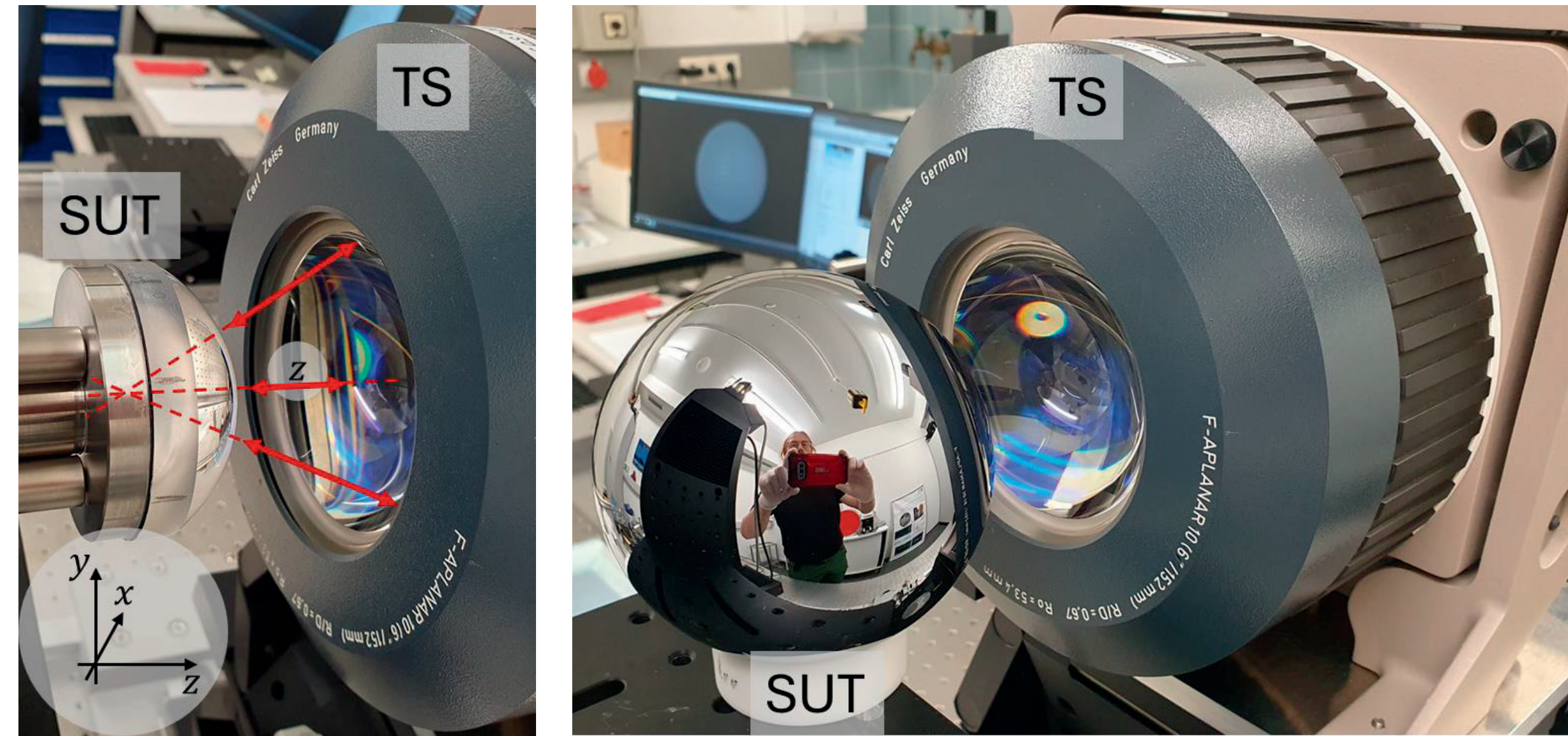


Interferometric sphericity measurements - impact of sample displacement on the measurement uncertainty

Markus Schake

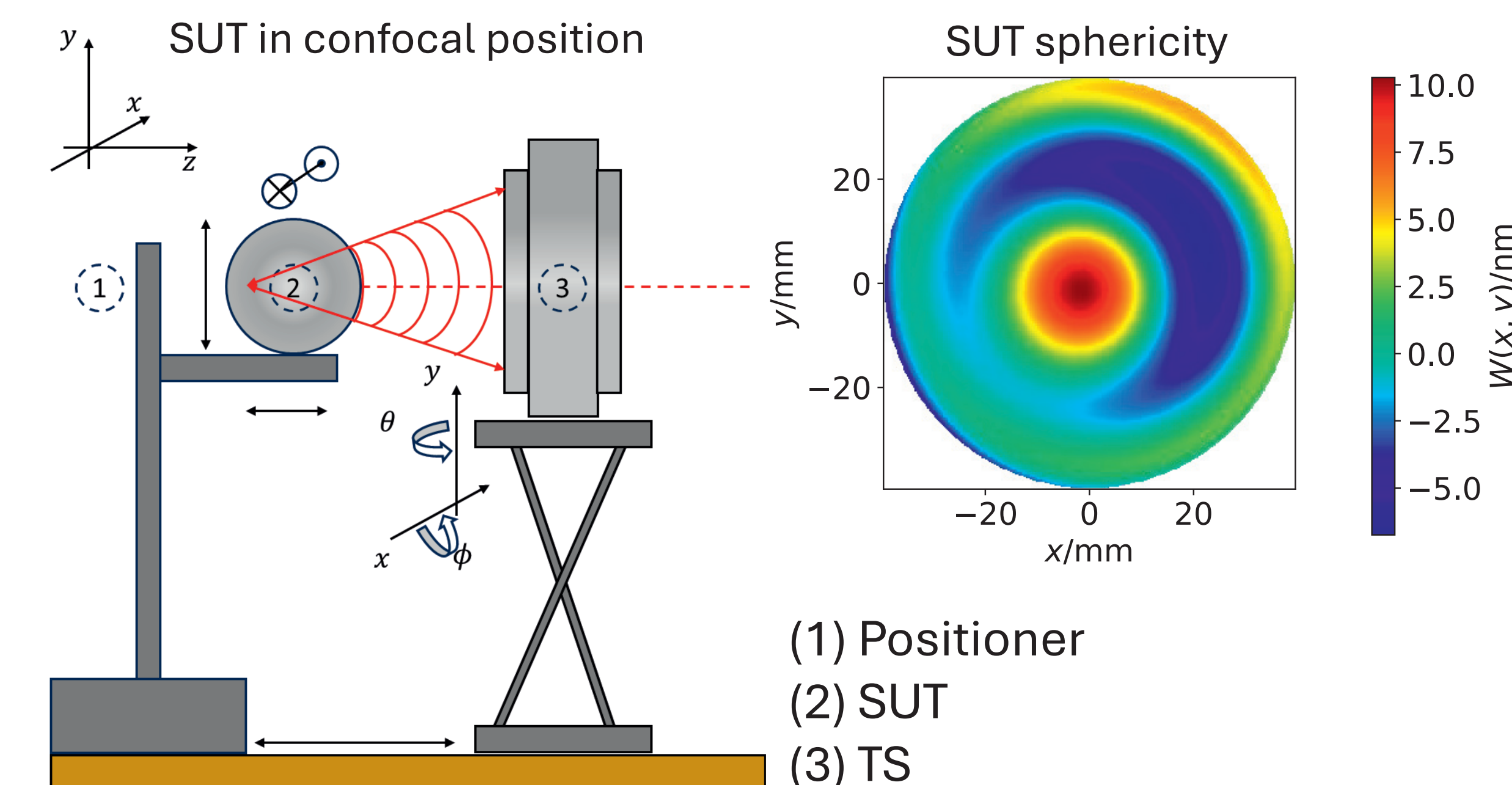
Measuring sphericity of spherical sections

At the national metrology institutes of Germany (PTB) and Japan (NMIJ), the form of spheres and spherical sections is calibrated by interferometric null-testing with measurement uncertainties in the nanometer range [1-4].



- The sample under test (SUT) is positioned in front of the transmission sphere (TS).
- A spherical wave converges towards the SUT.
- The SUT is moved along the optical axis (z-axis) until it reaches the confocal position.
- The SUT is aligned in the image field directions (x, y-direction).
- An almost fringe-free interferogram indicates good alignment in the confocal position.

Theory of aberrations and displacements



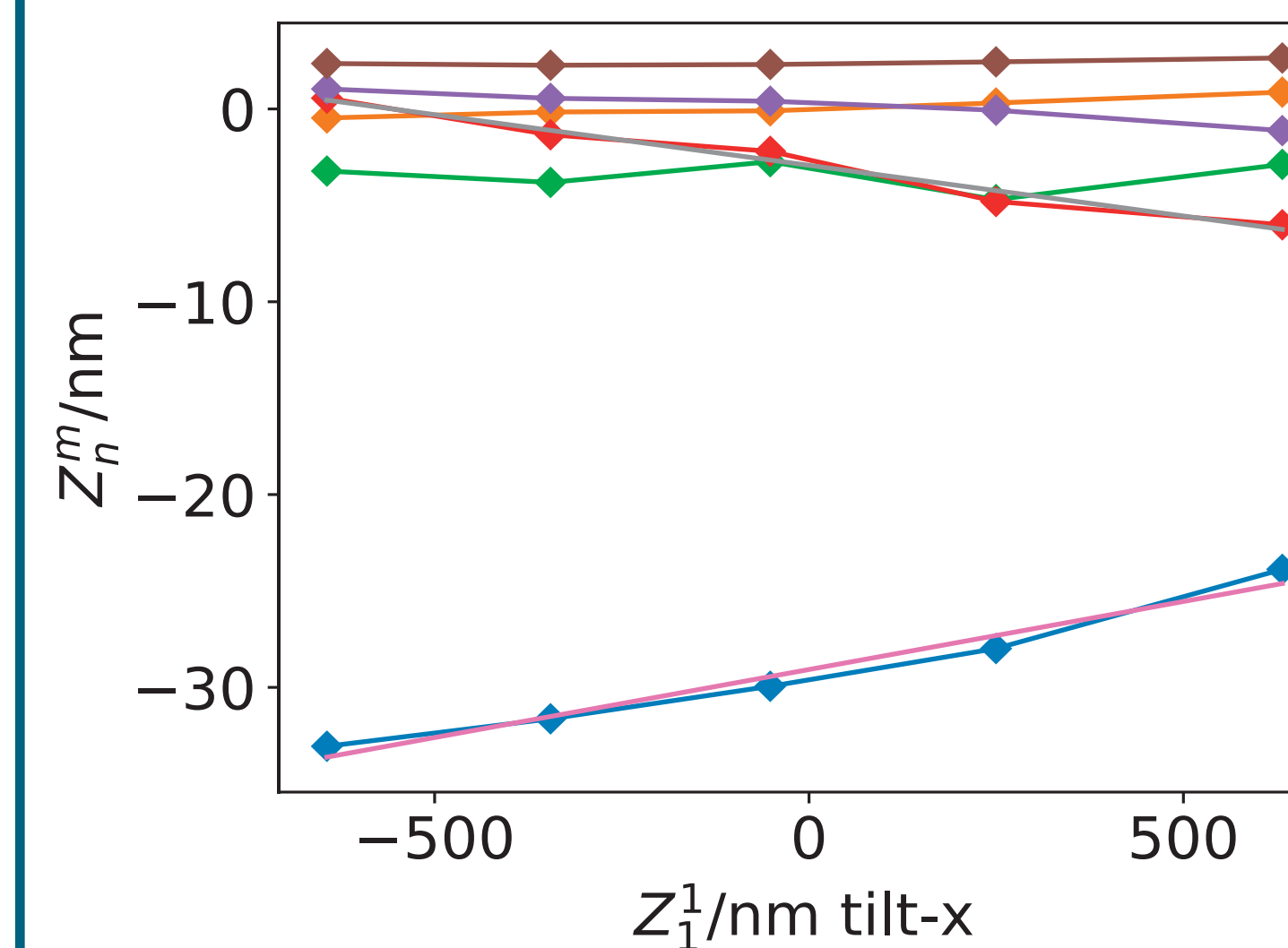
- In the confocal position only the deviation of the surface from a perfect sphere contributes to the interferogram.
- These form errors are referred to as the sphericity
- The inherent sphericity of the TS needs to be compensated.
- The TS sphericity is calibrated at PTB using a silicon sphere as a reference [3]. At NMIJ a random ball test may be performed [1].

- Lateral displacement of the SUT results in a tilted spherical wavefront.
- The characteristic fringe pattern of the tilted wave is shown in the bottom left figure.
- A lateral displacement of some microns should cause wavefront tilting and a negligible cylindrical form error [2].

Displacement errors in experimental results

PTB and the NMIJ [1] conducted experiments to validate the model for lateral displacement errors. At PTB the highly polished Silicon sphere with curvature radius $R_{SI} \approx 46.8$ mm was measured using different transmission spheres.

Xonox 0350, $R_{TS} \approx 102$ mm, $D_{cl} \approx 95$ mm



- Sphericity is expressed as Zernike coefficients. (legend at the bottom)
- Most coefficients (e.g. Z_2^2, Z_2^{-2}, Z_4^0) are not influenced by the tilt.
- The change in Z_2^0 observed with TS Xonox 0350 is caused by unintended defocusing while performing the lateral motion.
- A dependence between tilt-x Z_1^1 and coma-x Z_3^1 is observed (also see [1]). It is approximately linear and listed in the following chart.

TS:	Xonox 0350	Xonox 0373	Xonox 0759
$\partial Z_3^1 / \partial Z_1^1$	-0.0053	-0.0044	-0.0067

- Applying tilt-y Z_1^{-1} , yields similar observations for coma-y Z_3^{-1} .

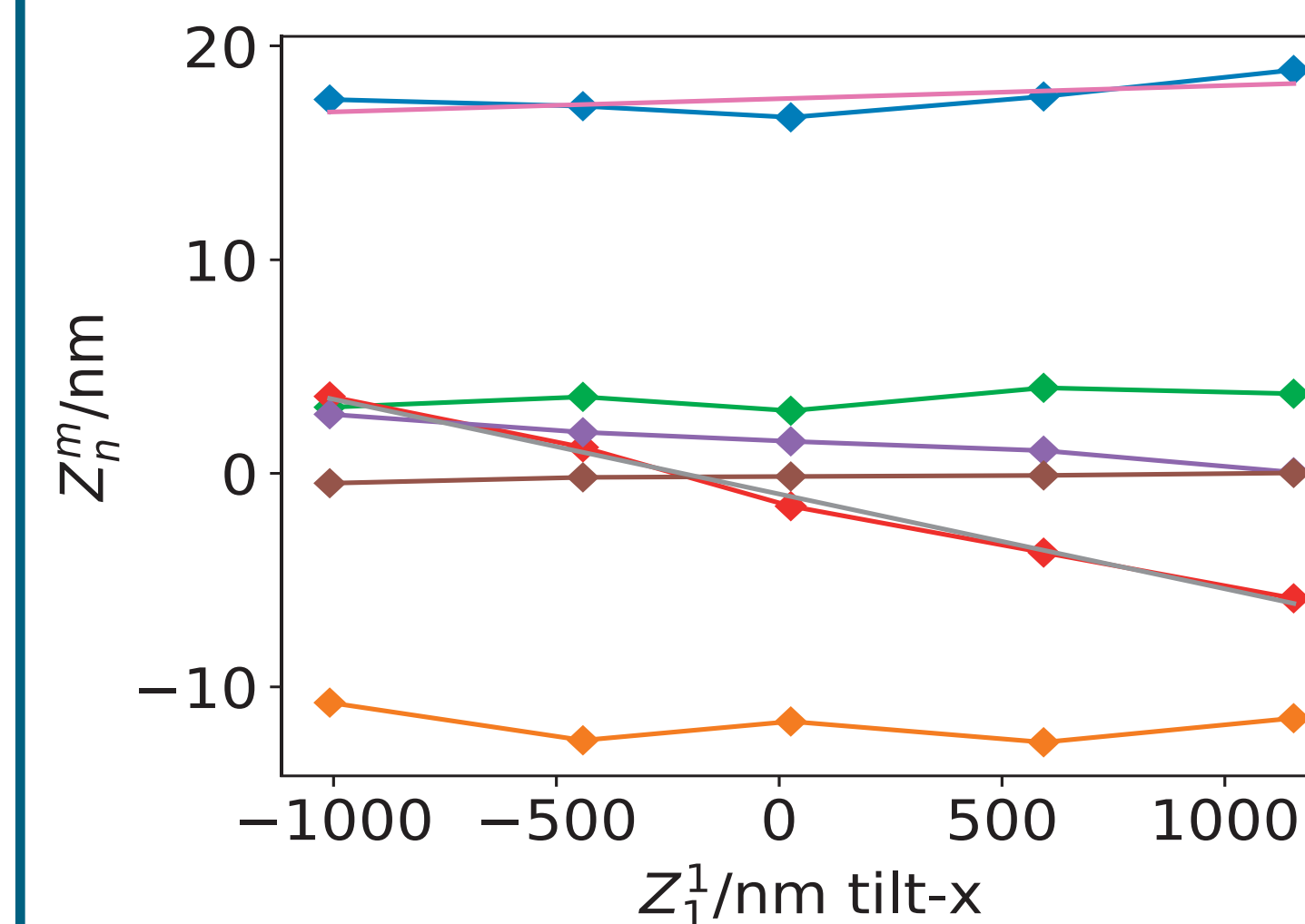
Conclusion

The origin of the coma term, which is observed with increasing lateral displacement and tilt, needs further investigation. However, the tilt error in measurements can typically be adjusted to be less than 100 nm. The error caused by the coma $e_c = Z_1^1 \cdot \partial Z_3^1 / \partial Z_1^1$ is expected to be less than 1 nm and thus is acceptable for the expanded measurement uncertainty $U = 11$ nm for coverage factor $k = 2$ which is assigned to sphericity measurements at PTB.

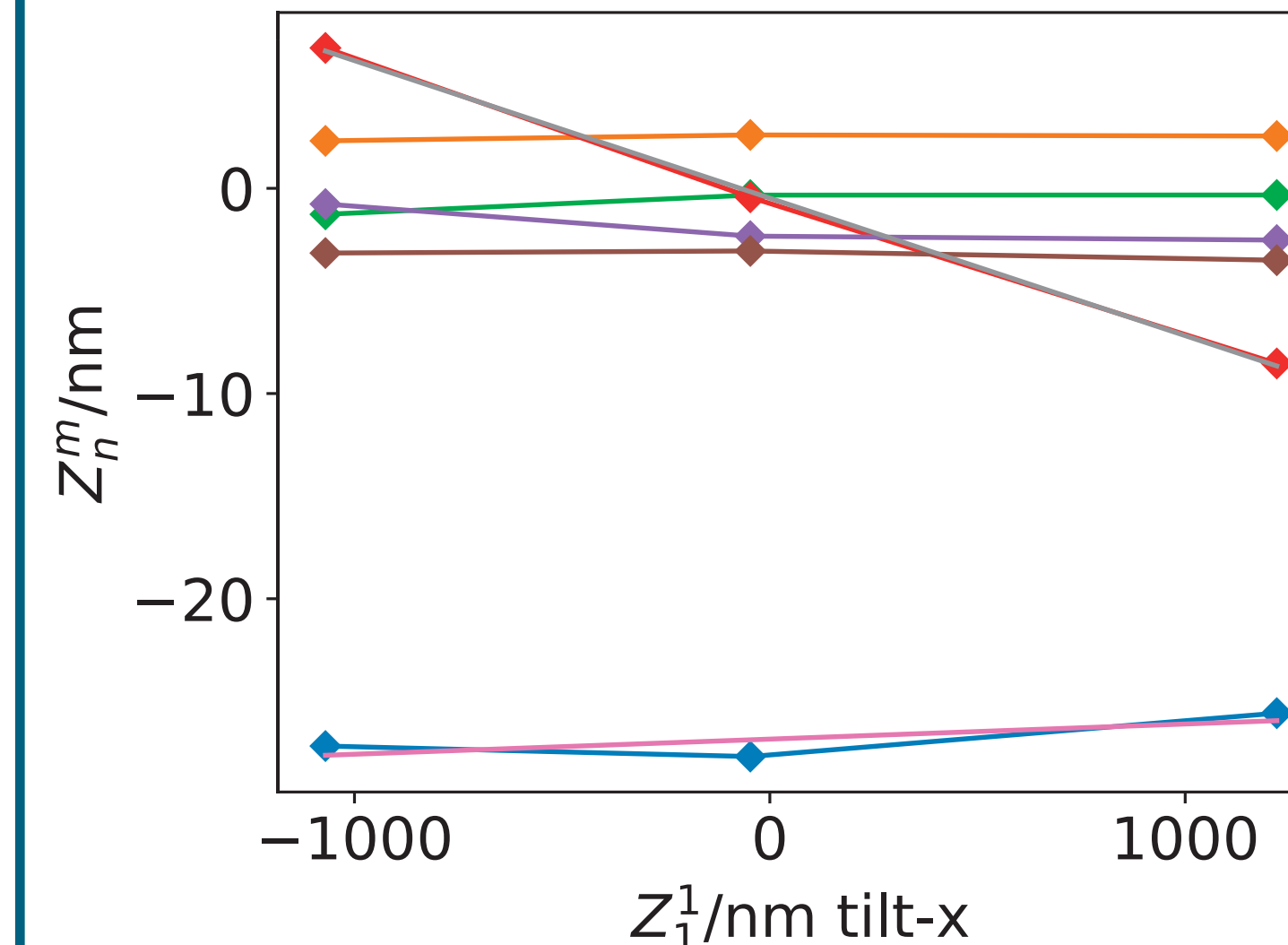
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- [2] Antonia Gronle, Christof Pruss, and Alois Herkommer, Opt. Express 30, 797-814, (2022), <https://doi.org/10.1364/OE.443420>
- [3] Torsten Mai and Arnold Nicolaus, Metrologia 54 487, (2017), <https://doi.org/10.1088/1681-7575/aa75d3>
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Xonox 0373, $R_{TS} \approx 167$ mm, $D_{cl} \approx 105$ mm



Xonox 0759, $R_{TS} \approx 291$ mm, $D_{cl} \approx 118$ mm



- Z_2^0 defocus
- Z_2^2 astigmatism-xy
- Z_2^{-2} astigmatism-45°
- Z_3^1 coma-x
- Z_3^{-1} coma-y
- Z_4^0 spherical
- Z_2^0 fit
- Z_3^1 fit



Special thanks to Natsumi Kawashima and Akiko Hirai for the interesting discussions at NMIJ.