Accelerating the next technology revolution

The First 0.5 NA Projection Optic for Extreme Ultraviolet Lithography (EUVL) Microfield Exposure Tool ("MET5")

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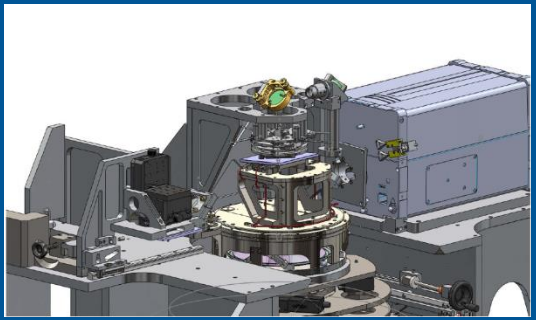
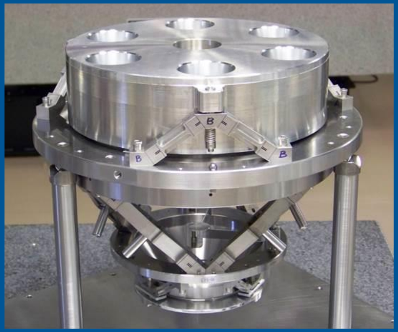
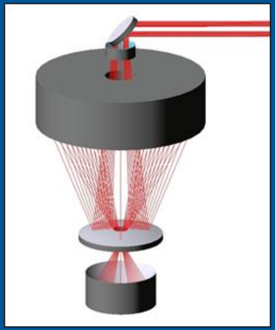


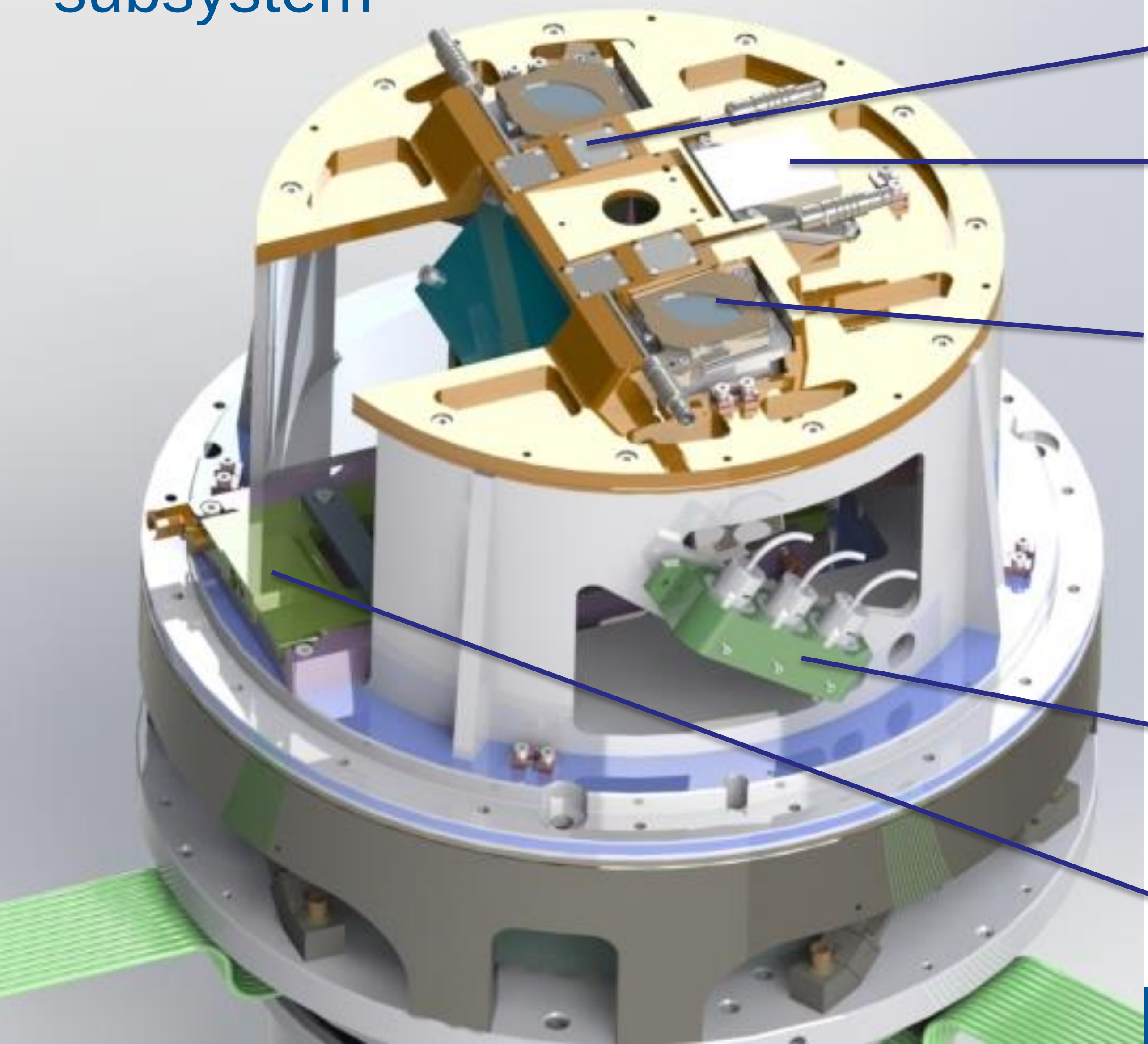




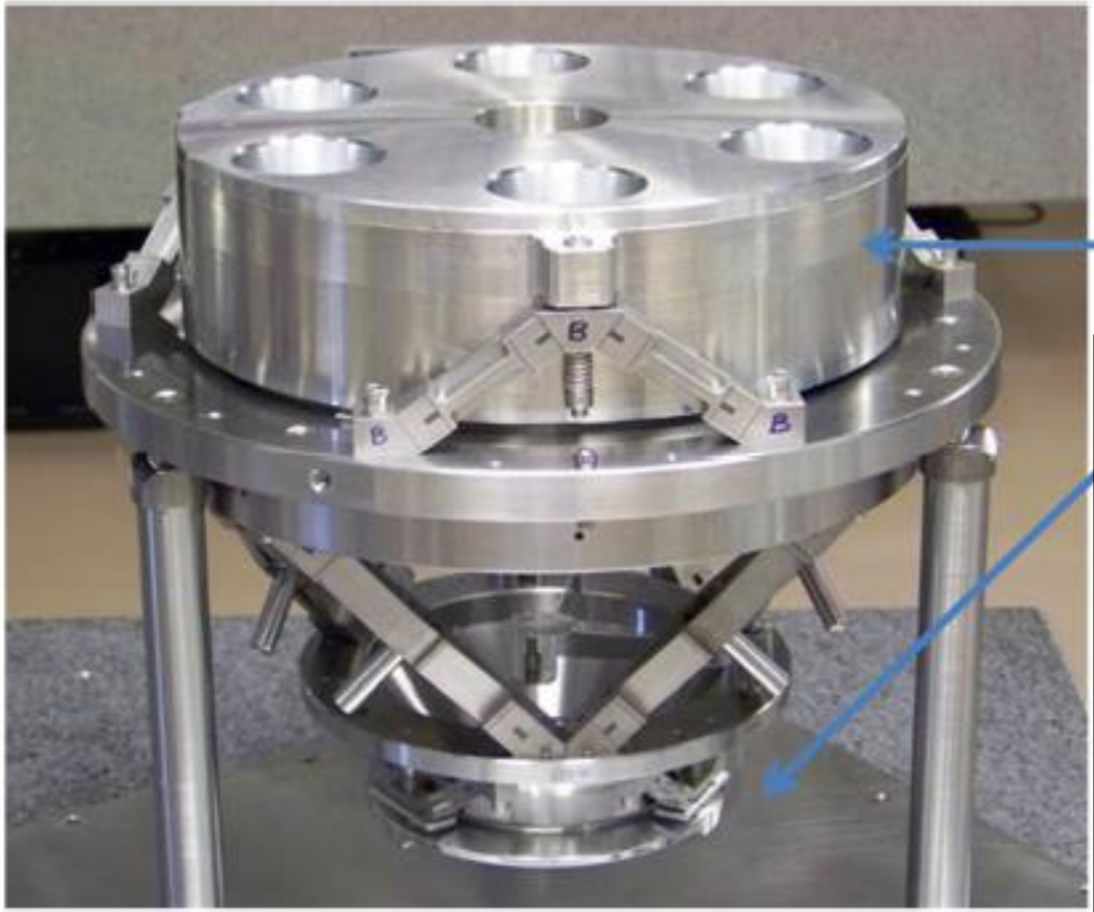
Agenda

- Introduction
- Mirror and metrology status
- Multilayer coating analysis
- MET5 platform
- Wavefront aerial image sensor

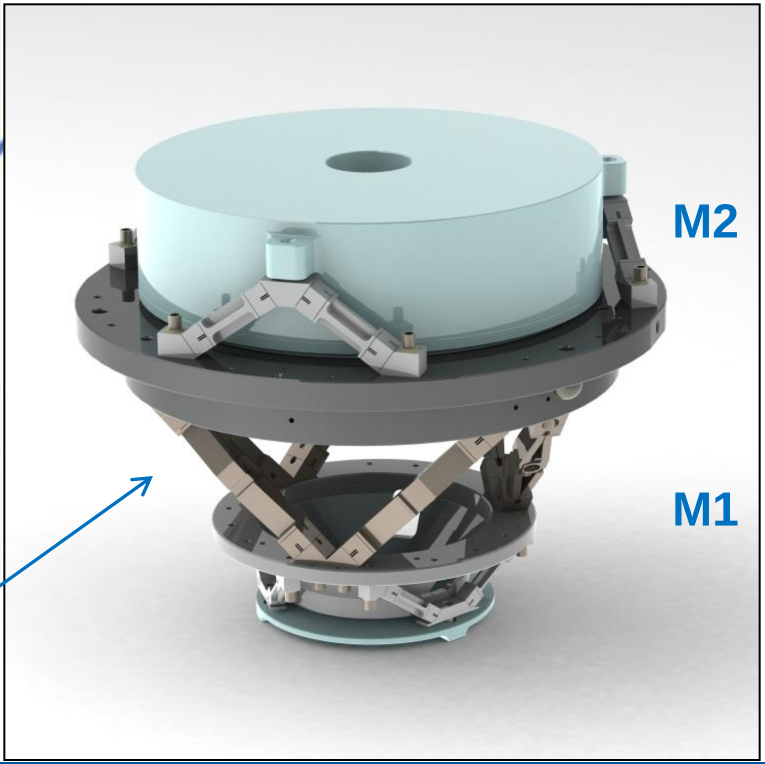
MET5 – Zeiss is building the illuminator and reticle metrology subsystem



MET5 - Zygo is building the projection optics box subsystem

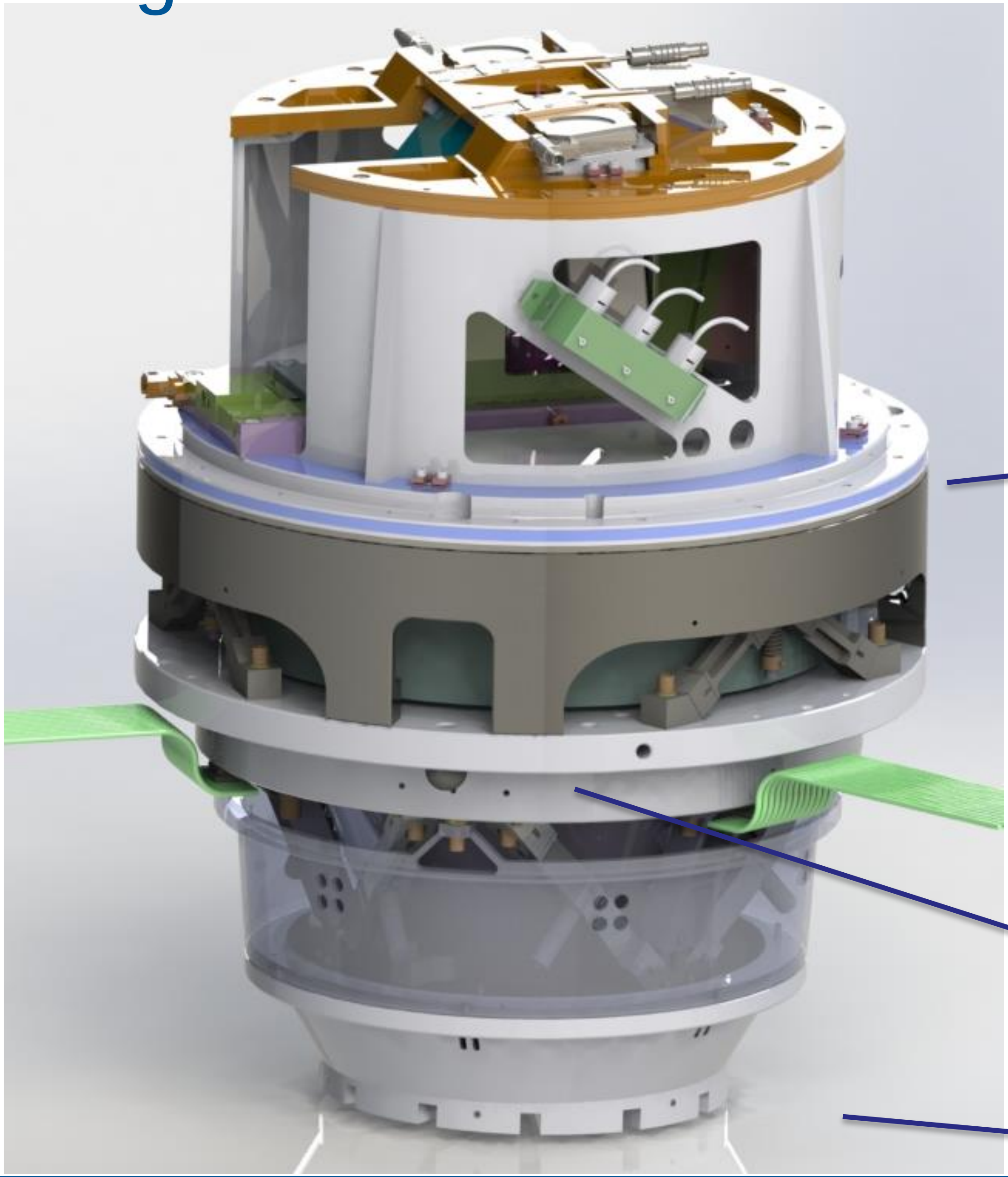


Prototype POB assembly with Aluminum surrogate mirrors



CAD of MET5 POB

Integrated 0.5 NA EUV MET



0.5 NA
5x magnification
Target resolution ≤ 8 nm

Zygo-Zeiss interface

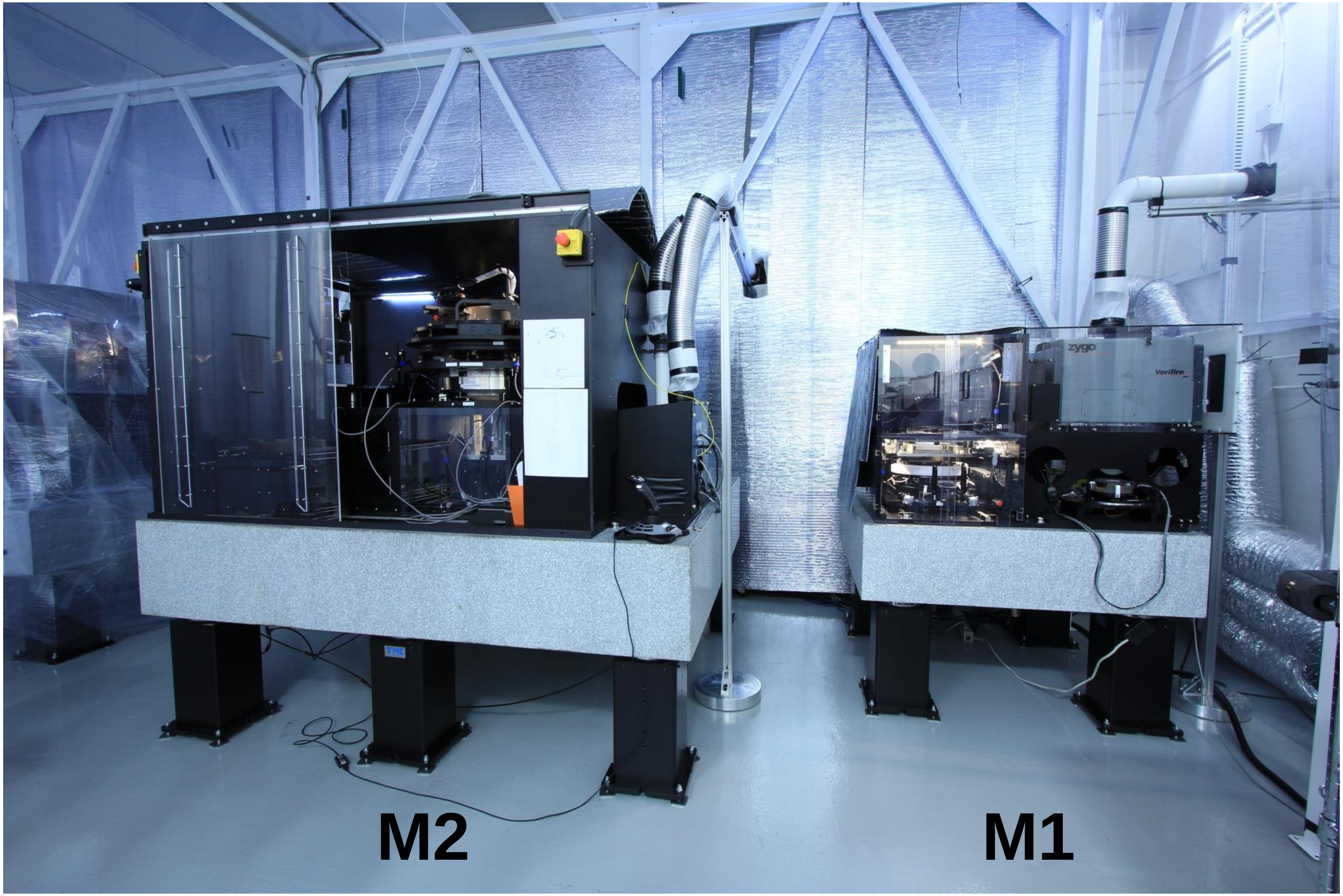
Three ball kinematic mount

height sensor channels

Mirror metrology

- M1 metrology
  - M1 test has figure test reproducibility needed to support final mirror fabrication.
    - Figure test reproducibility < 20pm RMS
- M2 metrology
  - Achieving acceptable repeatability and reproducibility for M2 took more effort
    - Primarily caused by larger M2 test cavity
  - Figure test reproducibility ~ 60pm RMS
    - Greater than desirable but made acceptable by averaging

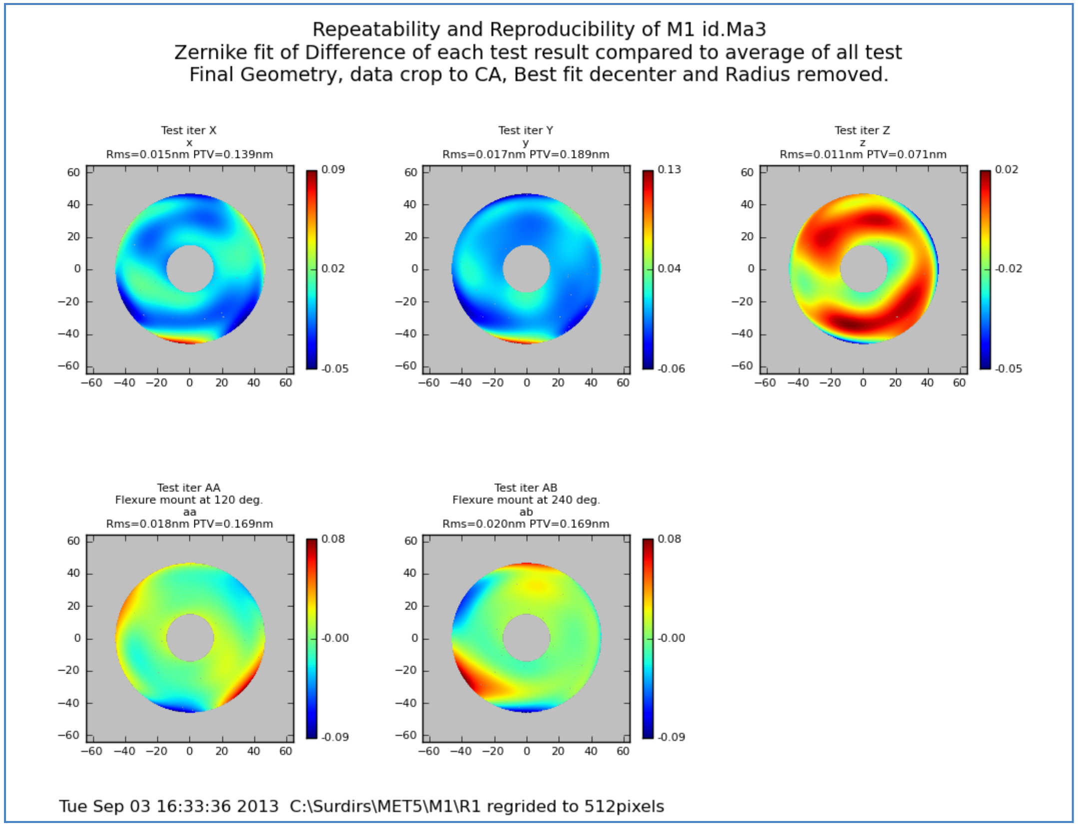
MET mirror metrology



M1 test reproducibility

- Several consecutive tests are performed on the same part.
  - In some cases, the part is removed from the test, thus measuring the metrology mount reproducibility.
  - Subtracting the average of all the test from each individual test result is an indication of the test repeatability and reproducibility.

- Average reproducibility of the figure measurement:
  - **16 pm RMS**



POB metrology

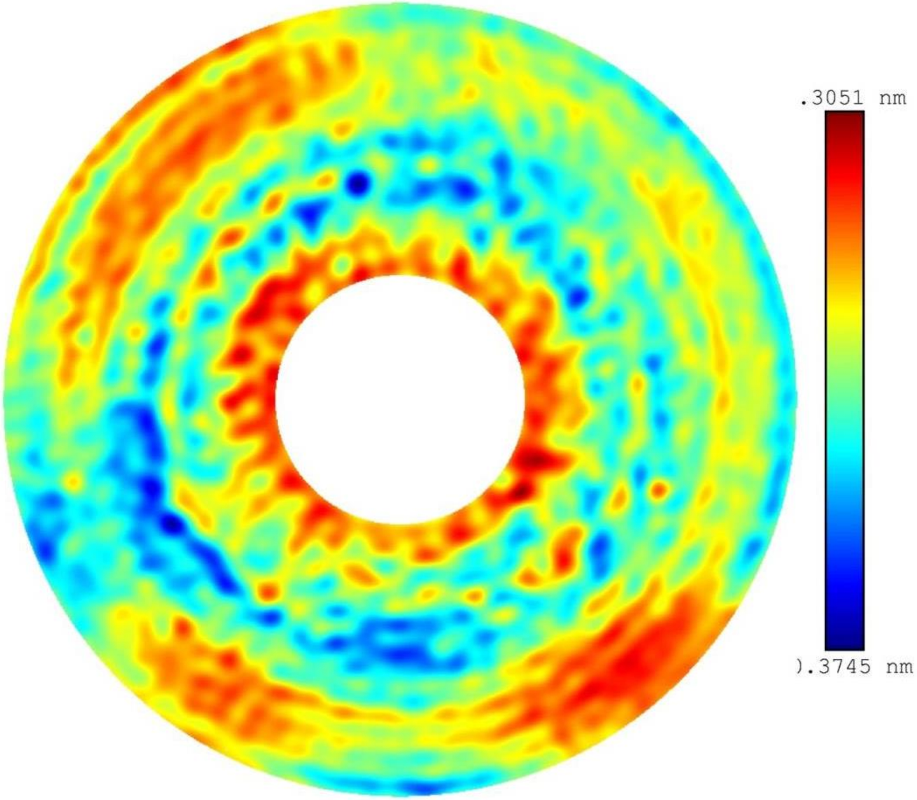
- The POB optical test is built and alignment activities have started.
  - Lessons learned from the mirror tests are being retro-fitted into the POB test.
  - Motion control and sensor feedback system is being programed.
    - Low level functionality shared between all 3 tests, written and already used.
  - POB Hexapod system alignment software written and motion control and sensor feedback system is being programed.

Wavefront Figure Error, Flare (MSFR) and HSFR Specifications

- Wave Front Error (WFE)
  - Center field point WFE 0.5nm RMS
    - Center field point WFE controls mirror figure
  - Surface Figure Error (SFE) for fabrication is 0.1nm RMS each mirror
- Flare specification - total Integrated flare < 5%
  - Where $Flare \cong \left(\frac{4\pi\sigma_1}{\lambda}\right)^2 + \left(\frac{4\pi\sigma_2}{\lambda}\right)^2$
    - σ_1 and σ_2 is the RMS Surface Error of M1 and M2
    - λ Actinic wavelength = 13.5 nm
  - 0.170 nm RMS Surface Error allocated to each mirror
    - Yields 2.5% flare for each mirror for a total of 5%
- HSFR is 0.15 nm RMS to reduce multilayer coatings reflectivity from surface roughness

M1 Figure Data: Error = 0.10 nm RMS
Low Pass Filtered @ 3mm

- Meets budget allocation for figure error of 0.1nm rms
- Result achieved on M1 development asphere using production process
  - Sharp mirrors in fabrication
- In addition Flare and HSFR requirements were all met on this surface as well



M1 Mirror Figure, Flare and HSFR

- EUV polishing achievements on MET5 M1 Mirror
  - Data flare range of 3mm – 0.43um
  - Figure, Flare and HSFR meet specification

Description	Specification	Achieved
Figure (CA - 3mm)	< 0.1nm rms	0.10nm rms ✔
Flare (3mm – 0.43um)	< 2.5%	0.7% ✔
Surface Roughness (3mm – 0.43um)	< 0.17nm rms	0.089nm rms ✔
HSFR (1um – 10nm)	< 0.15nm rms	0.118nm rms ✔

M2 Mirror Achievements

- EUV polishing results on MET5 M2 Mirrors

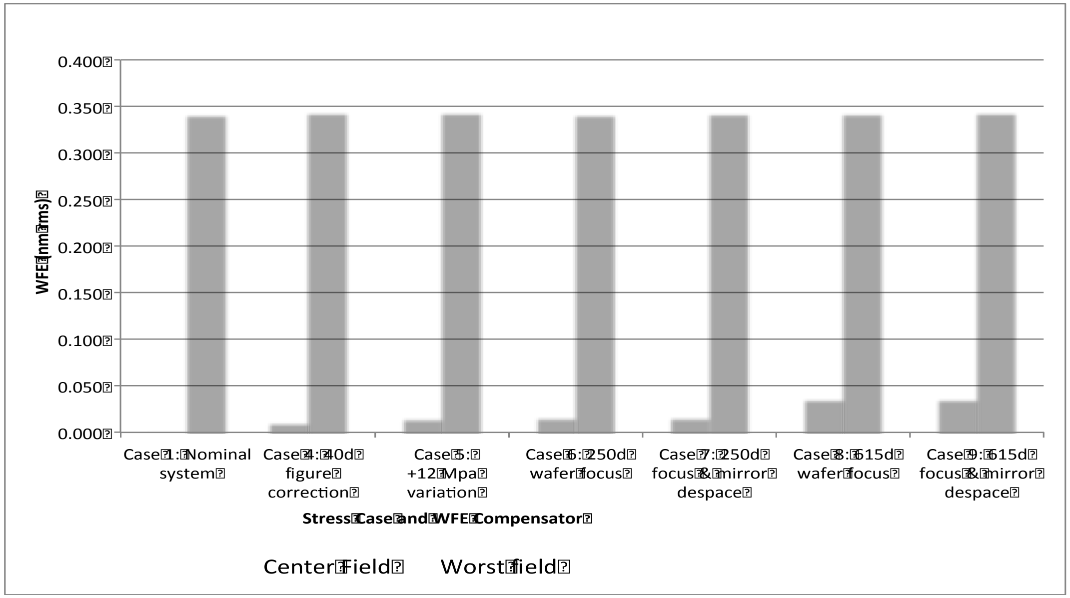
Description	Goal	Achieved
Figure (CA - 8mm)	< 0.1nm rms	in process
Flare (8mm – 1.2um)	< 2.5%	in process
Surface Roughness (8mm – 1.2um) (8mm – 1mm) (1mm – 1.2um)	< 0.17nm rms 0.12nm rms 0.12nm rms	in process expected < 0.12nm rms achieved 0.11nm rms ✔
HSFR (1um – 10nm)	< 0.15nm rms	0.06nm rms ✔

- Development effort has focused on achieving the 1mm – 1.2um spec
- A mirror is consistently below 0.1nm rms in 8mm to 1mm spatial period
  - Supports Flare 2.5% requirement

Multilayer mirror effects – Film stress

- Stress in the EUV ML coating will change the shape of the mirrors at the sub-nanometer level
  - Magnitude of bending is predicted based on samples and FEA
  - Verification of the model is performed on a set of test mirrors
- Also the EUV ML coating stress relaxes after deposition
  - Stress also varies from run-to-run
- The effect of the stress on POB WFE is evaluated
  - Stress level at 40 days chosen as baseline condition
  - Stress relaxation system effect evaluated at 250 and 615 days
    - Stress data exists for 250 day case
    - 615 day case based on linear extrapolation of relaxation curve
      - Considered a worst case; relaxation curve is expected to approach an asymptote rather than continue linearly

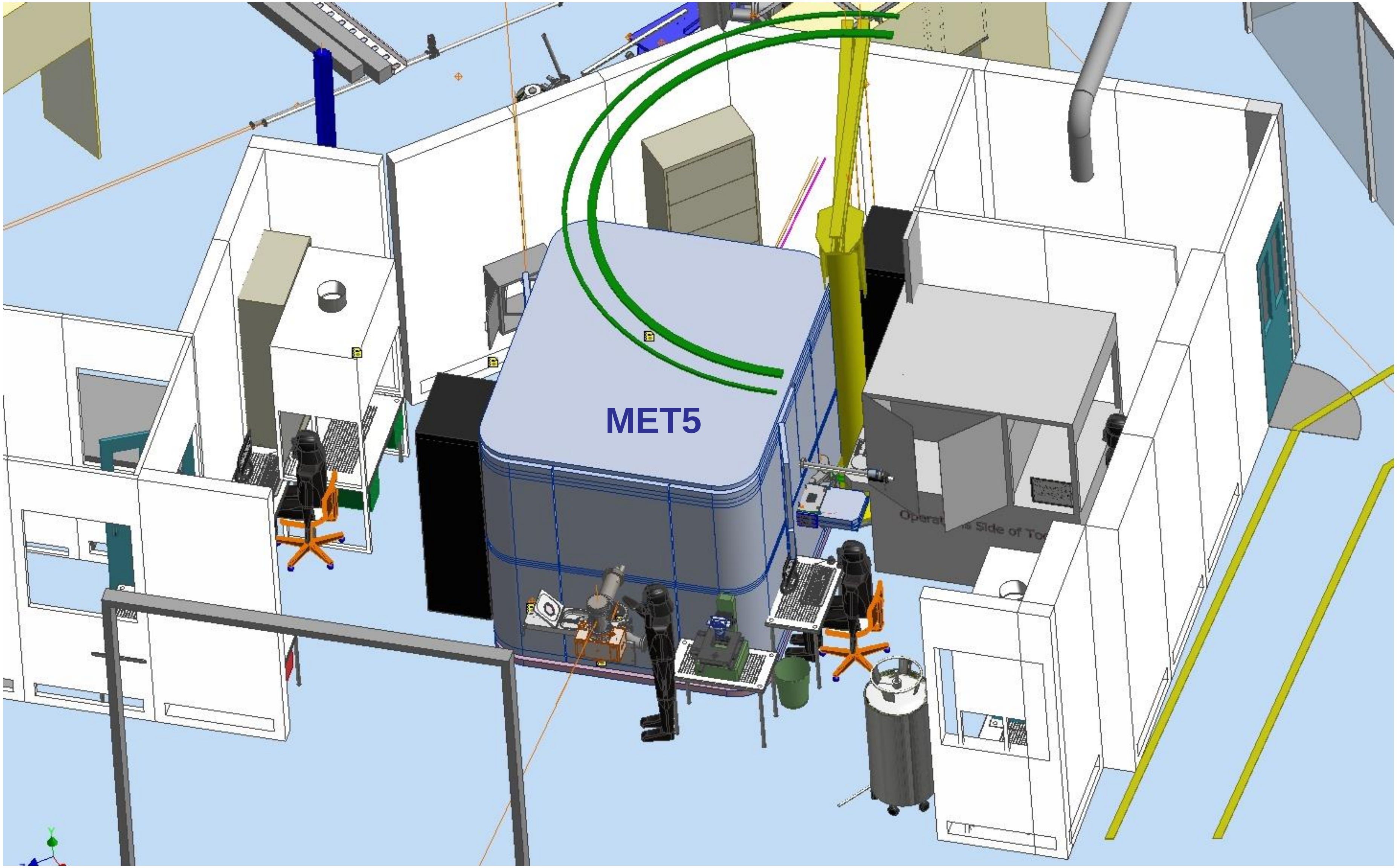
Summary of WFE Modeling
Stress effects are low and acceptable



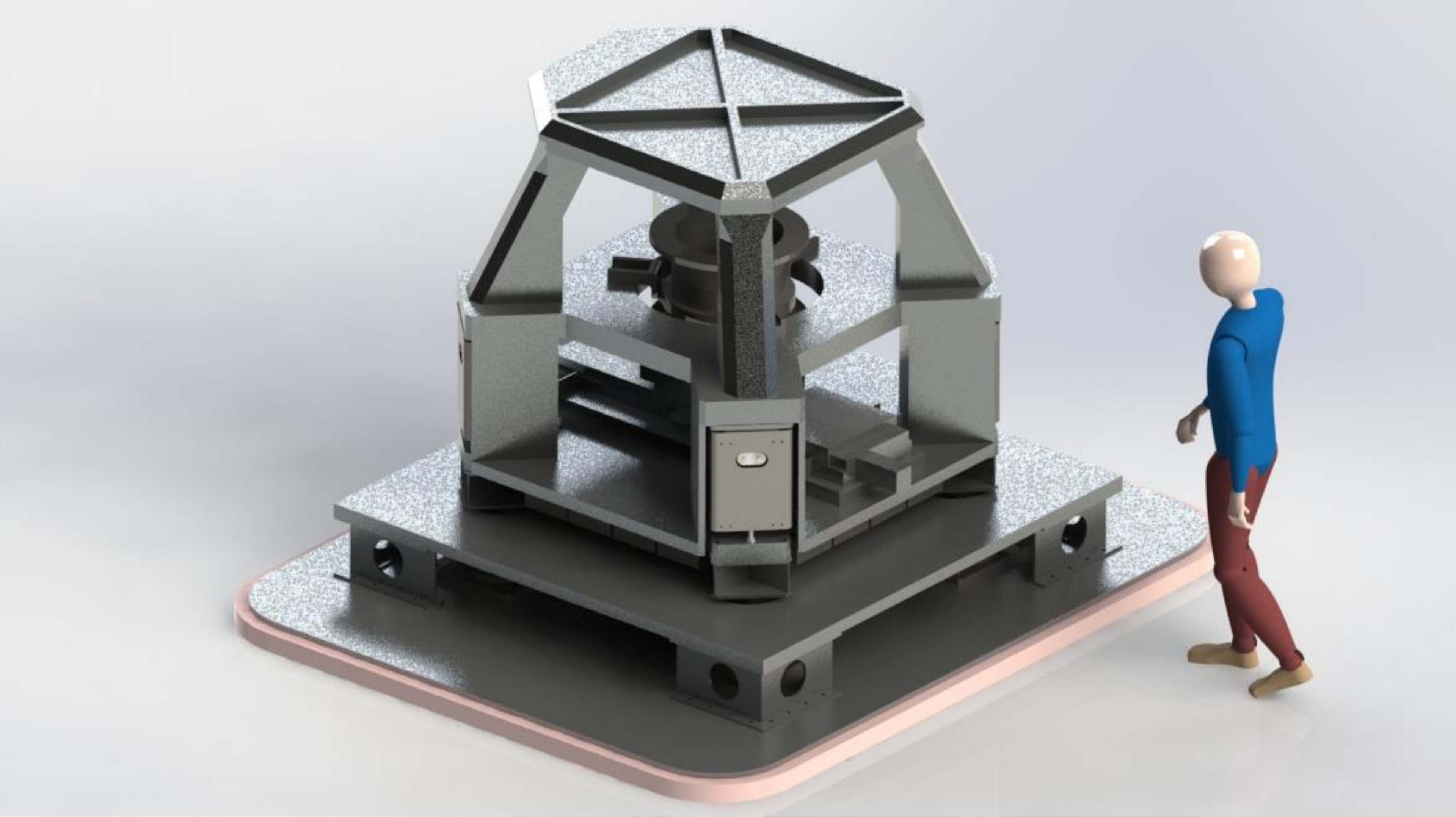
Note: Figure correction, only wafer focus is needed to optimize the center field

- Stress relaxation after 250 & 615 days causes minor WFE degradation
  - Adds max 0.04nm rms to center field
  - Stress should stabilize to a value lower than this
- With the exception of the center field point, the design aberrations dominate any aberration induced by coating stress
  - RMS of 0.34nm at the corner of the field.(design+ML coating induced)

Lawrence Berkeley National Lab Advanced Light Source

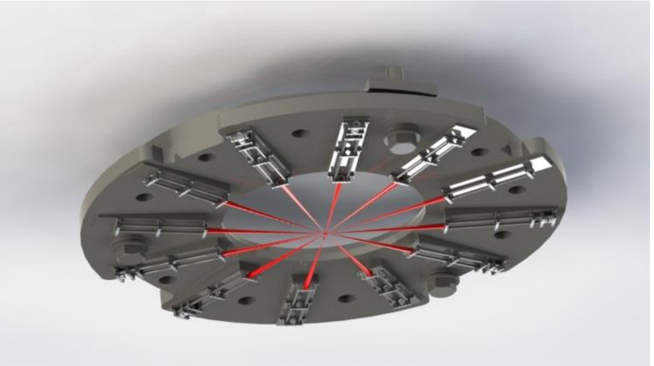


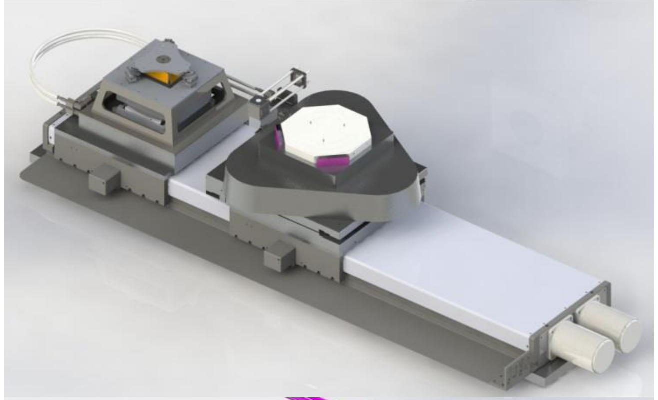
Berkeley MET5 – A new platform targeting ≤ 8 nm imaging

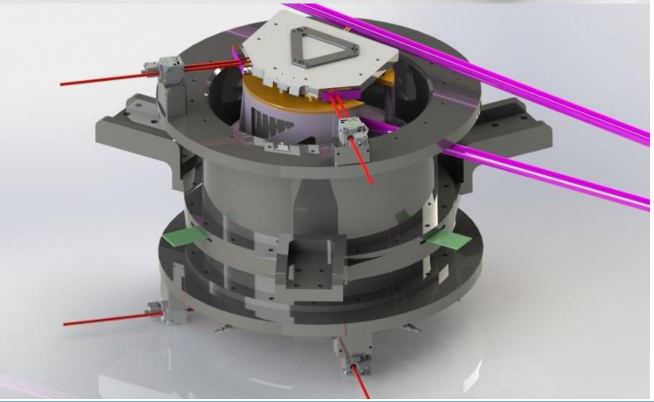


Improvements in Berkeley MET5 targeting ≤ 8 nm imaging

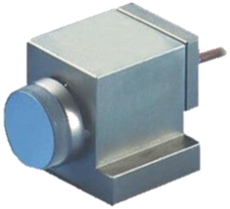
- New 6-channel height sensor for wafer Z/tip/tilt
  - Shot-noise limited performance
  - Noise floor < 1 nm
- Dual wafer plane stage with integrated wavefront interferometer
  - Supports in-situ measurement of EUV wavefront quality
- Integrated distance measurement interferometer for active stability control
- In vacuum ultra-high performance passive vibration isolation system



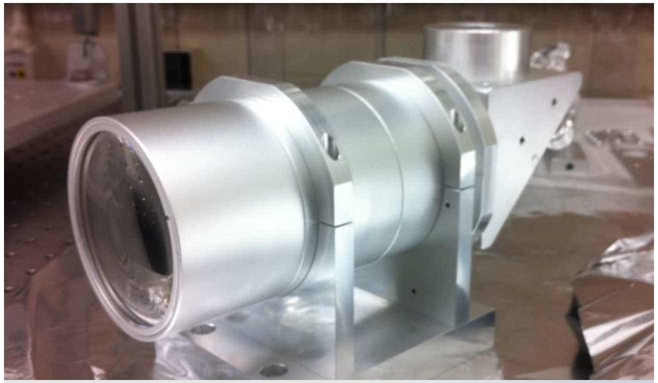




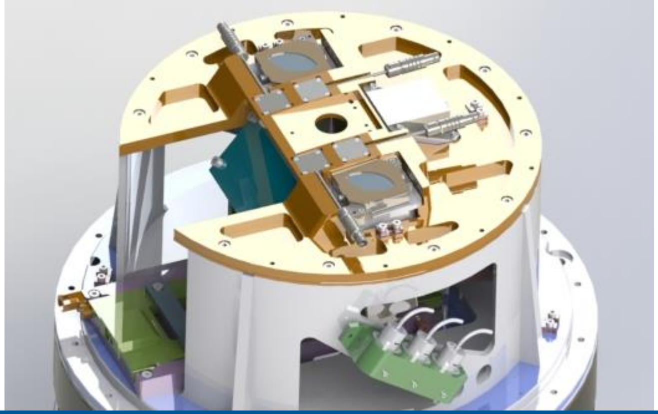
Improvements in Berkeley MET5 targeting ≤ 8 nm imaging - cont



- Computer controlled lossless pupil fill and field scanning



- Integrated pupil fill monitor

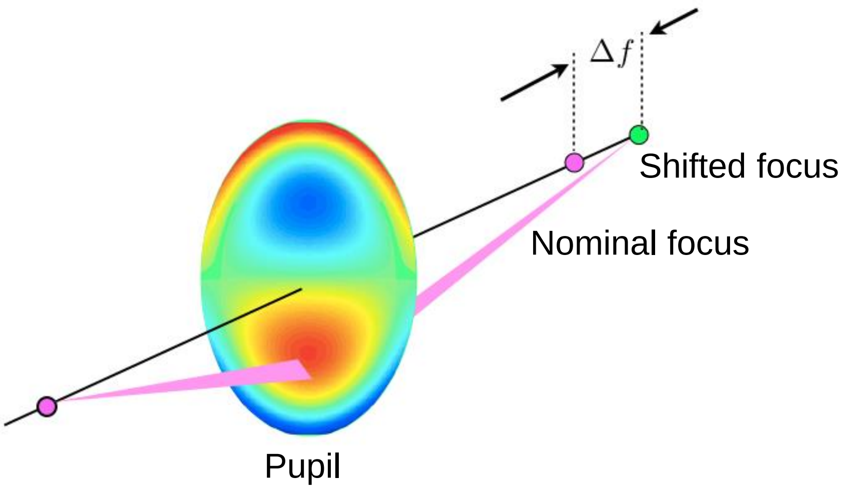


- Integrated conjugate transfer sensors
  - x/y/z/tip/tilt

AIS: Principal behind the in-situ wavefront Aerial Image Sensor

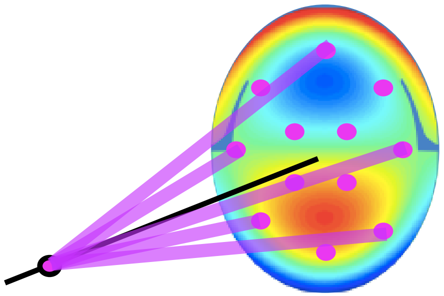
High-NA exposure tools

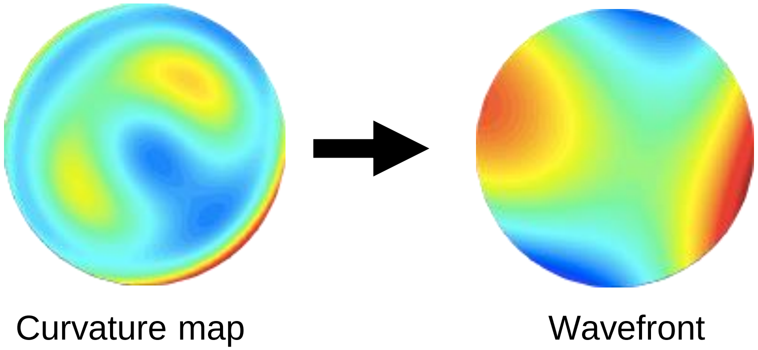
Aberrations cause focus shifts across pupil



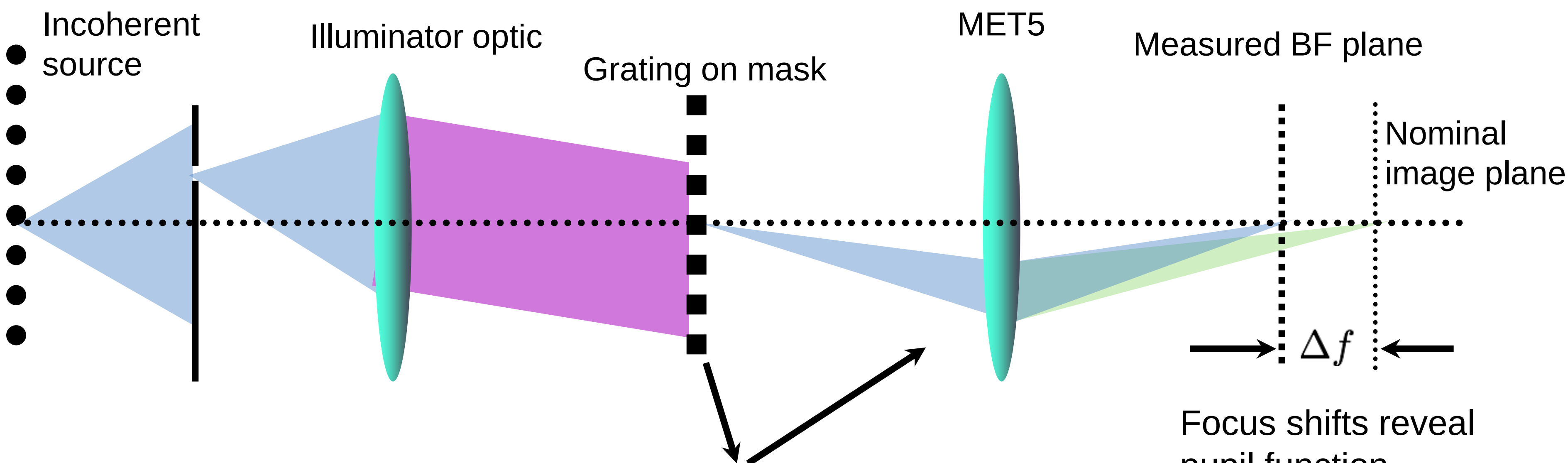
Focus shifts reveal pupil function curvature (2nd derivative) which is fit to aberration coefficients using a least-squares algorithm

Probe localized regions across pupil and measure focus shifts



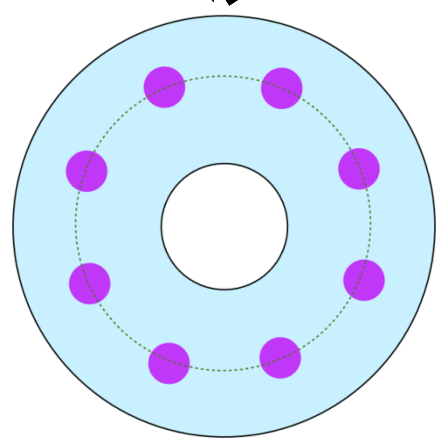


Implementation in Albany MET5 –
Probe positions are offset monopole illumination



Focus shifts reveal pupil function curvature

Different gratings on mask move illumination to sample the MET5 optic

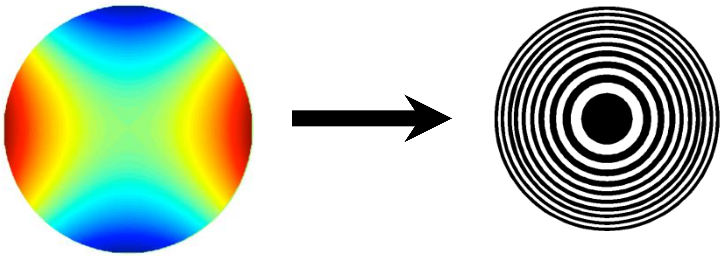


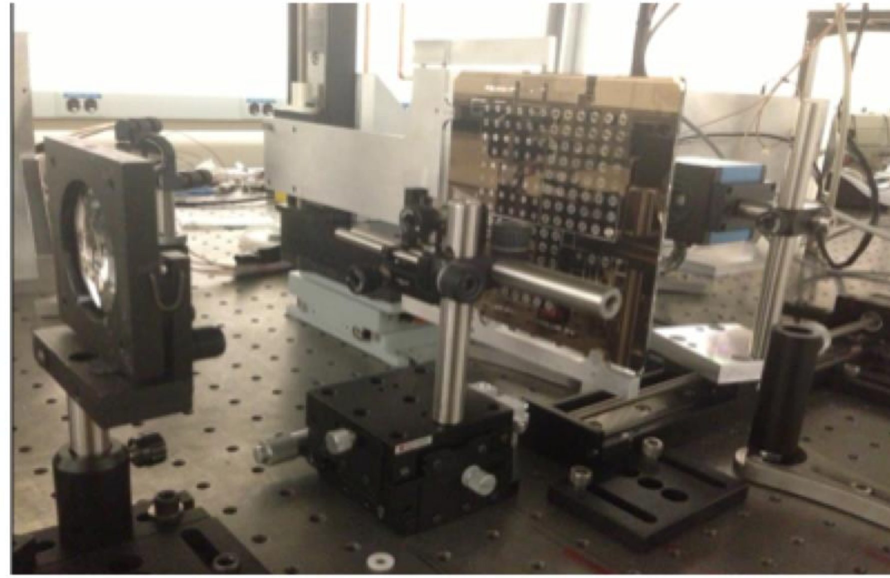
MET5 setup
- 16 probe locations
- 15 Zernikes

Visible light prototype tested –

All this and more in Ryan's talk Wed at 3:20 pm

Known aberrations coded into zone plates



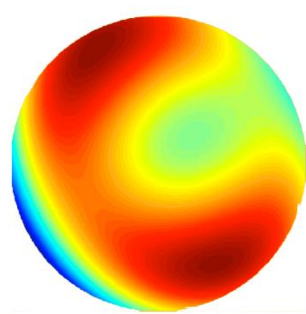


ZP Mask Layout

REF	Z4 10 mWaves	Z4 20 mWaves	Z4 50 mWaves	Z4 100 mWaves	Z4 200 mWaves
Z5 20 mWaves	Z5 50 mWaves	Z5 100 mWaves	Z7 20 mWaves	Z7 50 mWaves	Z7 100 mWaves
REF	Z6 10 mWaves	Z6 20 mWaves	Z6 50 mWaves	Z6 100 mWaves	Z6 200 mWaves
Z9 20 mWaves	Z9 50 mWaves	Z9 100 mWaves	Z10 20 mWaves	Z10 50 mWaves	Z10 100 mWaves
REF	Z8 10 mWaves	Z8 20 mWaves	Z8 50 mWaves	Z8 100 mWaves	Z8 200 mWaves
Z11 20 mWaves	Z11 50 mWaves	Z12 20 mWaves	Z12 50 mWaves	Z13 20 mWaves	Z13 50 mWaves
Z14 20 mWaves	Z14 50 mWaves	Z15 20 mWaves	Z15 50 mWaves	Z1-15 20 mWaves	Z1-15 50 mWaves
REF	Z1-8 10 mWaves	Z1-8 20 mWaves	Z1-8 50 mWaves	Z1-8 100 mWaves	Z1-8 200 mWaves

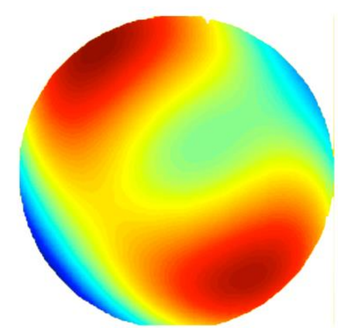
Results for λ = 543 nm

Accuracy: **λ/30,** Precision: **λ/100**



Input wave

Z1-Z8



Reconstructed wave

THANK YOU FOR YOUR ATTENTION