Slanted-edge MTF focus test verification with PRF testing to establish best focus position of infinite conjugate space optical systems

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Motivations

- Fixed focus instrument
- Increase confidence in FPA positioning
- For mission success, verification, by independent methods, is key

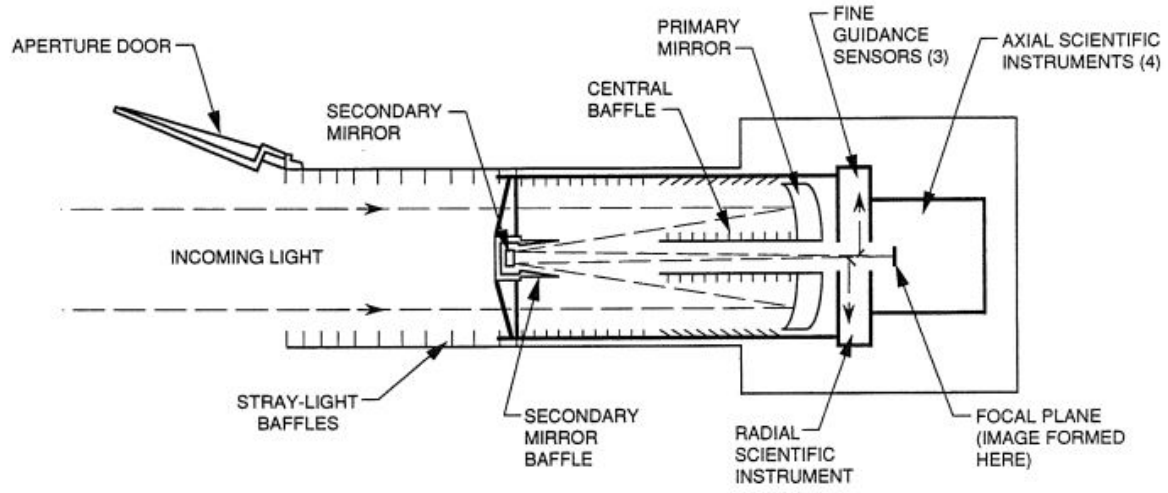
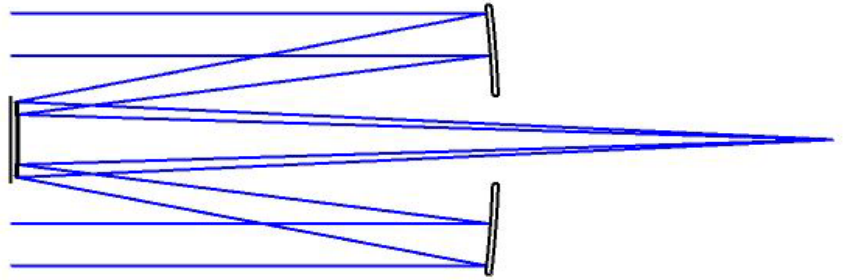


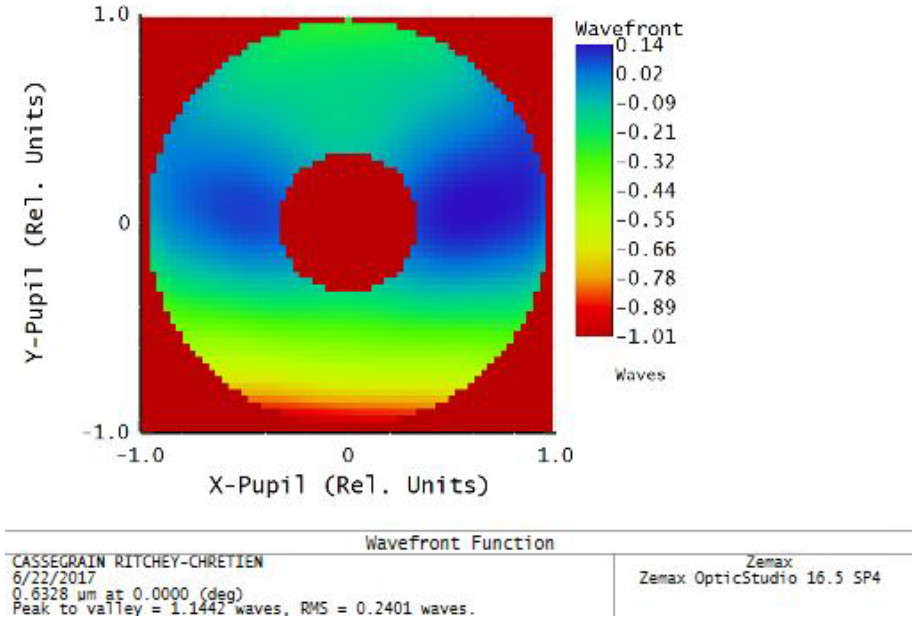
Figure 2-1. Optical Telescope Assembly.

The Hubble Space Telescope Optical Systems Failure Report – NASA 1990

Description of UUT

- Ritchey–Chrétien telescope
- Fixed focus
- Significant gravity-induced astigmatism
- Non-monochrome FPA





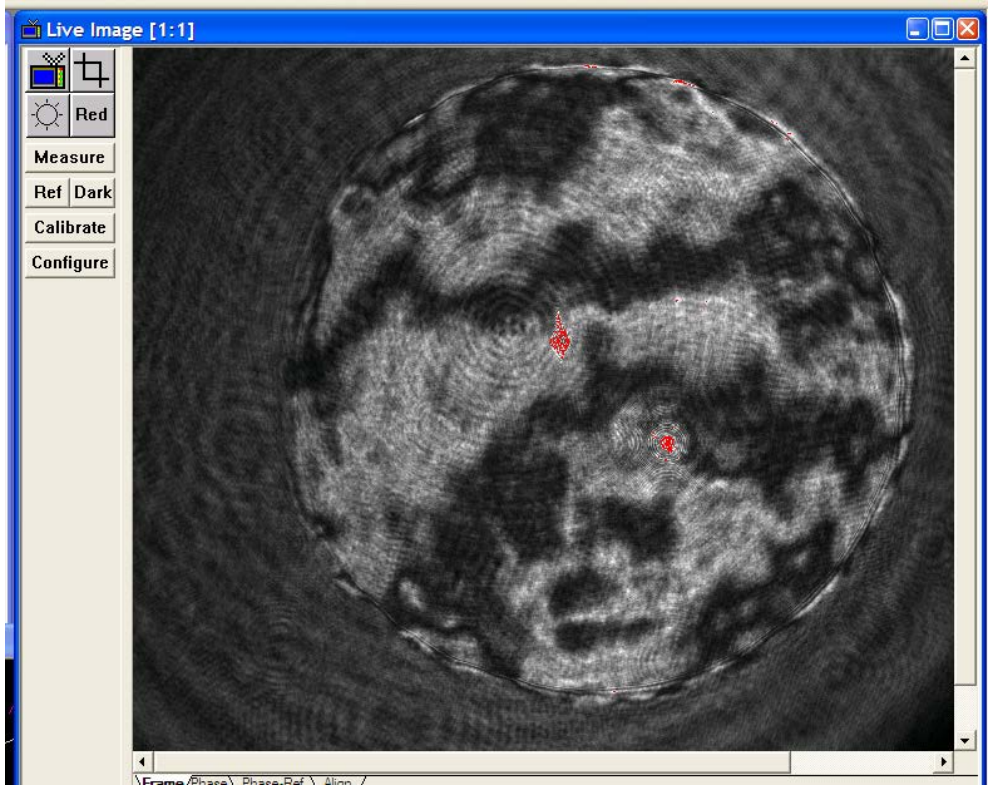
- Testing approach should be tailored to the UUT

Methods to Define Imaging Performance

- Best focus position: the position of the detector that achieves the “best imaging performance”
- WFE (wave front error)
- MTF (modulation transfer function)
- PRF (point response function, a.k.a. point spread function)
- Requirements for Testing
  - Both primary and verification methods must be independent
  - Entire system as a whole must be tested (at infinite conjugate)
  - Operational environment must be able to be simulated
  - Time in vacuum chamber is limited, therefore tests should be similar in setup
  - Verification on-orbit is a plus

Interferometric Wave Front Error Testing

- Phase interferometry with a reference surface
- Aberration content is characterized in detail for a single optical surface
- High measurement accuracy
- Fast measurement
- Entire optical system cannot be tested

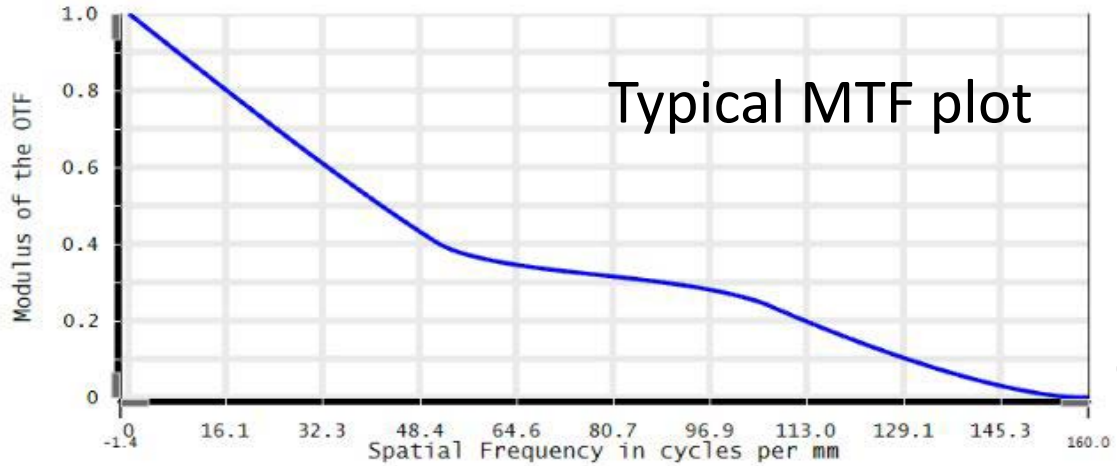


Example interferogram

Modulation Transfer Function

- Magnitude of the complex OTF
- Slanted knife edge target is used in testing
  - International Standard ISO 12233:2014

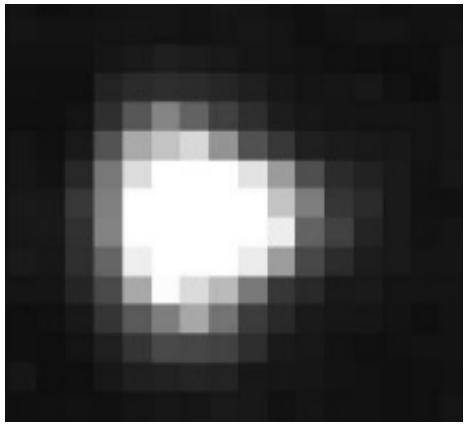
- Meets all requirements for testing
- Multiplicative, such that MTFs can be combined (useful)
- Can be verified in orbit
- Spatial frequency is included



Point Response Function

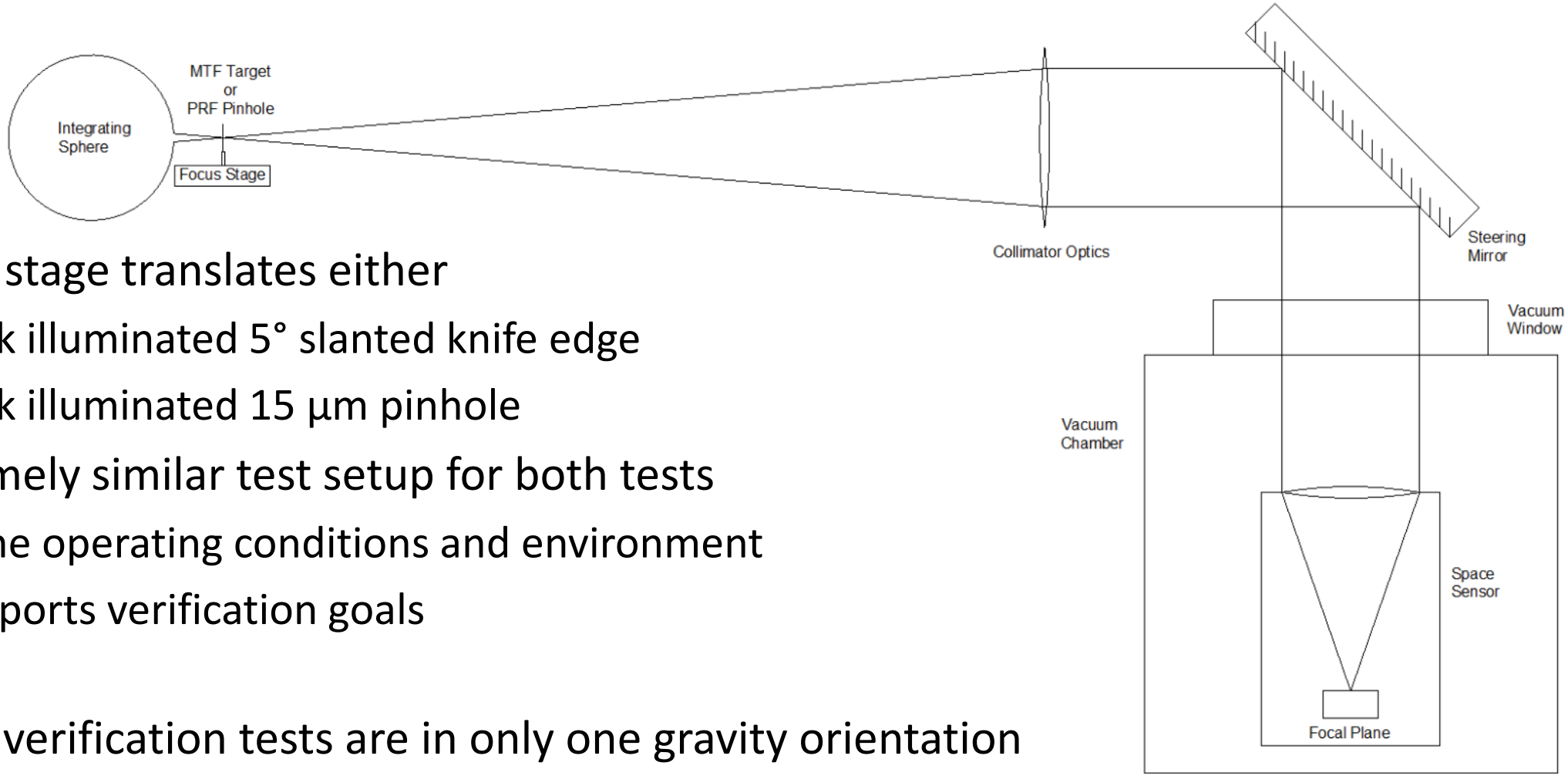
- Optical system's response to a point source input
- Small pinhole is used to simulate point source

- Meets all requirements for testing
- Pairs well with MTF test
  - Independent methods
- Pixel sampling can result in noise
- Can be verified in orbit



Example PRF, near best focus

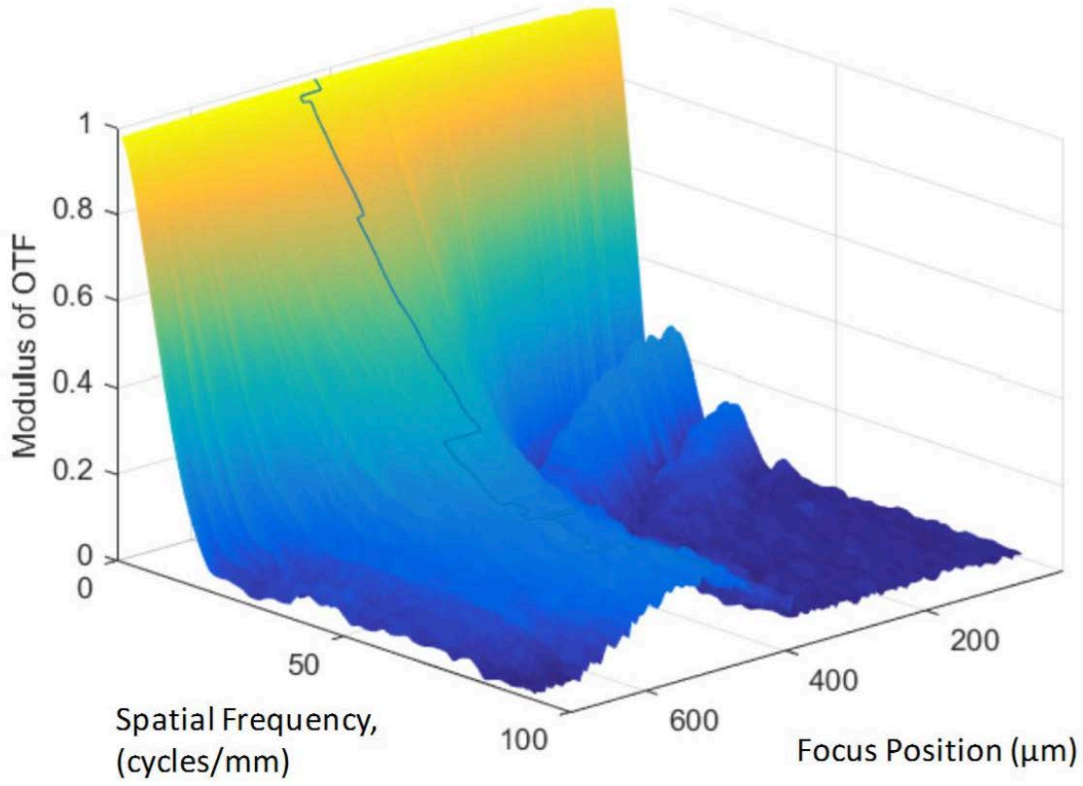
Setup



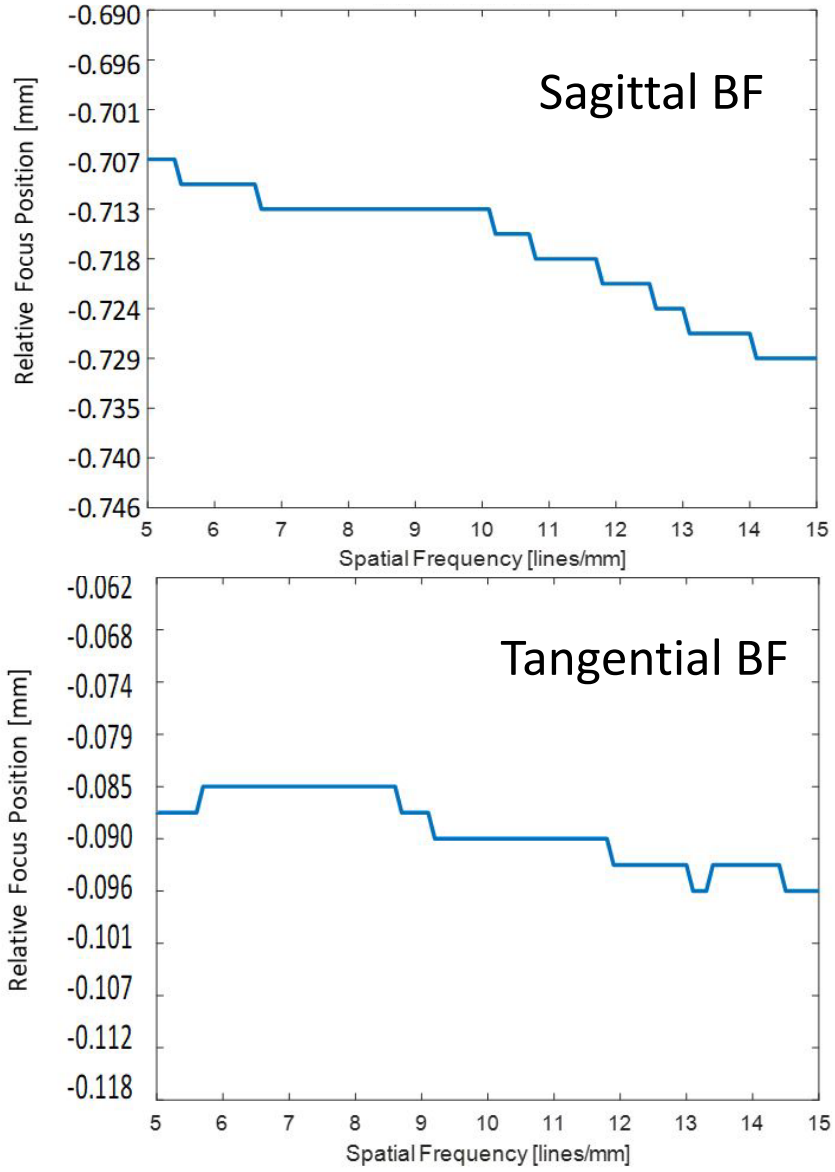
- Focus stage translates either
  - Back illuminated 5° slanted knife edge
  - Back illuminated 15 µm pinhole
- Extremely similar test setup for both tests
  - Same operating conditions and environment
  - Supports verification goals

- Initial verification tests are in only one gravity orientation

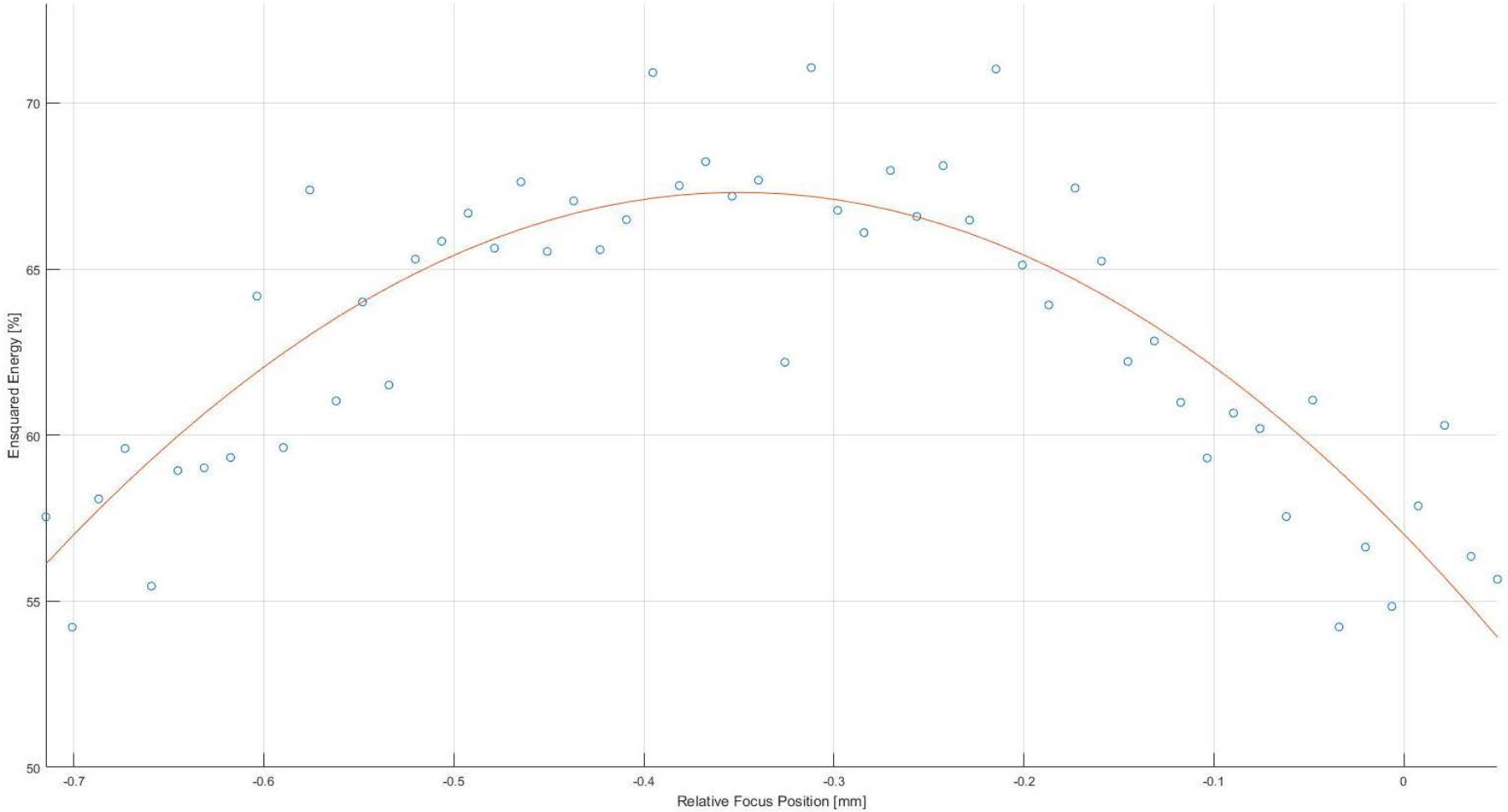
MTF Results – Single Grav. Orientation

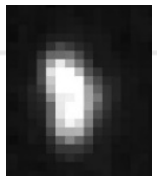


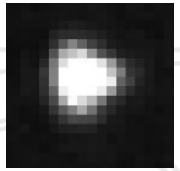
T. Newswander, L. Reinhart, et al., "Slanted-edge MTF testing for establishing focus alignment at infinite conjugate of space optical systems with gravity sag effects," Proc. SPIE, 10401-28 (2017).

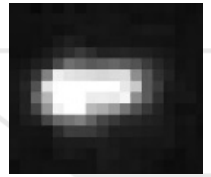


PRF Results – Single Grav. Orientation
Ensquared Energy vs Focus Position









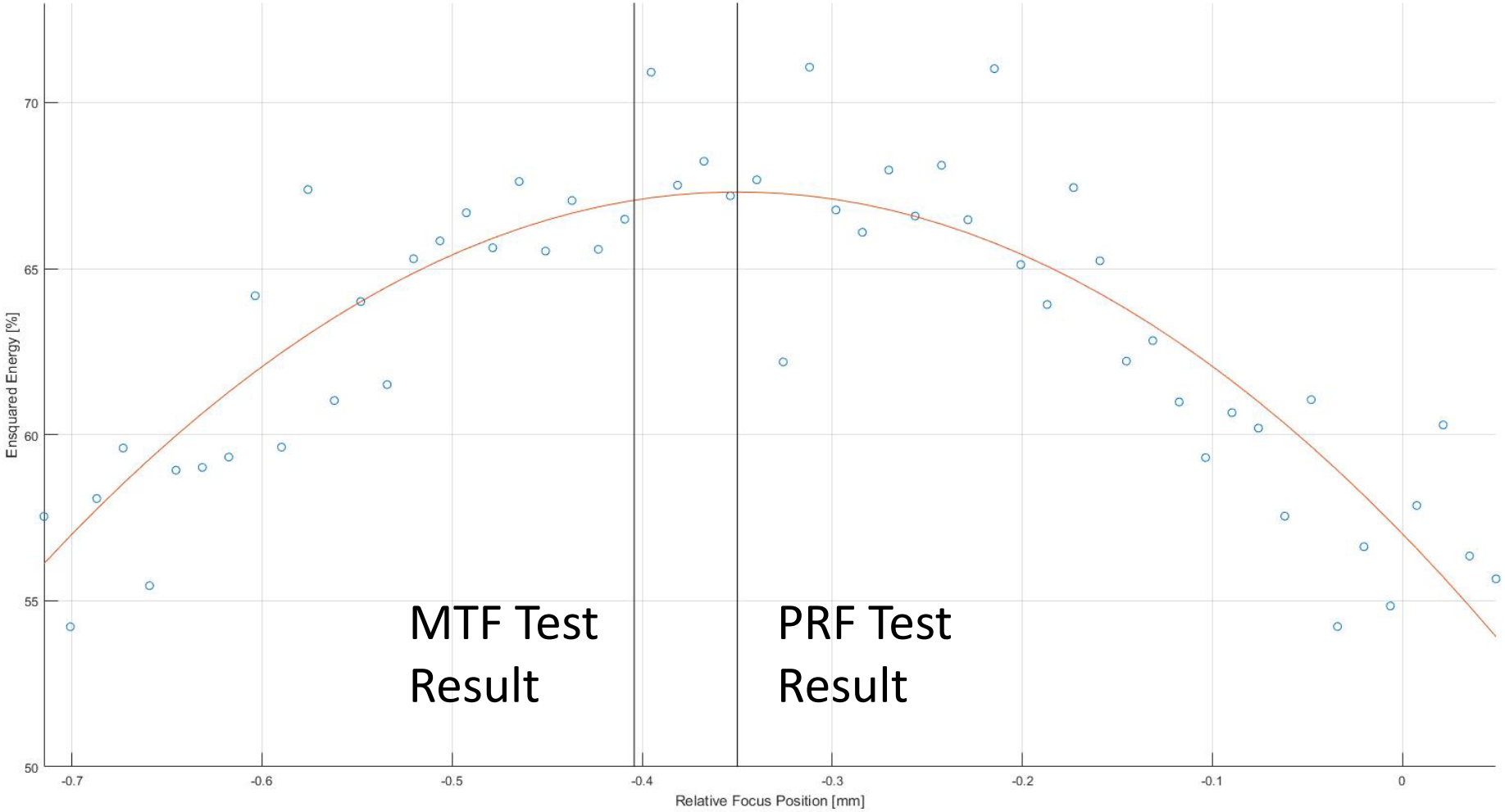
Focus Tolerance Budget

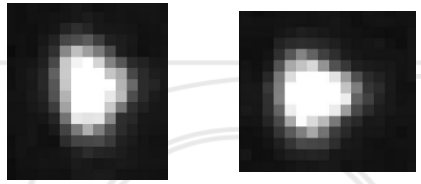
Category	Description	Bilateral Tol. +/- Microns
Test Setup	Collimator WFE	0.5
	Collimator focus	0.5
	Focus stage accuracy	3
	Focus stage stability	10
	Knife edge or pinhole alignment	0.5
	Vacuum window	5
Measurement	Data analysis repeatability	10
	Measurement resolution	3
Shim	Shim fabrication tolerance	12.5
Margin	Focus margin	10
	Worst Case	52
	RSS	23
	MRSS	**30**

- The measurement tolerances are estimates based on currently available data
  - Rigorous measurement uncertainty analysis through additional test data is planned
- MRSS includes the number of independent error sources in the statistical summation*

*Dimensioning and Tolerancing Handbook – Drake 1999

Comparison of MTF and PRF Results
Single Grav. Orientation





54 µm discrepancy

Conclusions and Comparisons

- MTF and PRF methods find the BF independently, in very different ways
- MTF test does not account for the magnitude of the aberration in sagittal or tangential BF
- PRF test is dependent on the magnitude of the aberration
- Peak $MTF_{tangential}$ > Peak $MTF_{sagittal}$
  - This supports the PRF-derived BF position offset from the MTF-derived BF
- The MTF test provides more information, leading to better gravity compensation
- Testing in both gravity orientations for both MTF and PRF test is planned to continue for verification, and matching results are now expected

Questions?