Testing some limits of long trace profilers using *Zemax* simulations.

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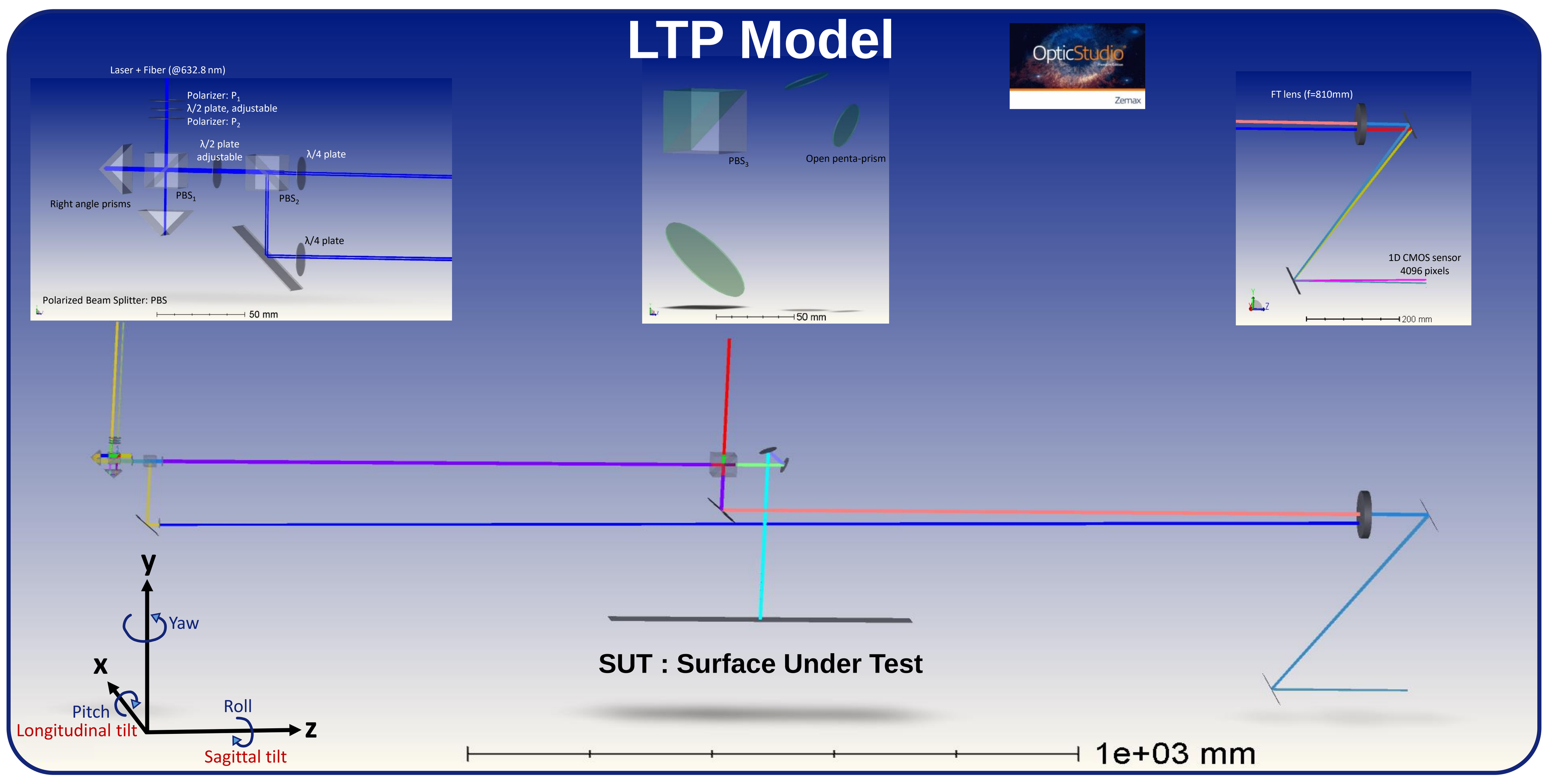
Acquiring direct images of distant exoplanets or focusing X-rays requires high performance optics. Laboratories and optics suppliers are therefore actively seeking to improve polishing methods and metrology. For slope-error evaluation, many accelerator-based light sources use Long Trace Profilers (LTP) whose measurement accuracy can be better than 80 nrad in a relatively short period of 6 hours[1], and which typically offer a better reproducibility in radius determination of mirrors than interferometers with stitching.

Introduction

The ESRF LTP has been modelled using Zemax from Optic Studio. This ray-tracing code offers the possibility to configure the simulations using Python code. This provides a convenient means to explore the potential influence of multiple parameters of the LTP (e.g. alignment, optical aberrations) upon the measurement accuracy.

LTP Model



Sagittal tilt

A geometrical study shows that a sagittal tilt on the SUT, or roll in the displacement of the movable head, induces a translation of the pattern along the X axis. This leads directly into a loss of intensity received by the sensor.

- **1rst figure**: Simulation: 2D pattern without sagittal tilt, the region of interest (256 central pixels) of the sensor is symbolized by a red rectangle.
- **2nd figure**: Simulation: we tilted (sagittal) the SUT by 100 µrad.
- **3rd figure**: Measurement: pattern read by the sensor (configuration of figure 1 in green, configuration of figure 2 in red).
- **4th figure**: Measurement (in red) & Simulation (in blue) : Amount of power received by the sensor (on the 256 central pixels) depending on the sagittal tilt.

Figure 1

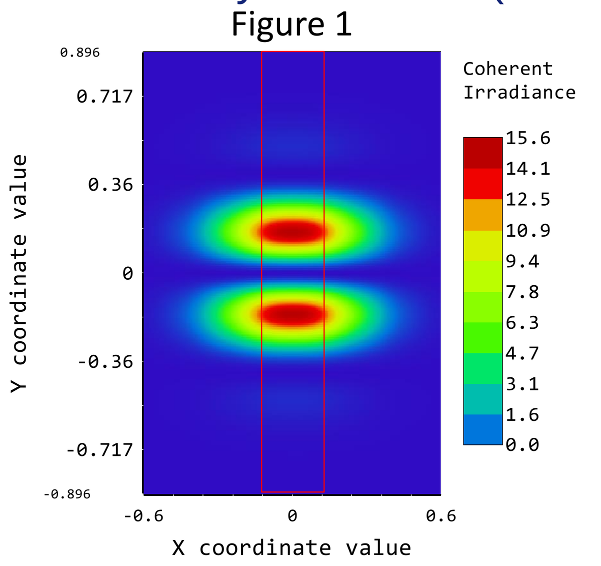


Figure 2

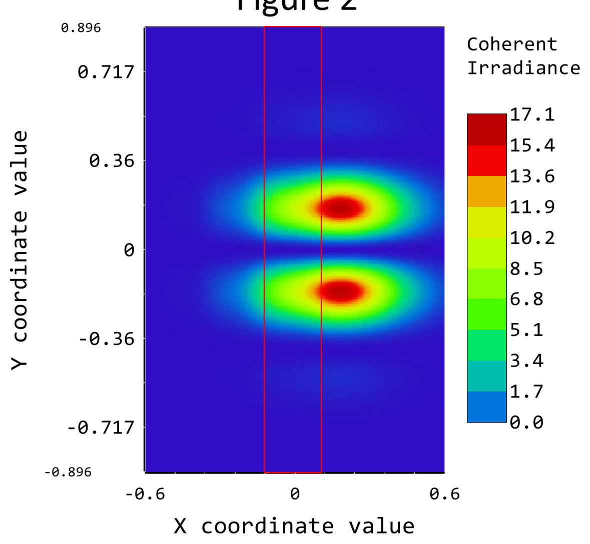


Figure 3

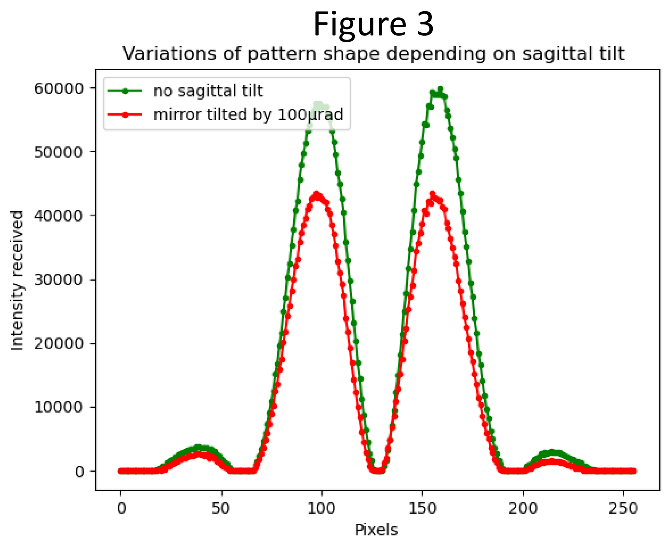
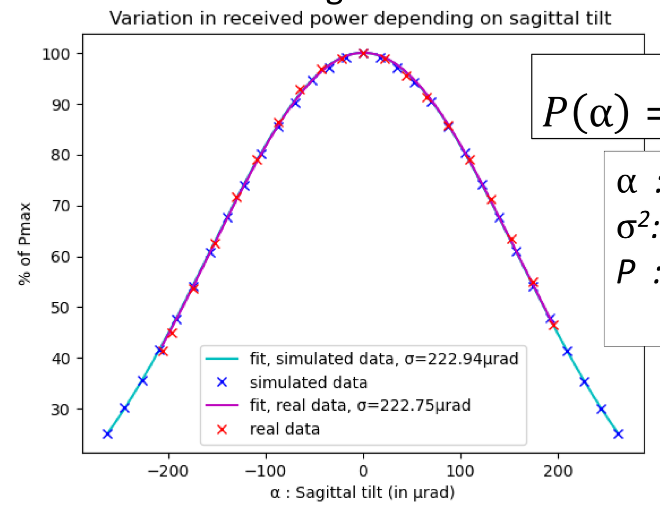


Figure 4



$$P(\alpha) = 100 \cdot e^{-\left(\frac{\alpha}{\sigma}\right)^2}$$

α : Sagittal tilt
σ²: Fitted variance
P : Power received (in % of Pmax)

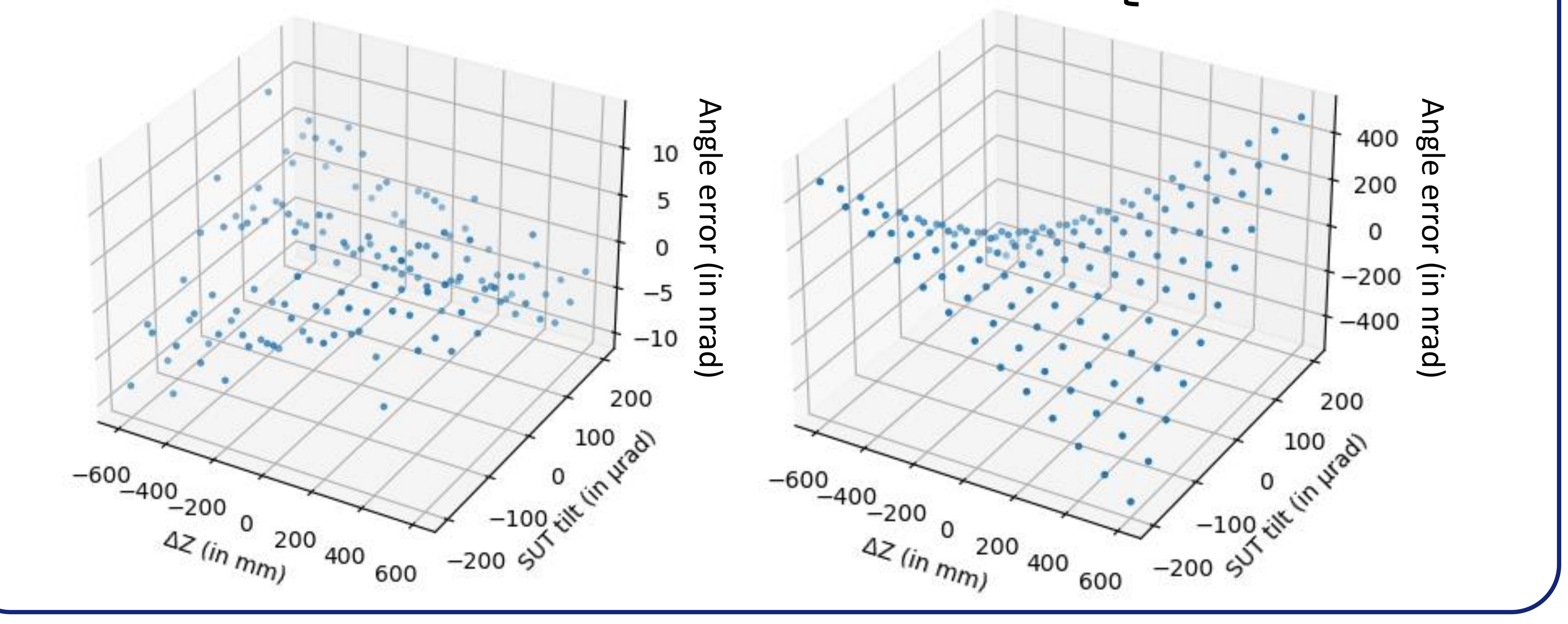
Sagittal tilt seems to have an impact on measurements, and those simulations are a starting point for understanding the sources of this effect.

Misalignment/misorientation of the sensor

- Misorientation (<5 deg) of the sensor does not induce significant measurement errors during simulations.
- Positioning the sensor 5 mm after the focal point induces a repeatable error in the slope determination (considering simulations). The formula: **Angle error = a*tilt*Δz** allows accurate modelling of this error.

Angle error: Repeatable error caused
a: Fitted coefficient
tilt: Longitudinal tilt on the mirror
ΔZ: Distance from the calibration point (moving head displacement centre)

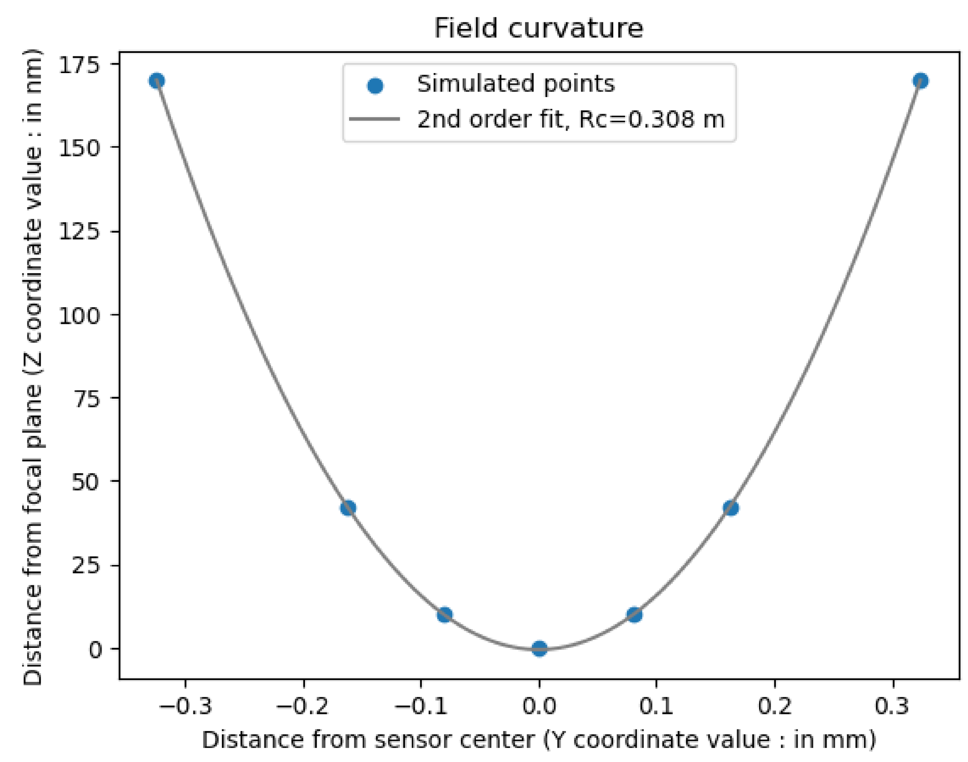
Angle error with the sensor in the focal plane (left figure), and 5mm after (right).



Field curvature

Using a converging FFT lens, the plane of focus of the LTP is curved at the sensor.

Using basic Zemax features, we determine the field curvature to be 0.3 meters. The clear length of the sensor being 0.7mm, this curvature can be neglected in the current configuration.



Geometry analysis

- State of polarisation along the optical path.
- Impact of yaw/pitch/roll during the movable head displacement.

Summary

- Simulations allow quick and precise geometry analysis of the LTP.
- Coupled with Python, it is possible to study the impact of various parameters simultaneously, and directly analyse and plot the results.

These are the first results of the ESRF LTP simulations. They will provide the foundation for in depth studies, such as the sagittal tilt impact on measurements and calibration.

Studies on misaligned and imperfect components, retrace error and ghost rays are also planned.

References:
[1]: A. Vivo et al., (2010). ESRF metrology laboratory: Overview of instrumentation, measurement techniques and data analysis. Proc. SPIE 7801. 5-10.1117/12.864141