SAND2012-6434C

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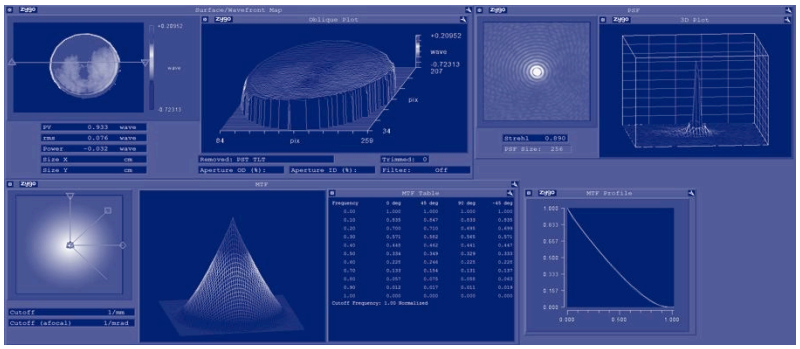

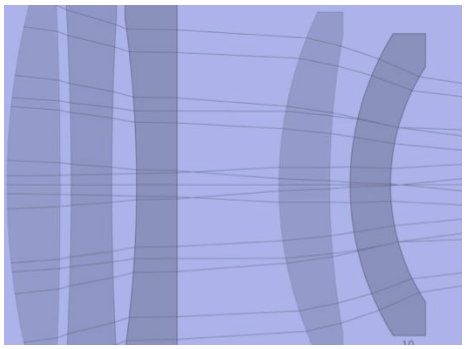

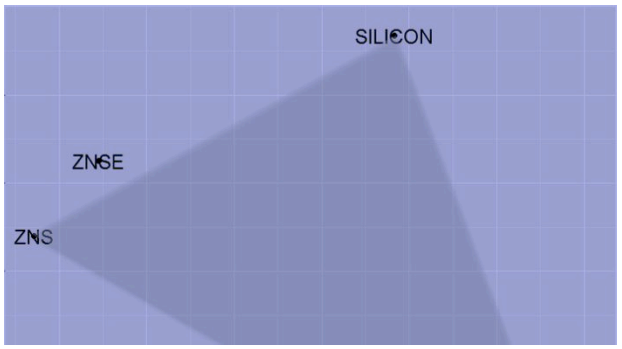

Optical design & performance testing of an athermal SWIR gas correlation imager

Anthony Tanbakuchi, Mark Smith, Jeff Mercier,
Steve Vigil, Todd Embree, Aaron Ison

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National Nuclear Security Administration

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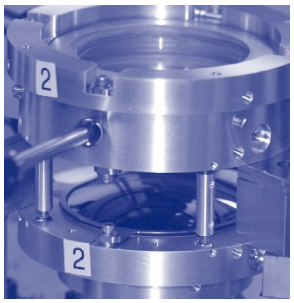
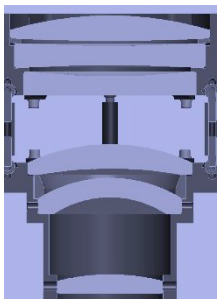
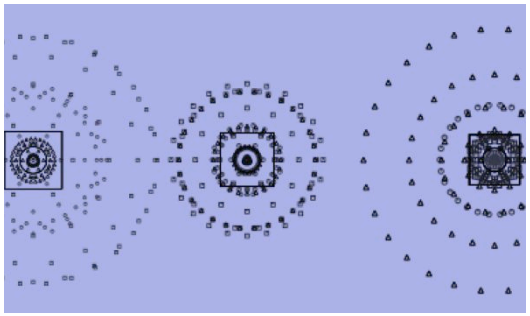
Motivation







Gas correlation imaging enables high specificity remote sensing of gas species based on unique molecular resonances that cause narrow band absorption.

- Build a field deployable methane imager.
- Rugged and stable for field use.
- Quick development cycle.
- Lower cost techniques.
- Flexible for testing & calibration.

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Gas Correlation Imaging

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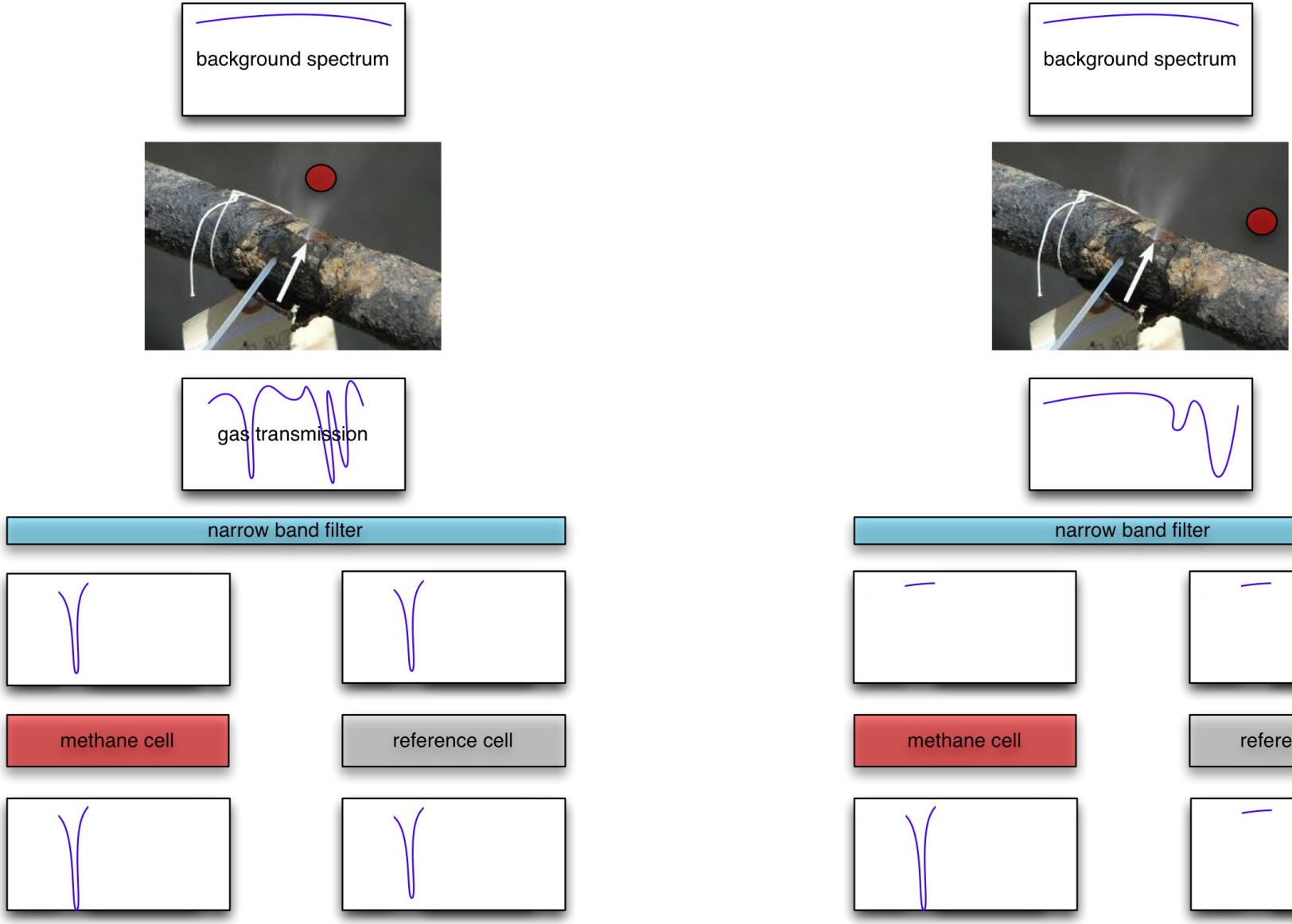
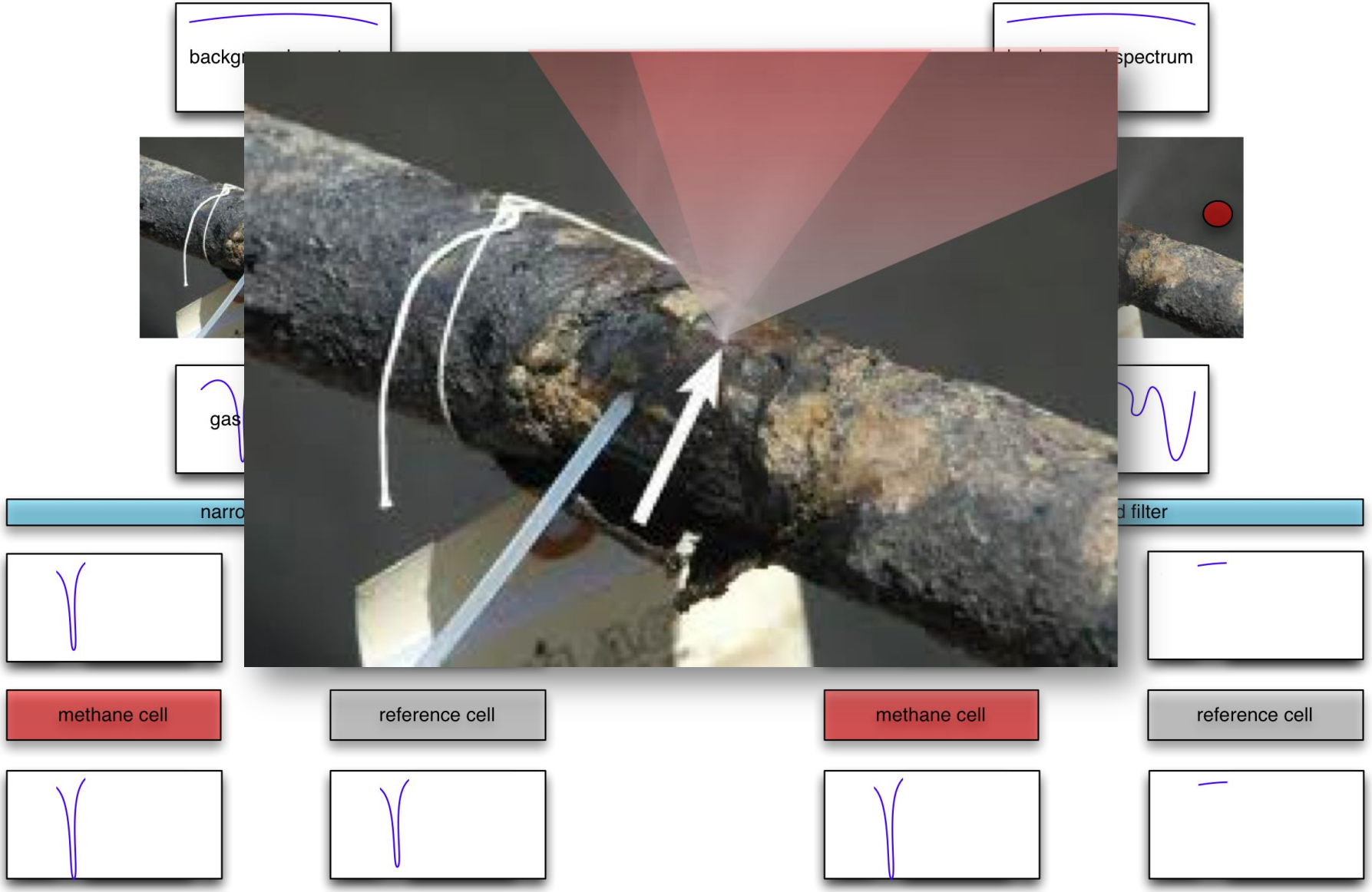


Gas Correlation Imaging



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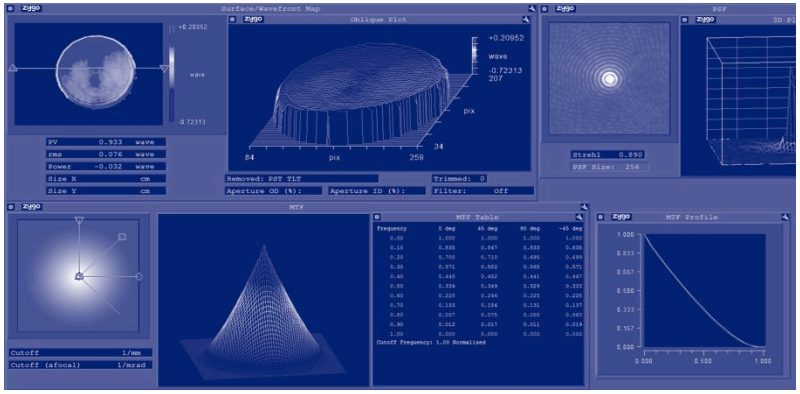

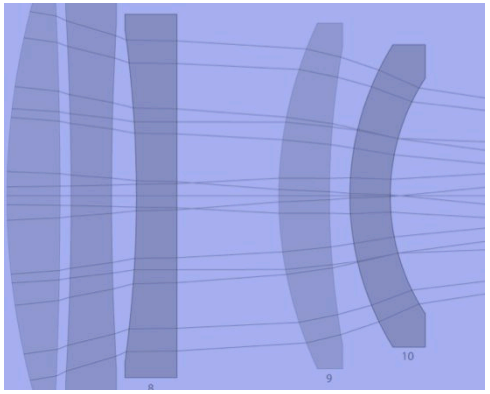

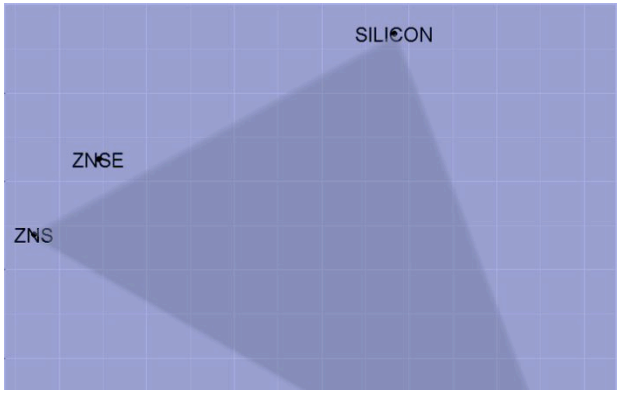

Design

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Design goals

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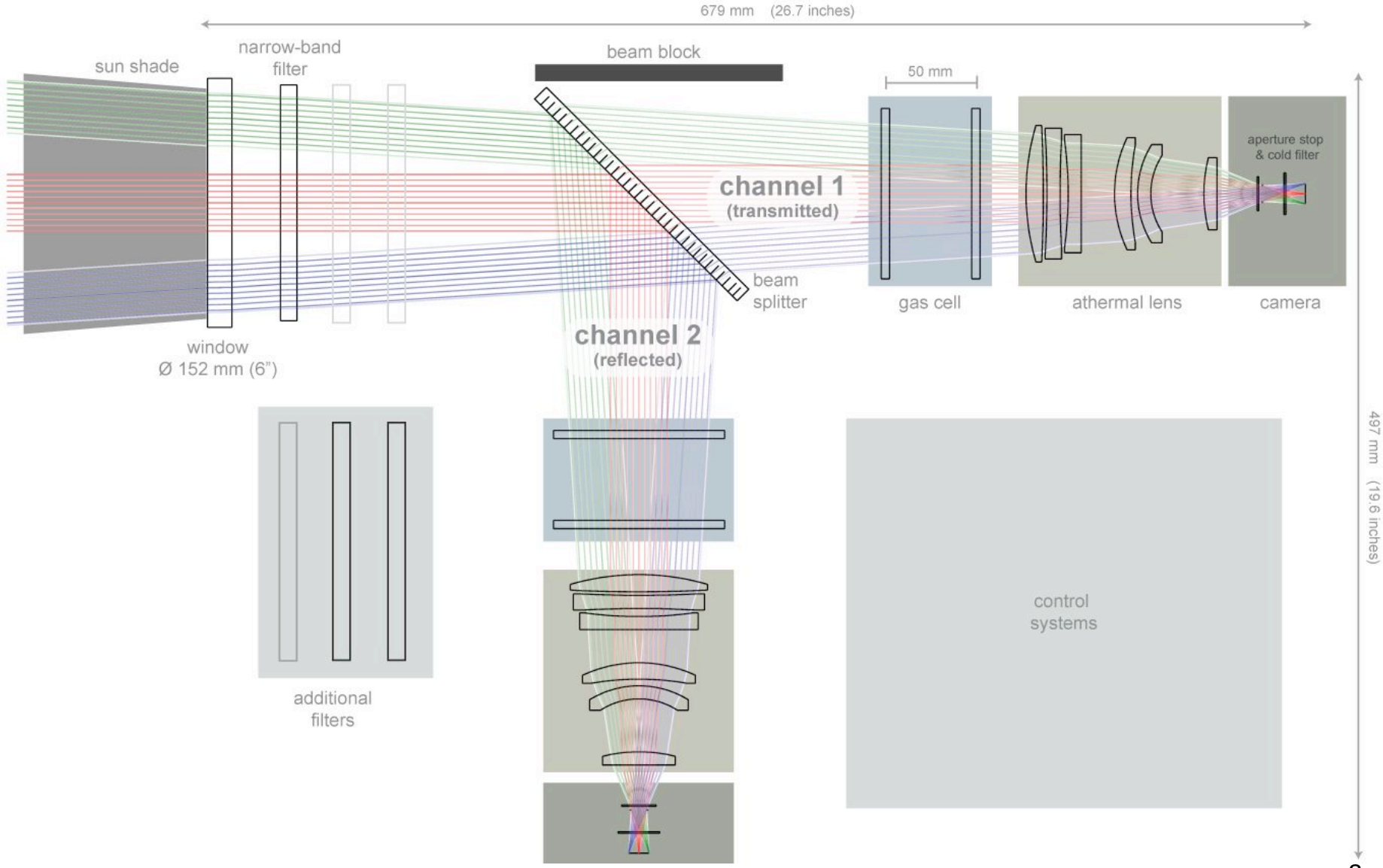
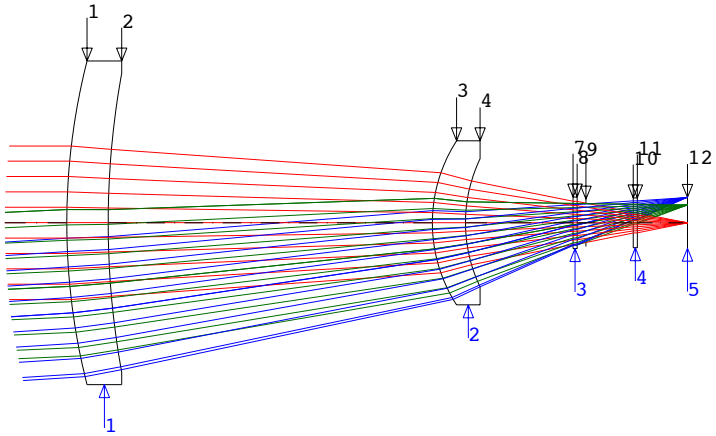
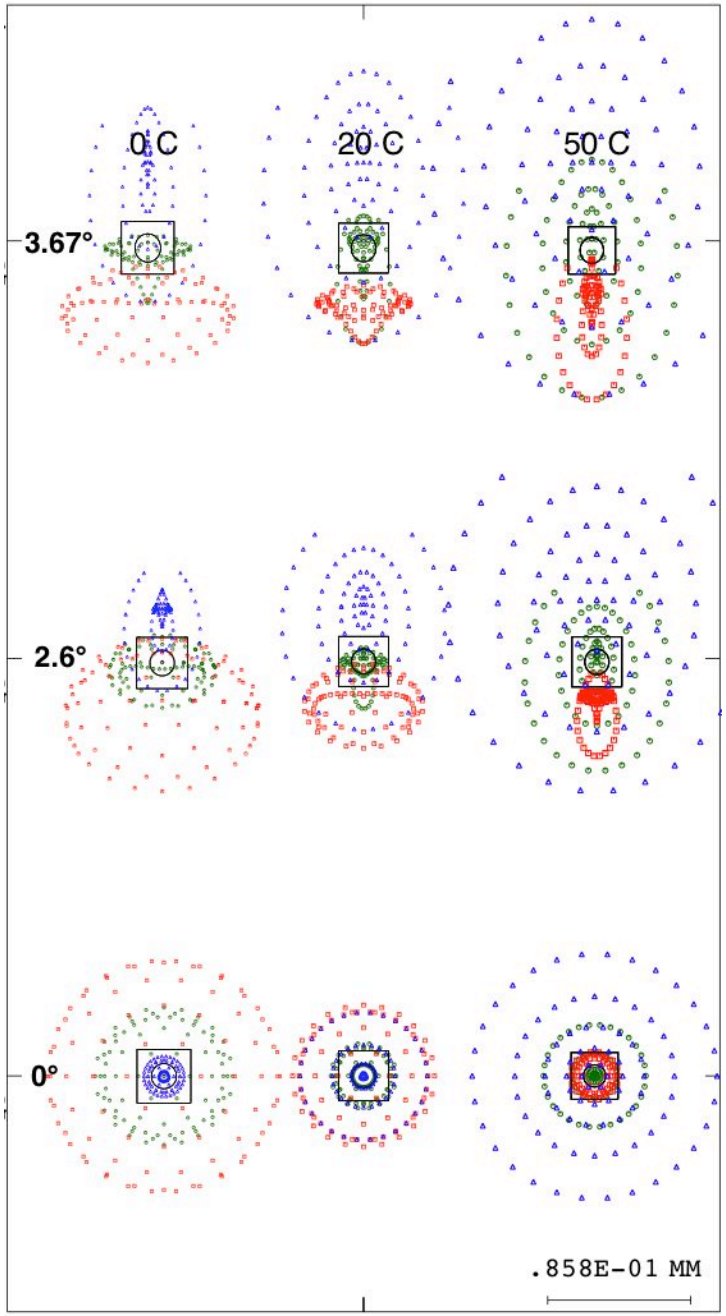
Parameter	Value
Spectral band	2.0-2.5 um
athermal temperature range	0 - 50 deg C
F-number	f/2.5
focal length	96 mm
entrance pupil dia	28.4 mm
full field of view	4.7 x 5.7 deg
detector pixel pitch	30 um
detector pixels	320 x 256
MTF goal at 16.6 cycle/mm	at least 50% for optics
30 um ensquared energy goal	70% or greater
depth of field	0.2 km to infinity

System layout



All silicon objective





Square represents 30 um pixel.

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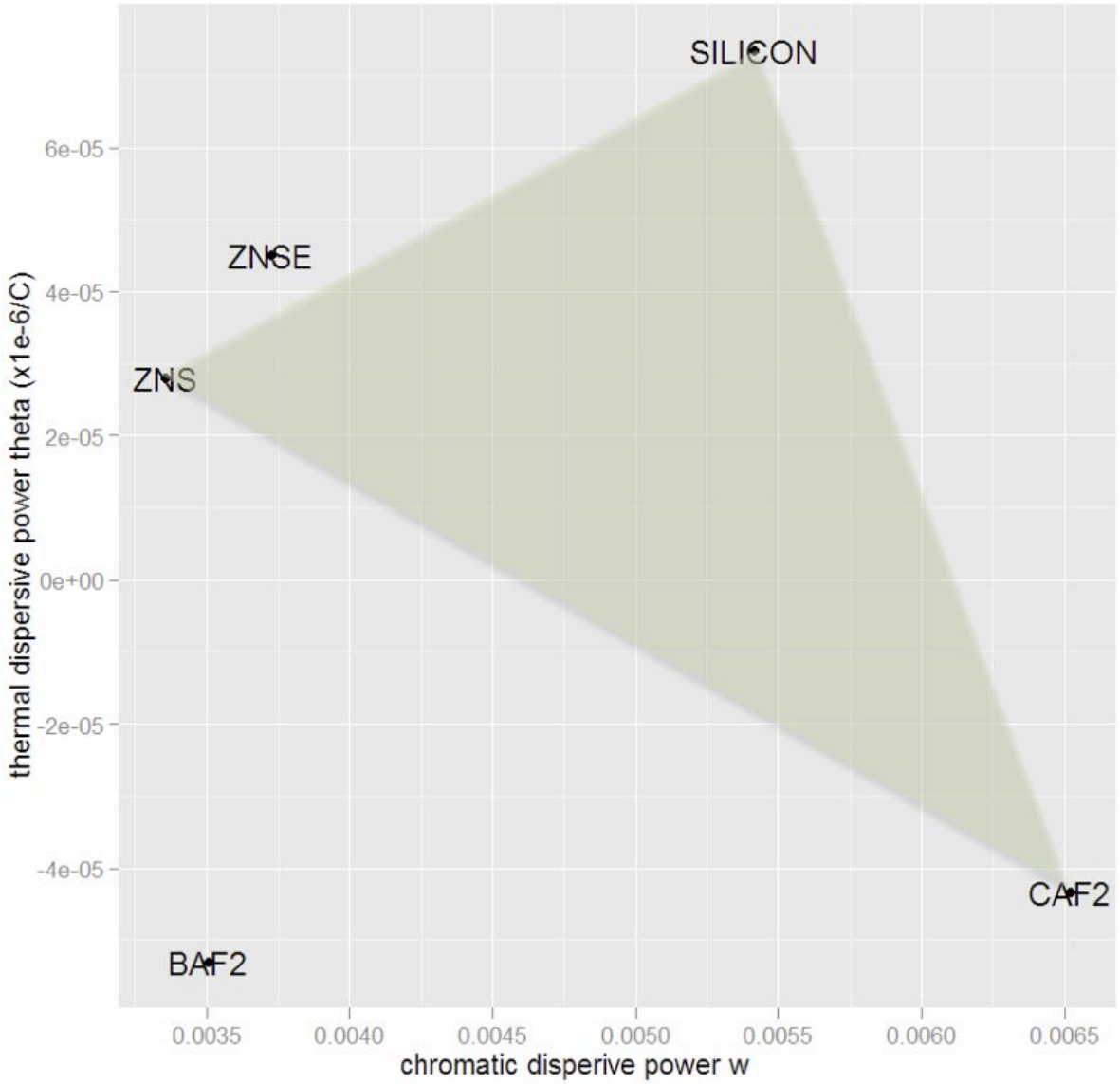
Design process for athermal achromat



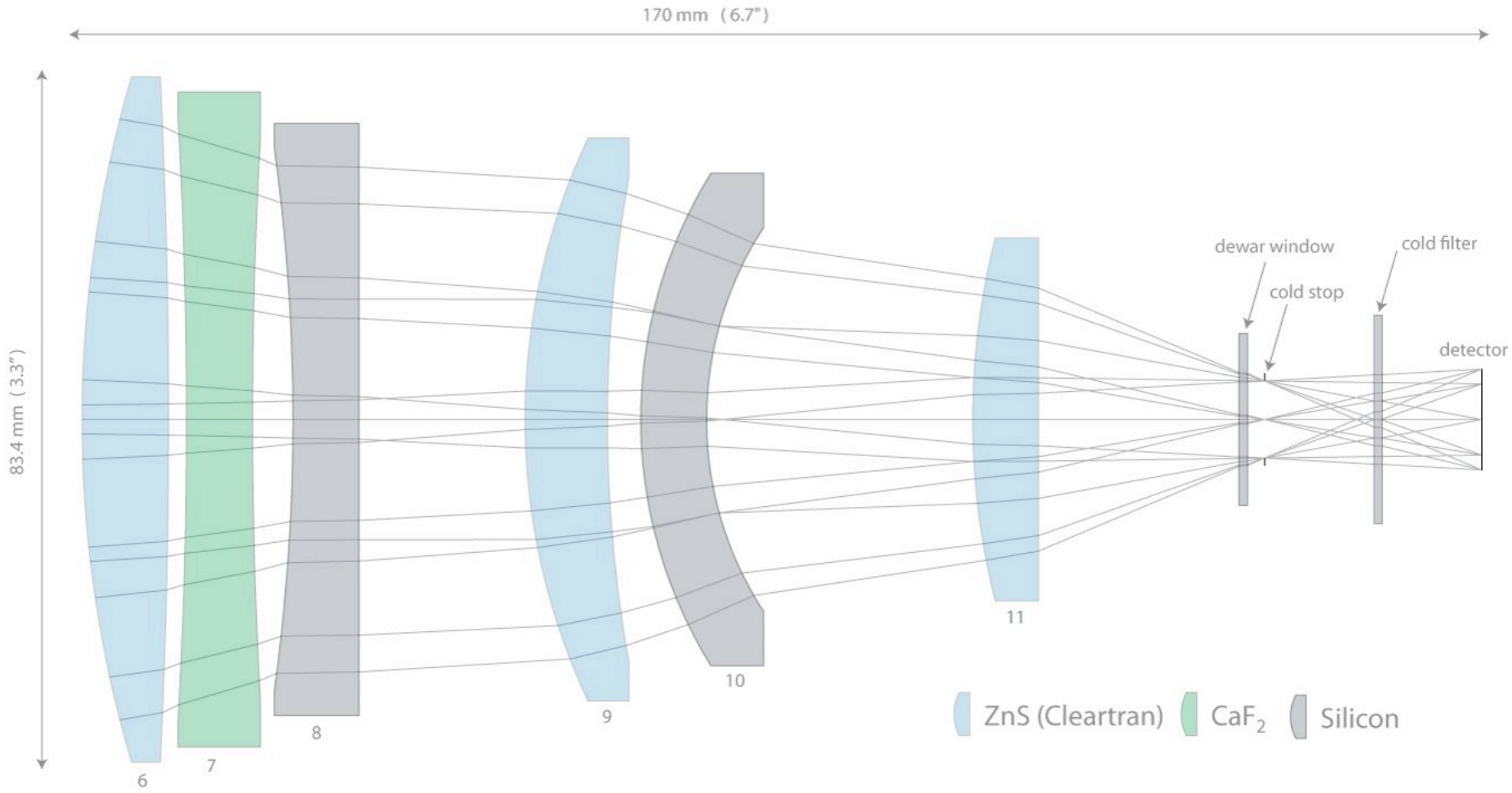
Analytical starting point for athermal achromat with minimum bending.

$$\omega_i = -\Delta\phi_i/\phi_i = -(\partial n_i/\partial\lambda)\Delta\lambda/(n_i - 1),$$

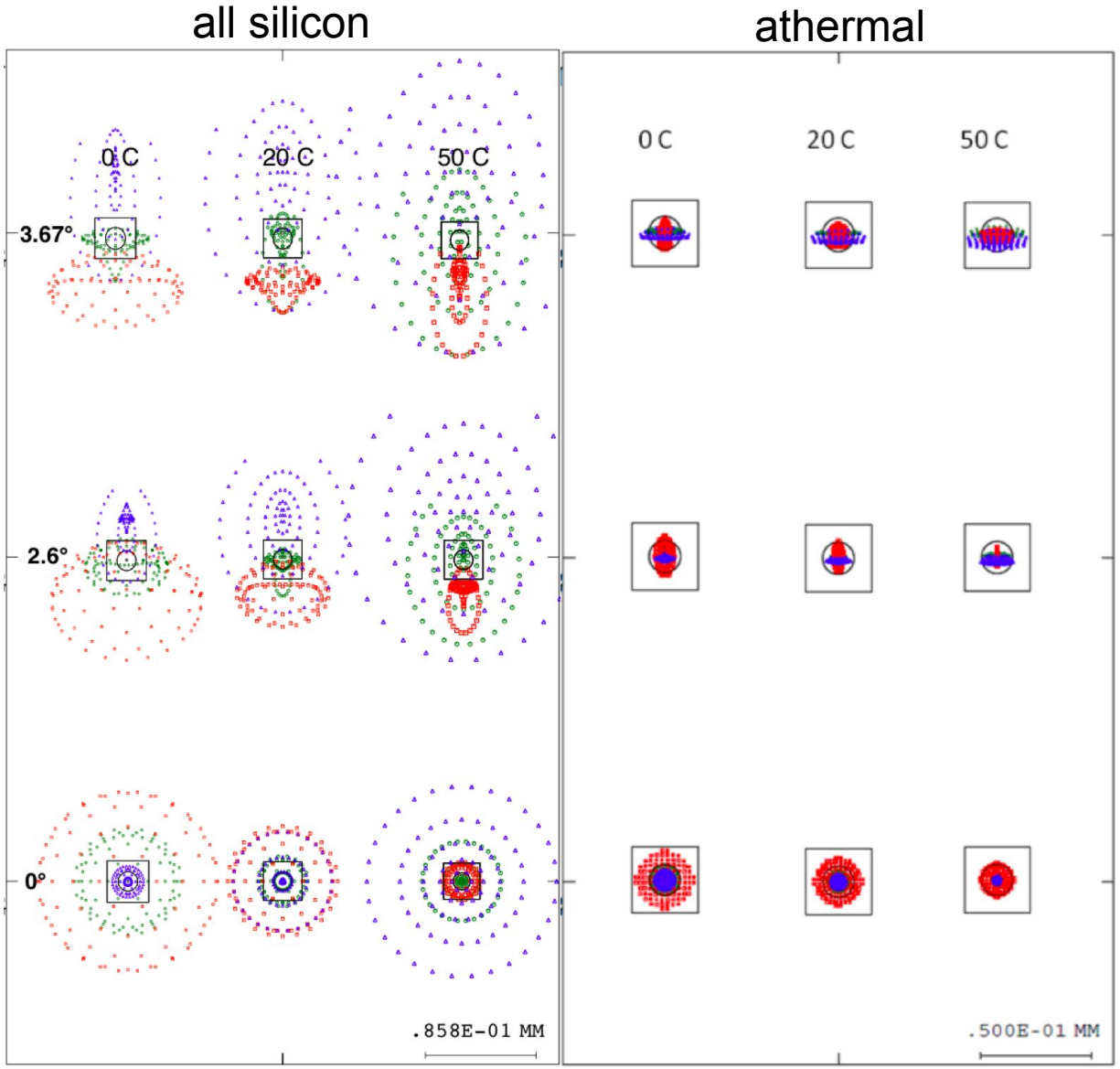
$$\theta_i = (\partial\phi_i/\partial T)/\phi_i = (\partial n_i/\partial T)/(n_i - 1) - \alpha_i,$$

Ref: Tamagawa, Y., S. Wakabayashi, T. Tajime, and T. Hashimoto. "Multilens System Design with an Athermal Chart." *Applied Optics* 33, no. 34 (1994): 8009–8013.

Athermal achromat objective

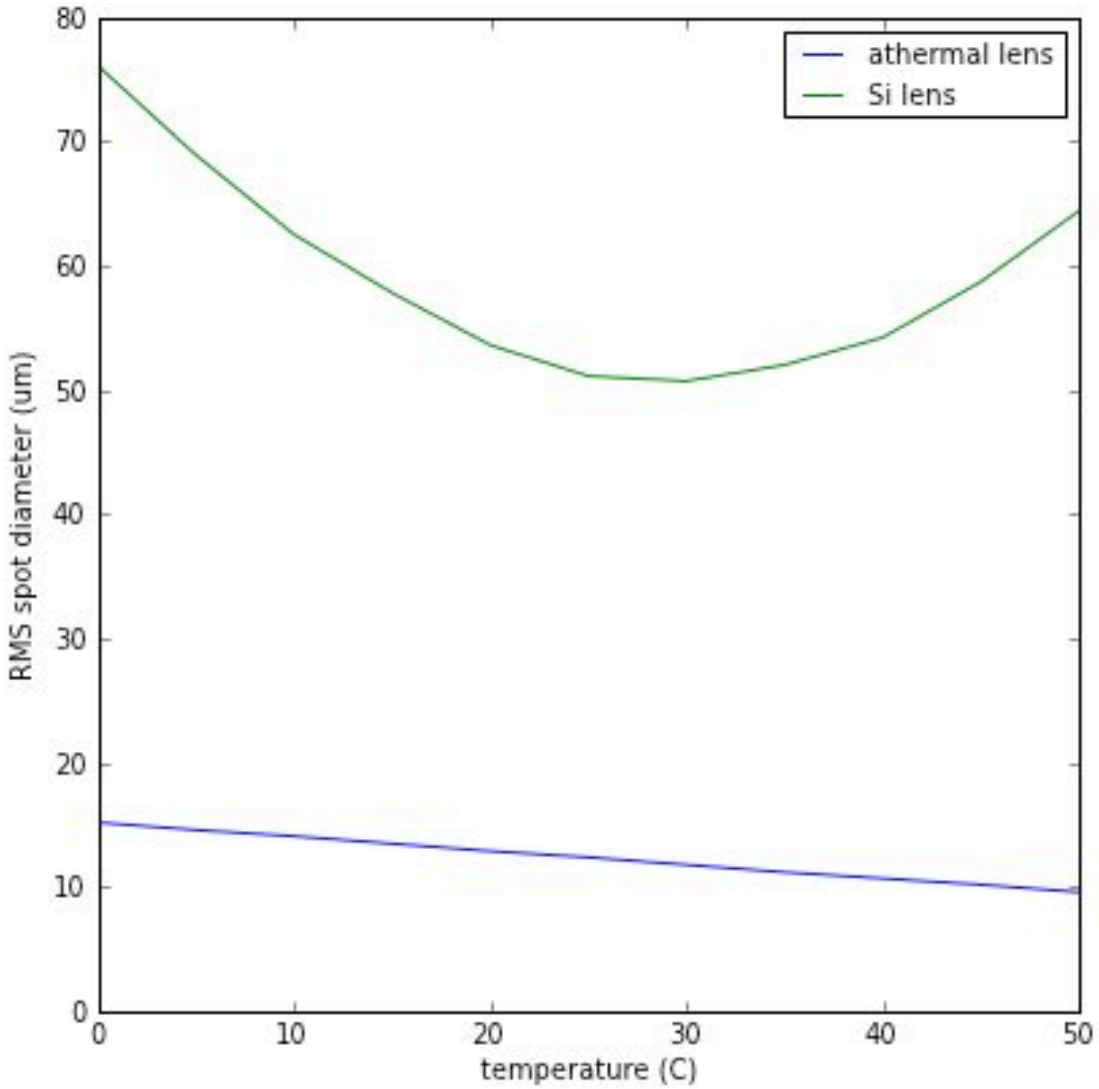


Performance comparison all silicon vs athermal

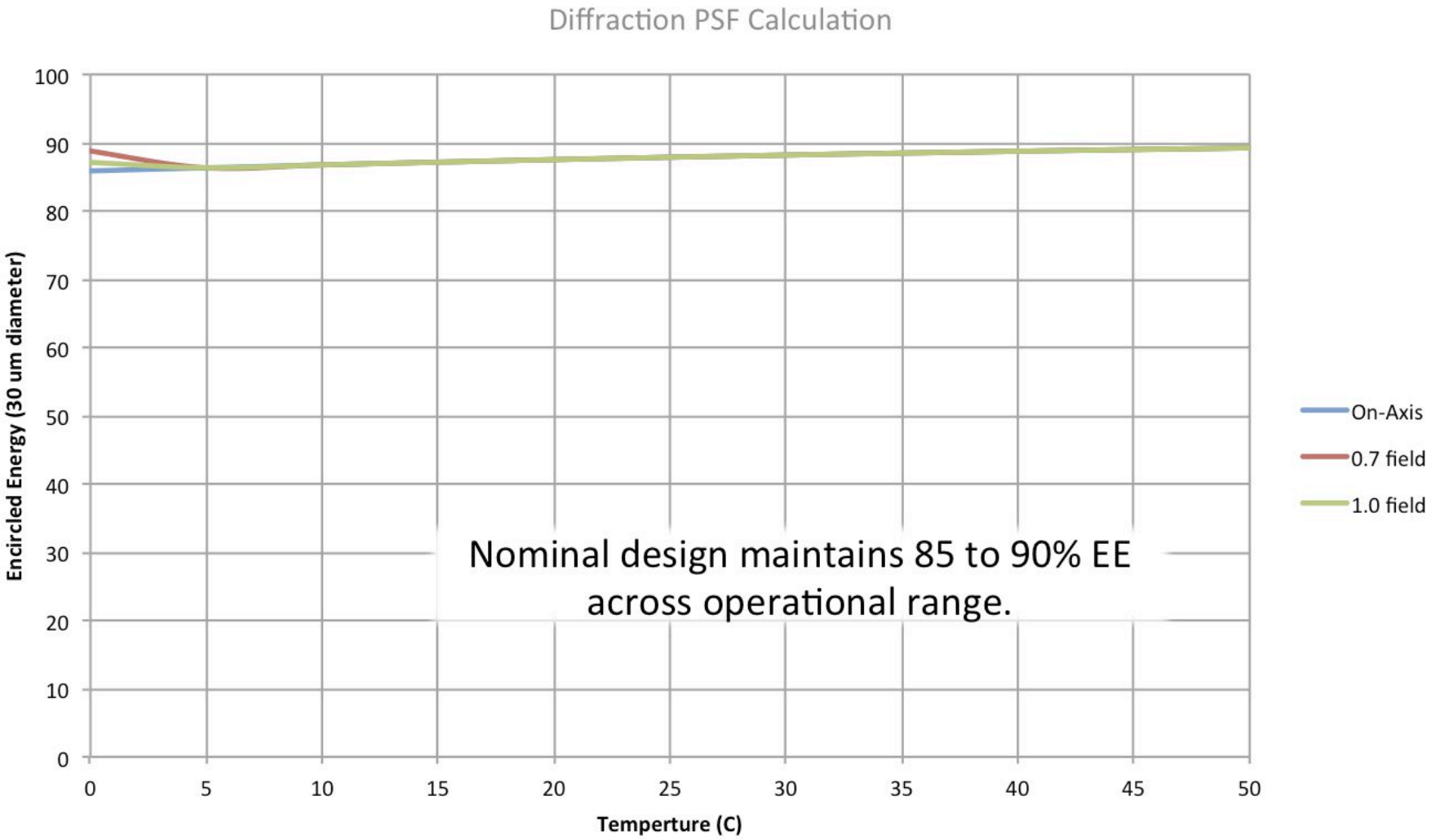


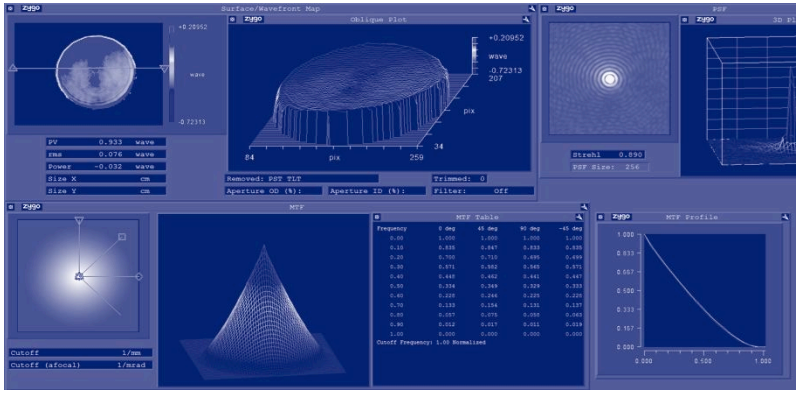
Square represents 30 um pixel.

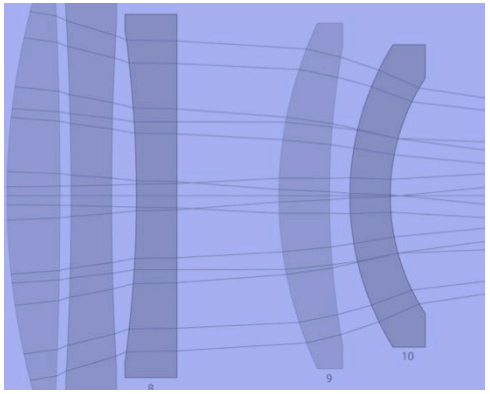
Spot size vs temperature

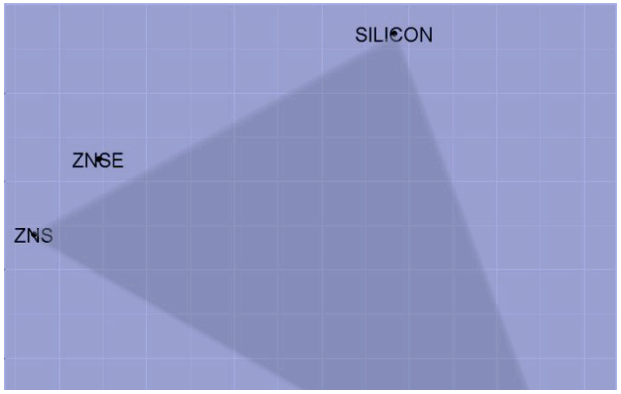


Athermal lens temperature performance









Tolerancing

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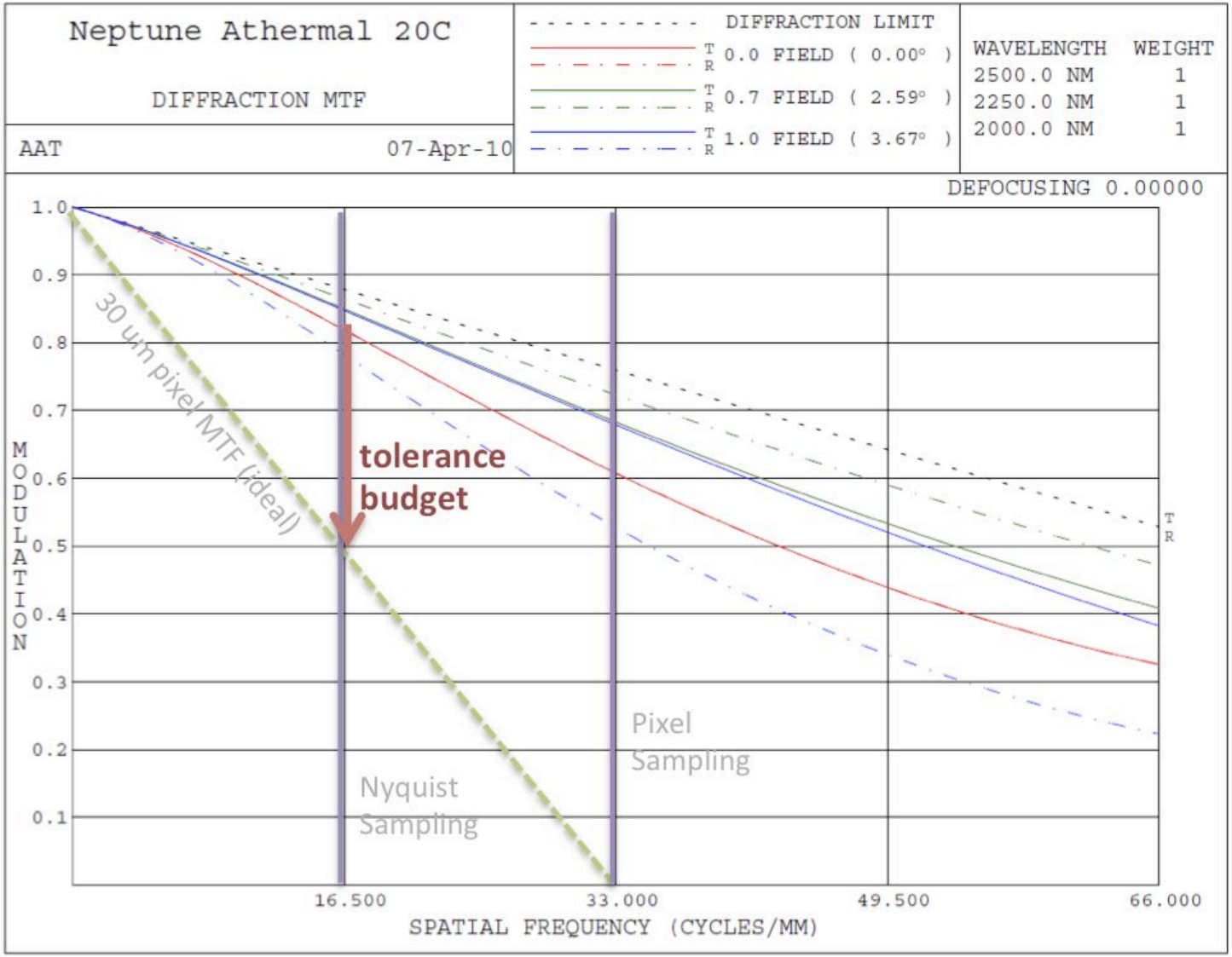
Tolerancing of MTF



Tolerances

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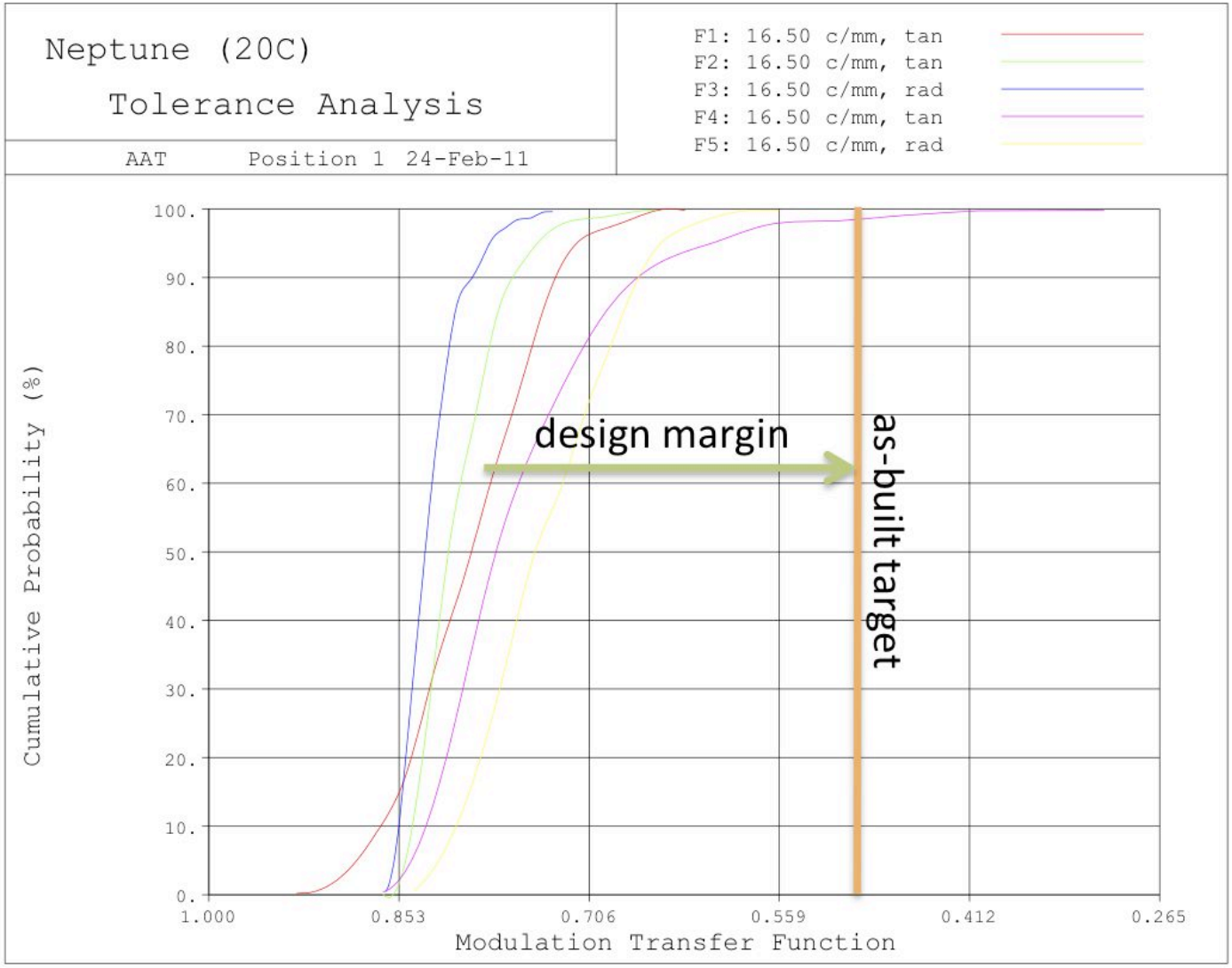
Fabrication

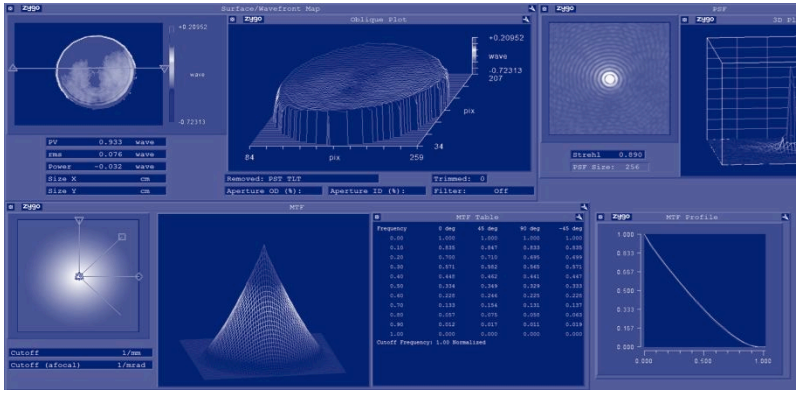
Parameter	Tolerance
Thickness	2 - 8 mils
wedge	0.5 - 4.5 arc min
irregularity	0.5 - 3 waves
power	2 - 12 waves

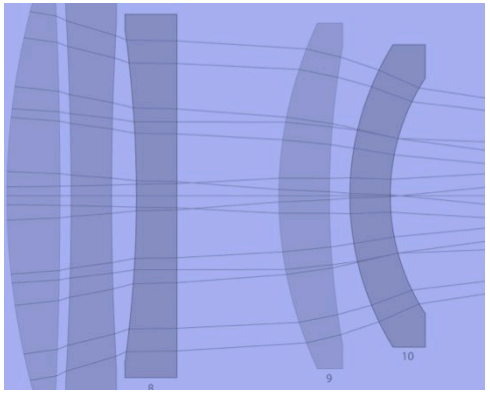
Alignment

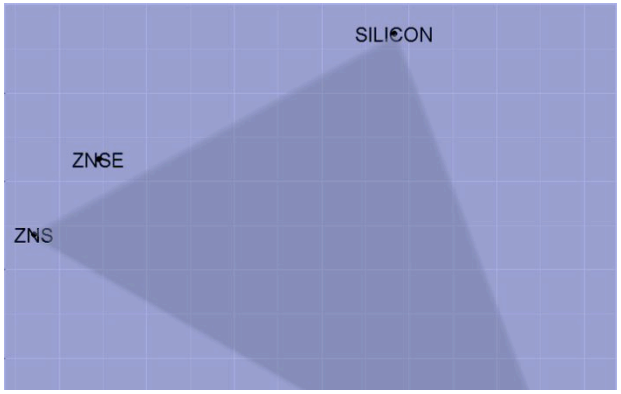
Parameter	Tolerance
despace	4 - 16 mils
tilt	1 - 10 arc min
decenter	6 - 8 mils

Statistical performance estimates









Assembly & Alignment

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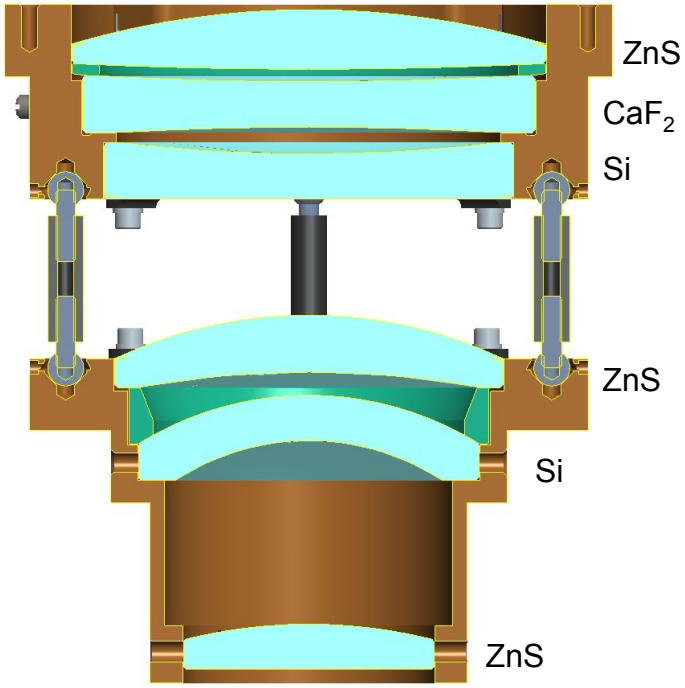
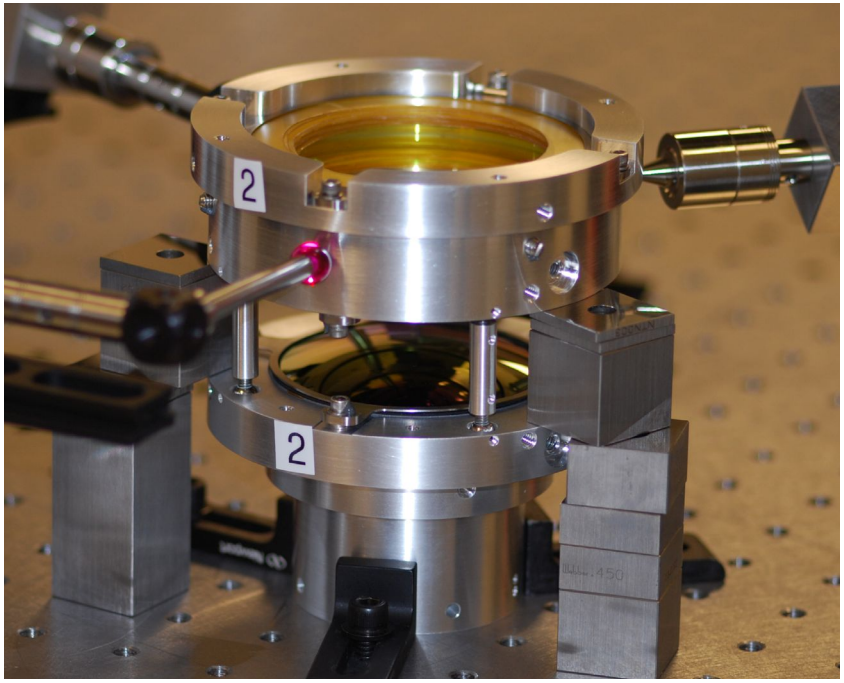
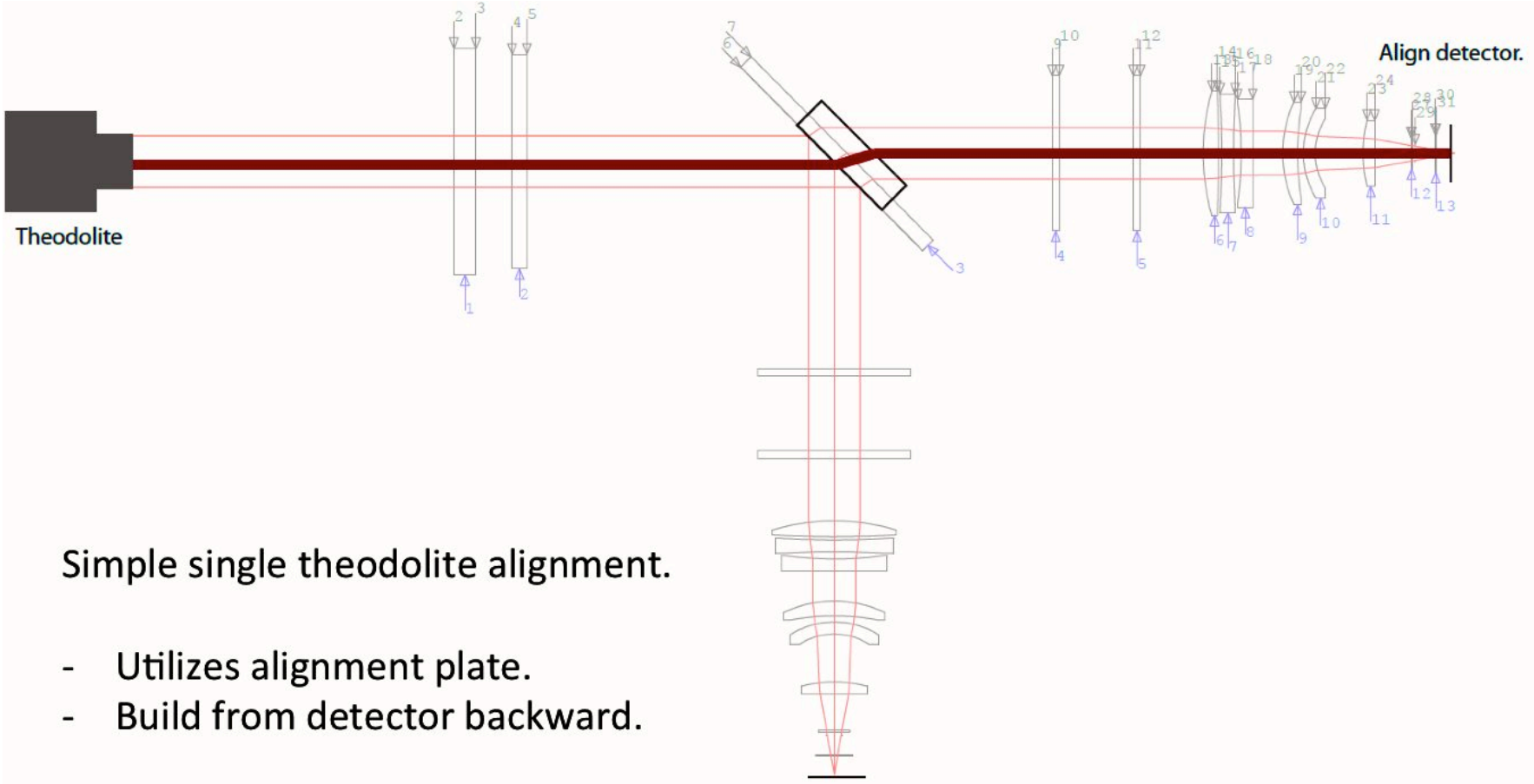
Lens housing





Optical Bench



Simple single theodolite alignment.

- Utilizes alignment plate.
- Build from detector backward.

System during assembly

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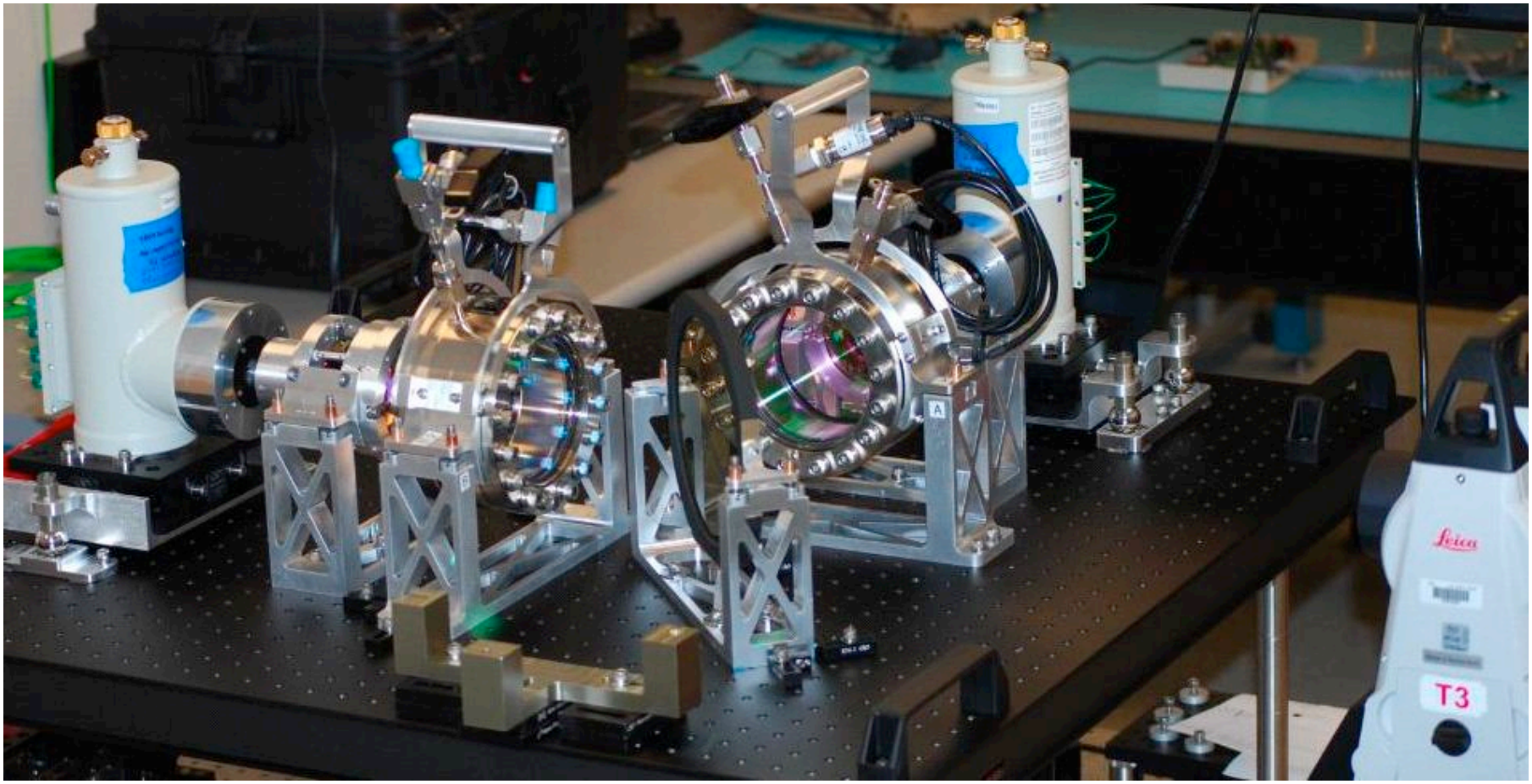

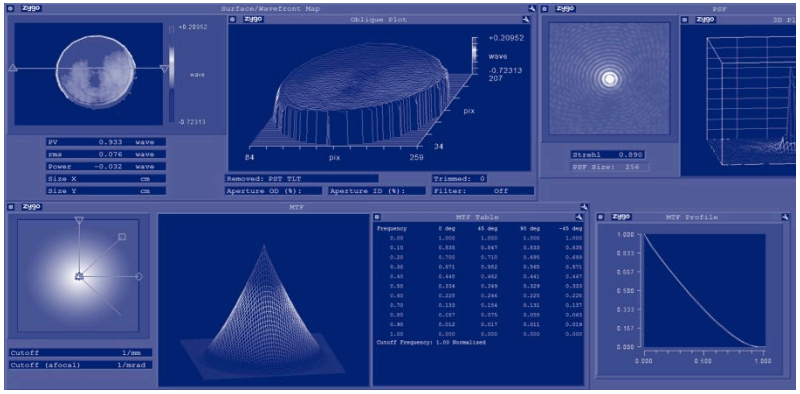

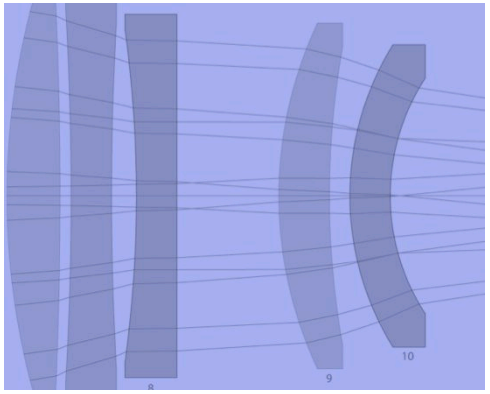

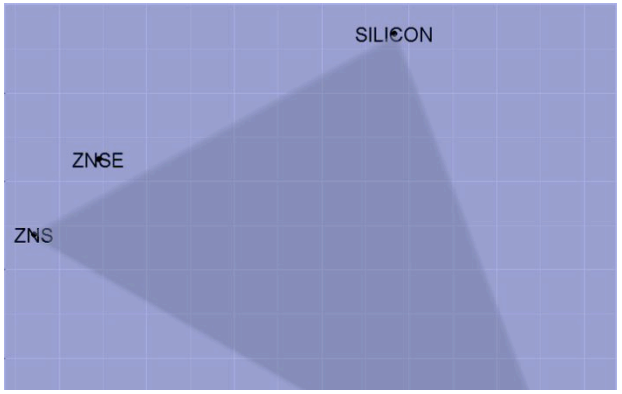

As-built performance

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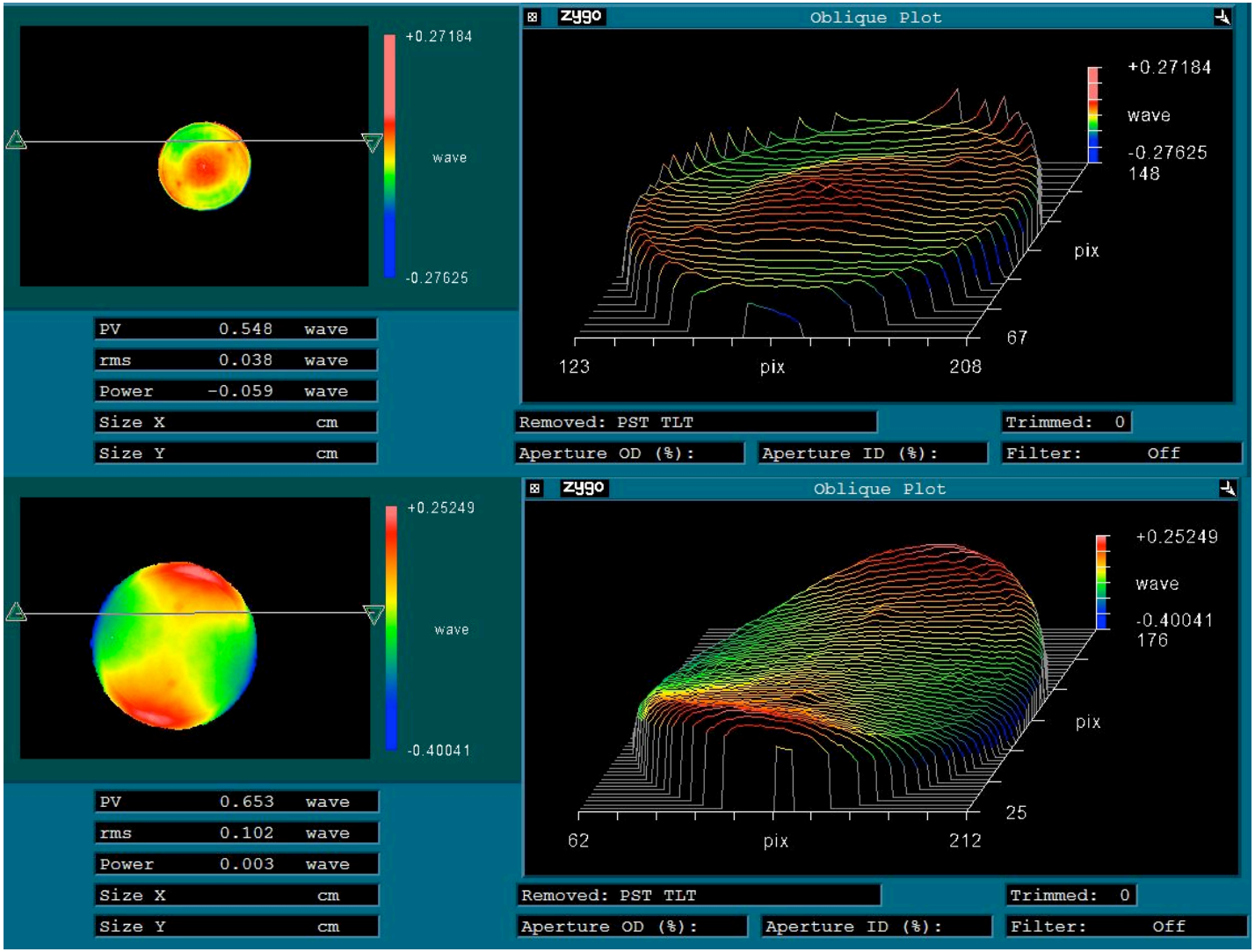
Objective 1

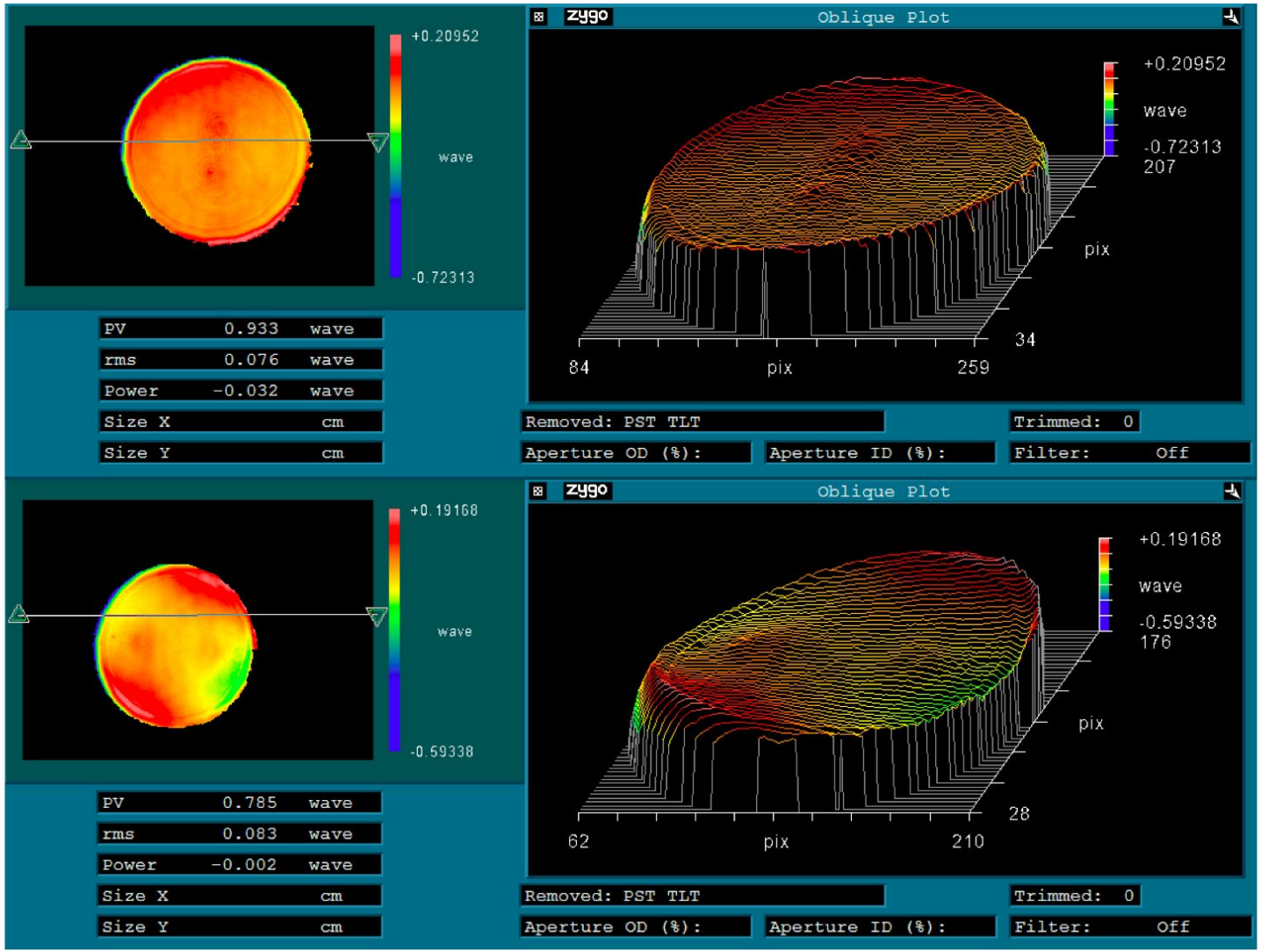


RMS

0.04 waves

0.10 waves

Objective 2



RMS

0.08 waves

0.08 waves

Model versus as-built

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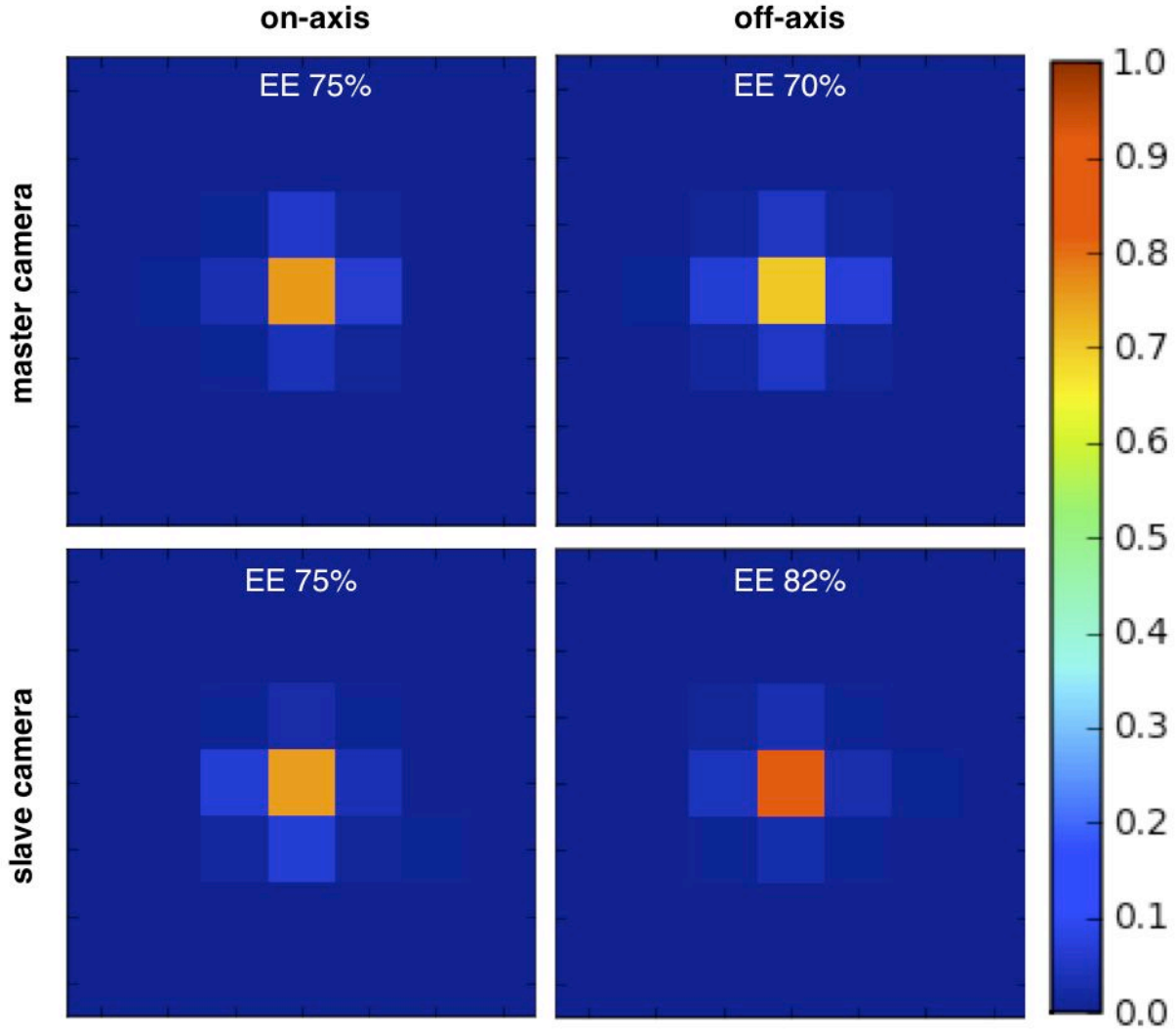
Setup	RMS WFE 0 deg	RMS WFE 2.6 deg
OPTICAL MODEL		
Design Residual	0.014	0.043
Modelled Tolerances	(97.7%) 0.112	(97.7%) 0.234
MEASURED		
Cell 1	(70%) 0.079	(55%) 0.103
Cell 2	(70%) 0.075	(40%) 0.083

Full system ensquared energy



Model predicts 77.5% field ave for finite source, finite distance, and tolerances.

Development of SWIR gas imager

- Analytical design for relaxed starting point.
- Good design margin enabled reasonable tolerances.
- Simple theodolite alignment.
- Cost effective system that meets system goals.

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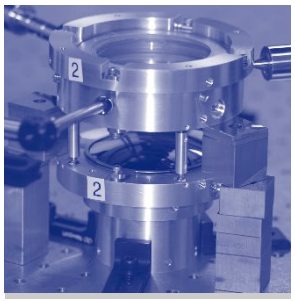

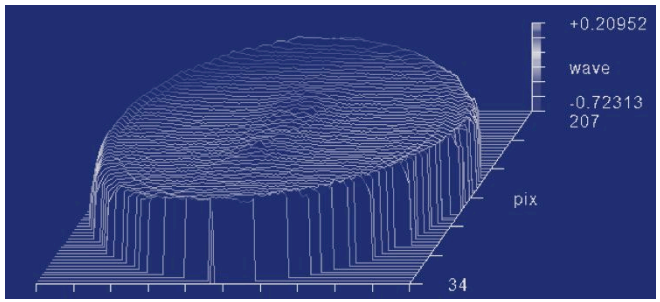

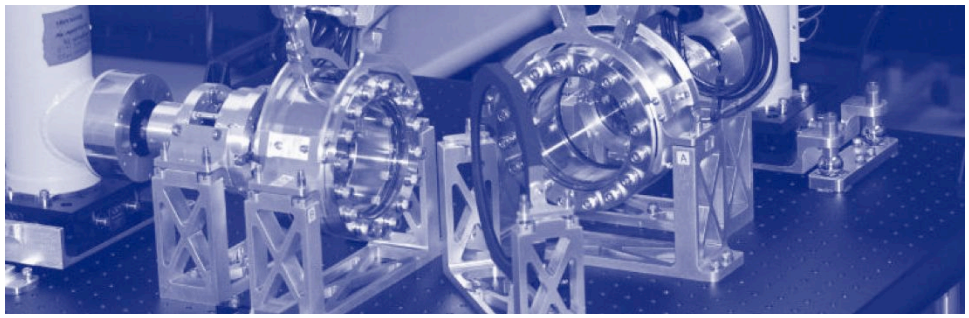

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