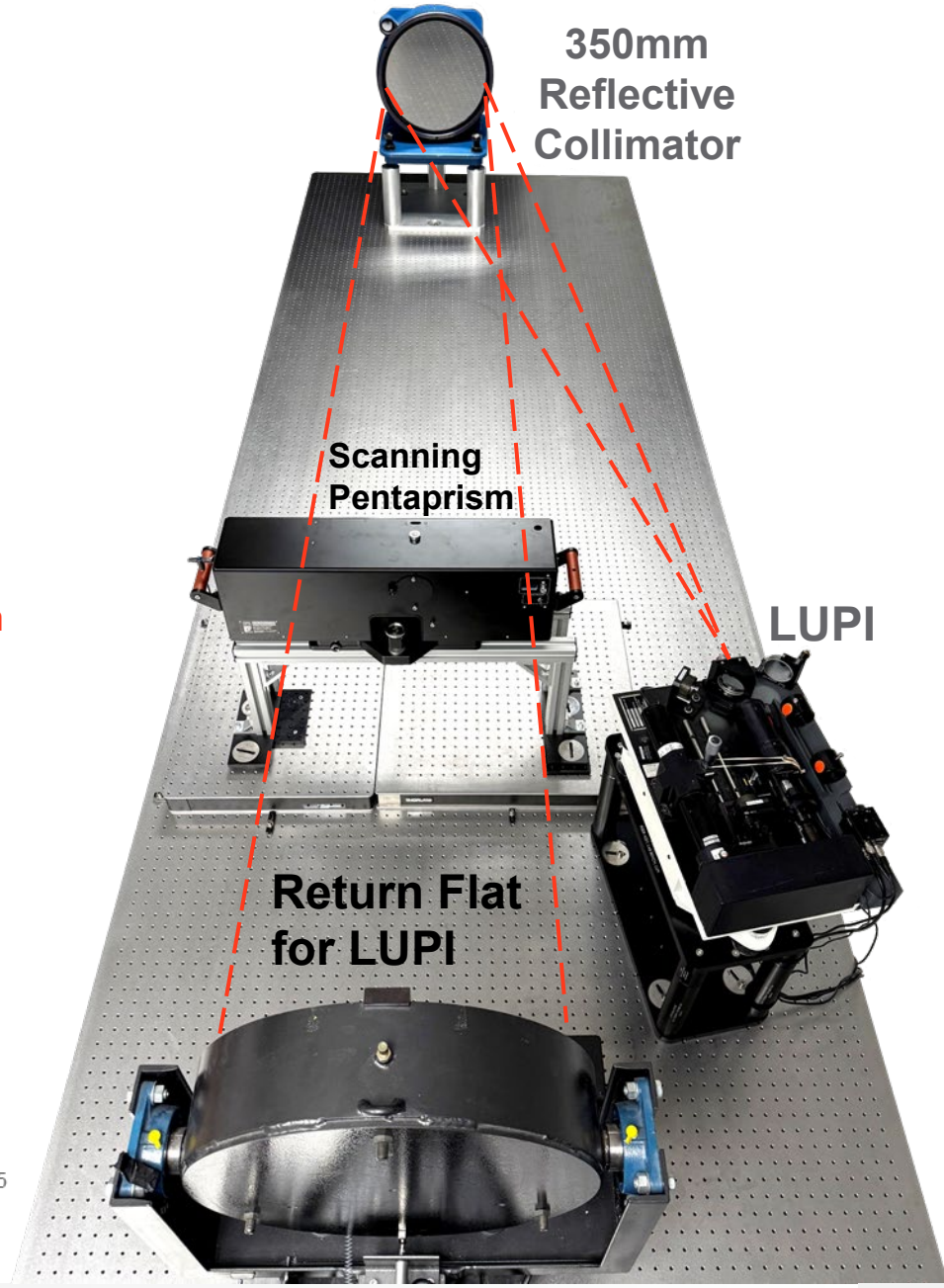
Measured Ray Fans



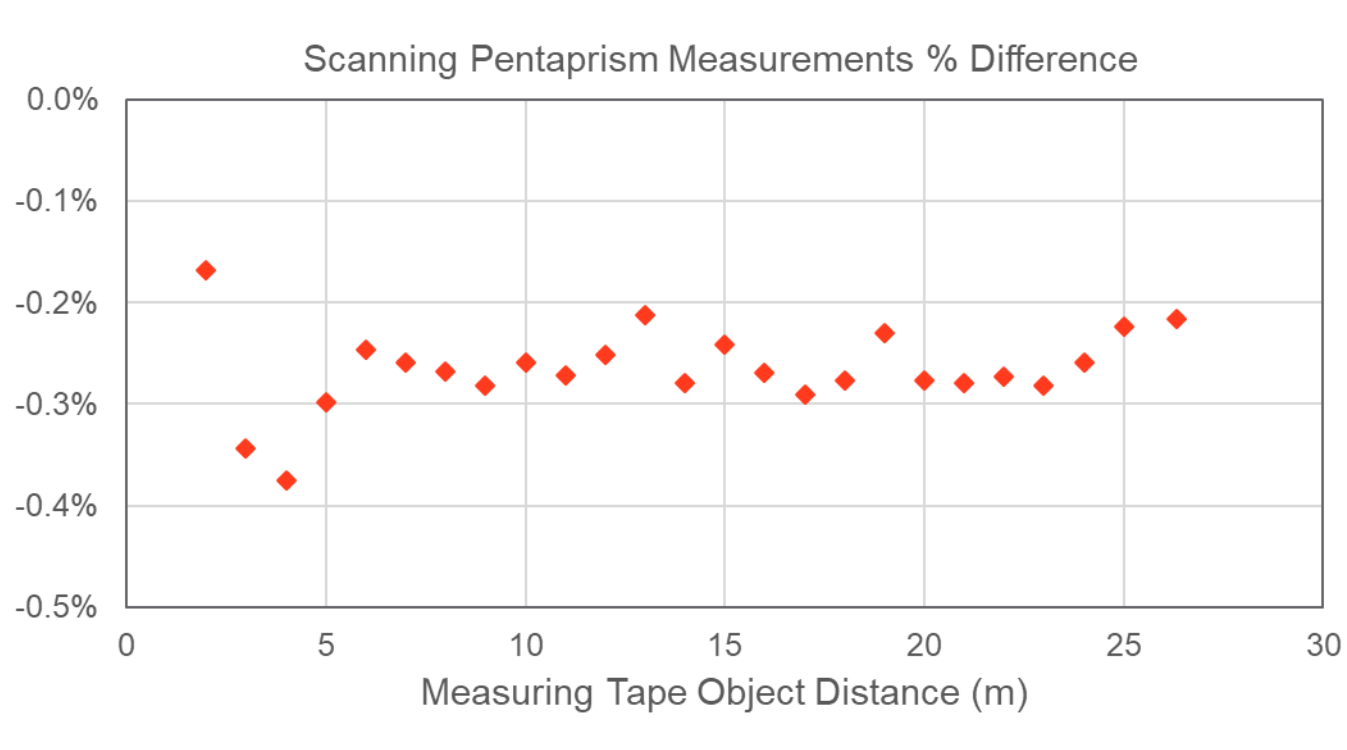
Measuring Departure from Collimation

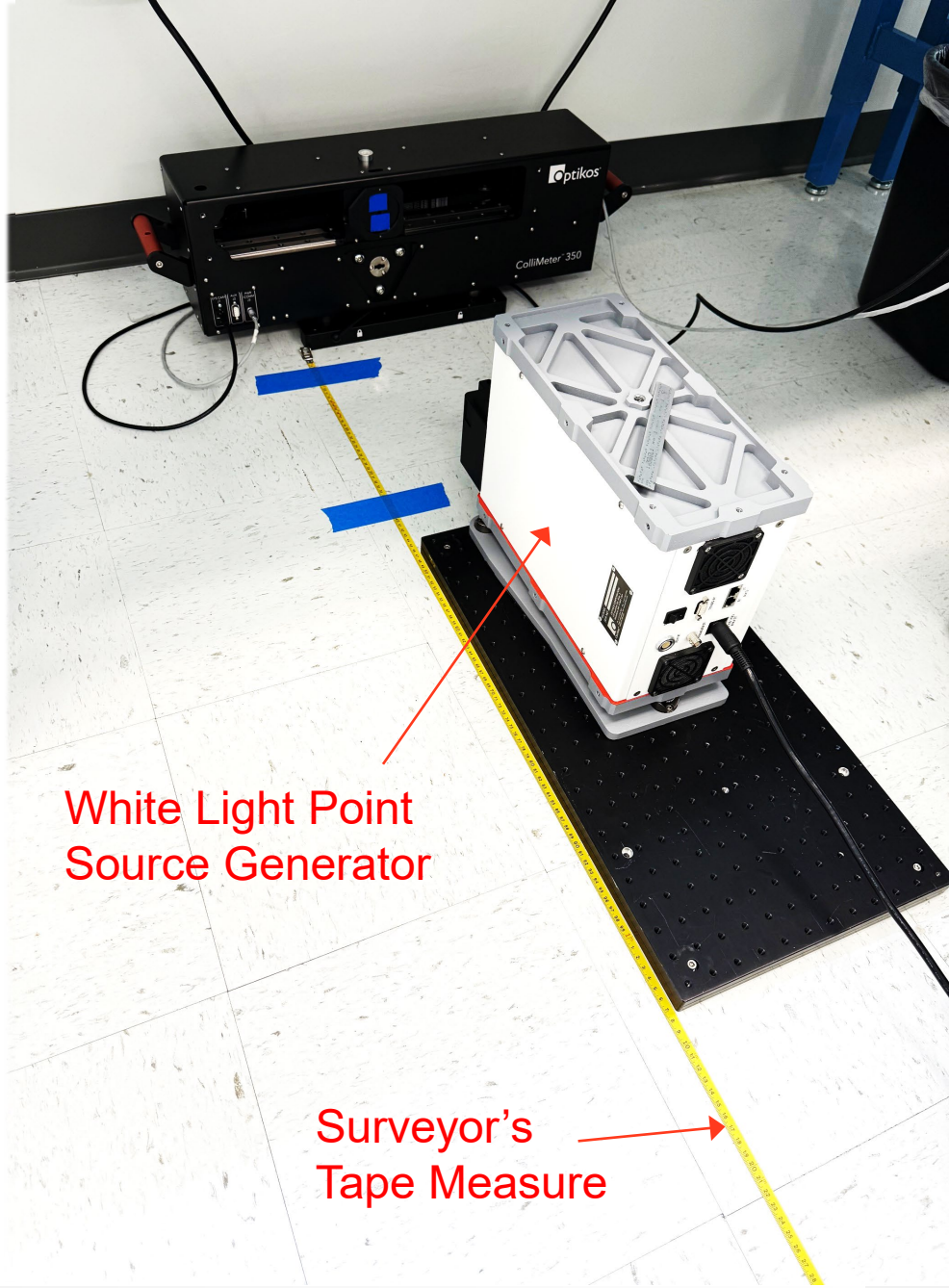
- Laser unequal path interferometer (LUPI) is both:
  1. Point source for collimation measurement
  2. Independent measurement of collimation





Measuring Finite Conjugates





- The scanning pentaprism is a versatile technique for determining conjugate distance of any optical beam!

Measuring Parallax

- The reticles of telescopic sights can be measured provided uniform background illumination.
- For the case of rifle scopes, this can directly measure the “zero parallax distance” on the objective side of the scope.

Thank you!

Come see the scanning pentaprism instrument at Optikos booth #841

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References

- Wetthauer and Brodhun, "Objektiv Untersuchungen," *Zeitschrift für Instrumentenkunde*, vol. 40, no. 5, pp. 96-97 (May 1920)
- R. N. Wilson, ""Matching Error" (Spherical Aberration) in the Hubble Space Telescope (HST): Some Technical Comments," *The Messenger*, no. 61, pp. 22-24 (1990)
- W. Scott Smith "Testing the 8.3-meter telescope optics", Proc. SPIE 2576, International Conference on Optical Fabrication and Testing, pp. 220-231 (August 1995); https://doi.org/10.1117/12.215597
- P. Su, J. H. Burge, B. Cuerden, J. Sasian and H. M. Martin, "Scanning pentaprism measurements of off-axis aspherics," Proc. SPIE 7018, Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation, 70183T (25 July 2008); https://doi.org/10.1117/12.789588
- S. Qian, W. Jark, P. Z. Takacs, K. J. Randall and W. Yun, "In situ surface profiler for high heat load mirror measurement," *Optical Engineering* 34(2), pp. 396-402 (1 February 1995); https://doi.org/10.1117/12.194834
- S. Qian, W. Jark and P. Z. Takacs, "The penta-prism LTP: A long-trace-profiler with stationary optical head and moving penta prism," *Review of Scientific Instruments*, vol. 66, p. 2562–2569 (1995); https://doi.org/10.1063/1.1145658
- K. von Bieren, "Pencil beam interferometer for aspherical optical surfaces," Proc. SPIE 0343 Laser Diagnostics, pp. 101-108 (19 November 1982); https://doi.org/10.1117/12.933743
- P. C. V. Mallik, C. Zhao and J. H. Burge, "Measurement of a 2-meter flat using a pentaprism scanning system," *Optical Engineering* 46(2), 023602 (1 February 2007); https://doi.org/10.1117/1.2700386
- *Optics and optical instruments — Accuracy of optical transfer function (OTF) measurement*, ISO 11421:1997(E), Geneva, Switzerland, (September 15 1997)
- K. Mohammadi, Y. S. Lee and T. Jennewein, "Characterization of optical aberrations with scanning pentaprism for large collimators," CLEO: Applications and Technology, Imaging Techniques Across Multiple Modalities and Dimensions (ATh1D), San Jose, 2022.