Investigating mirror surface parameters for the Einstein Telescope interferometer

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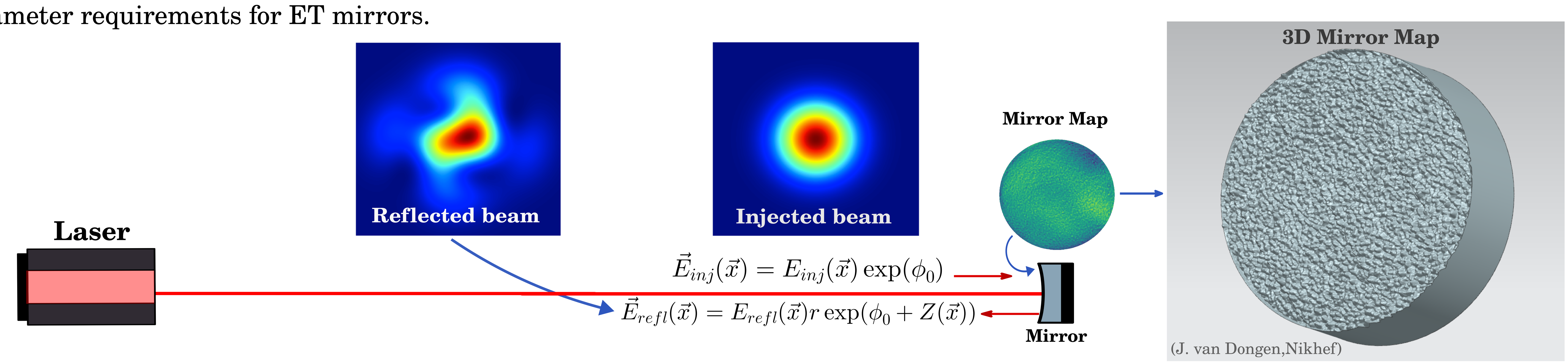
Introduction:

The Einstein Telescope (ET) project aims to prove an up-close examination of gravitational waves originating from sources near the birth of the Universe. When an incident beam encounters the imperfect surface of a mirror, it introduces a wave-front distortion that affects the beam quality. The surface can be represented as Mirror Maps, this is an array containing optical path information.
To provide parameter specifications for ET mirrors we need to predict their performances in the interferometer. Therefore we are developing Virtual Mirror Maps, based on Advanced LIGO and Advanced Virgo mirror data, using a combination of well-known analysis strategies (Zernike basis and Fast Fourier Transformation) with the addition of some random content to make each one unique. Finally we do optical simulations with Finesse software to evaluate the Virtual Mirror Maps and ultimatly provide surface parameter requirements for ET mirrors.



Generating Virtual Mirror Maps:

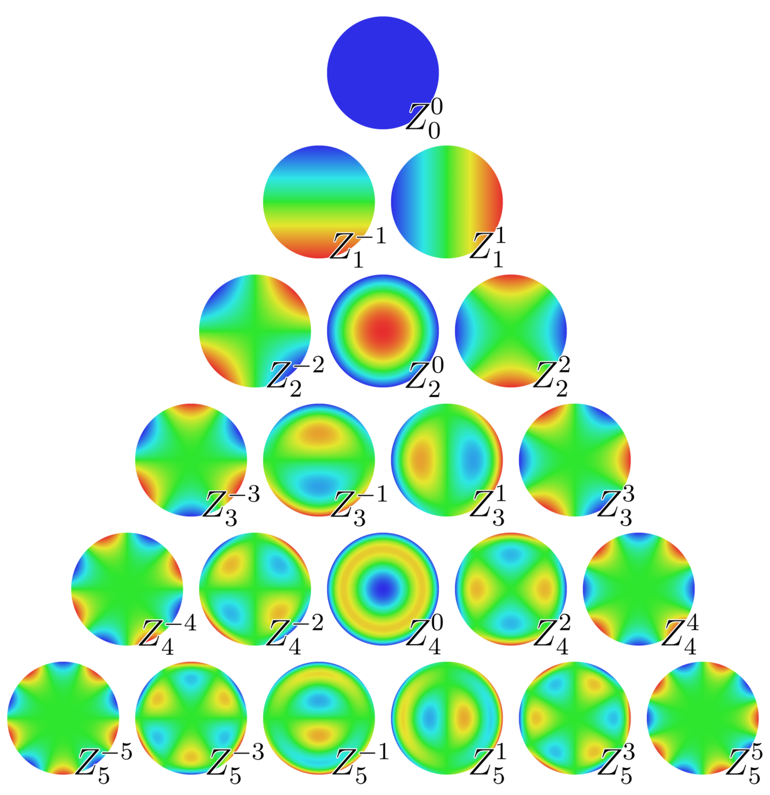
With our algorithm we blend the informations extracted from the Mirror Maps using Zernike and FFT tools to generate Virtual Mirror Maps that have a realistic likelihood of behaving like actual ET mirrors in interferometers.

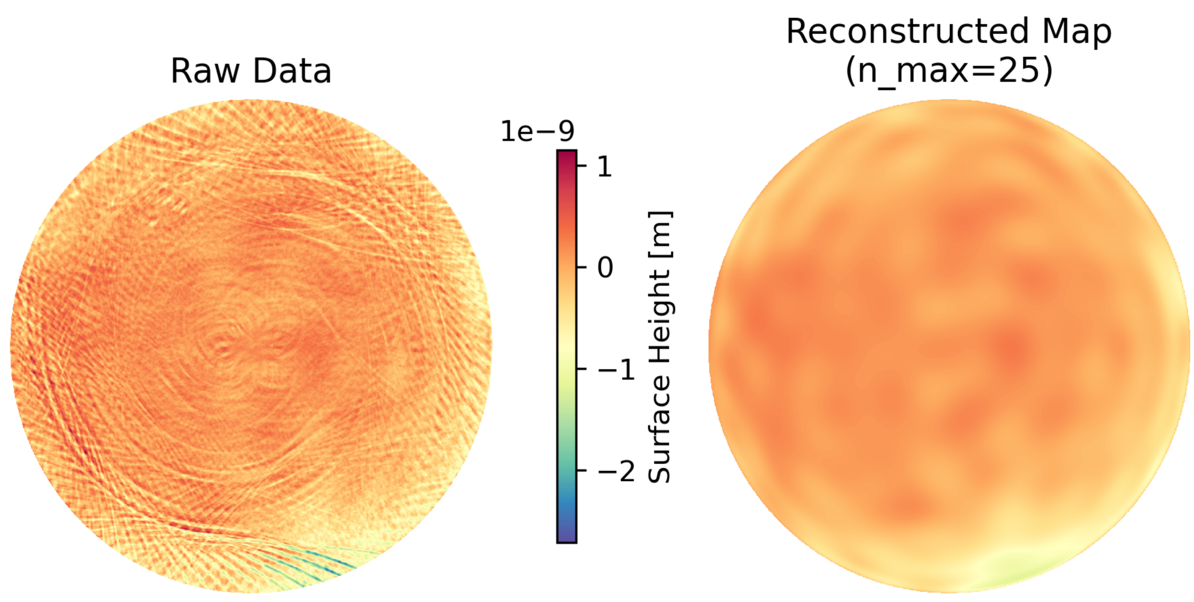
Zernike:

Zernike polynomials can represent a wide range of distortion types with a relatively small number of coefficients, making it easier to work with and interpret wavefront data. Its orthogonality simplifies the analysis of complex wavefronts

$$Z_n^{+m}(\rho,\phi) = A_n^{+m}\cos(m\phi)R_n^m(\rho)\ \textit{even polynomial},$$

$$Z_n^{-m}(\rho,\phi) = A_n^{-m}\sin(m\phi)R_n^m(\rho)\ \textit{odd polynomial}$$





Project status:

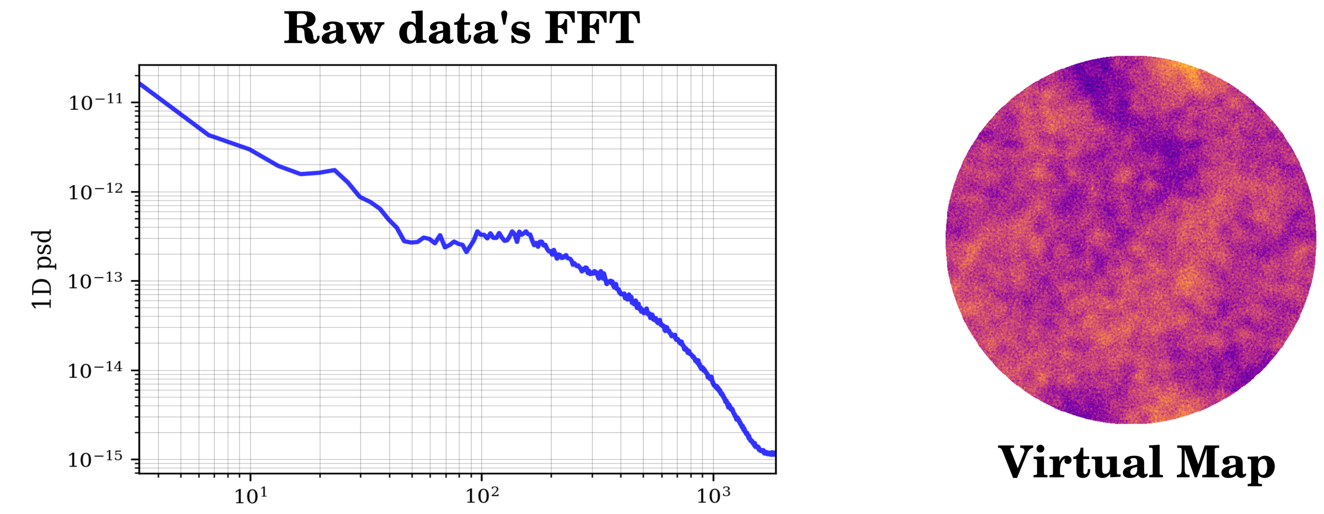
We are reviewing different surface reproduction tools and exploring the potential of our algorithm to produce Virtual Mirror Maps that can provide ET mirror surface parameters.

What's next?:

A deeper understanding of how well-known surface reconstruction tools work and provide a way to merge them will lead to a Virtual Mirror Maps repository shareable with the Gravitational Waves community.

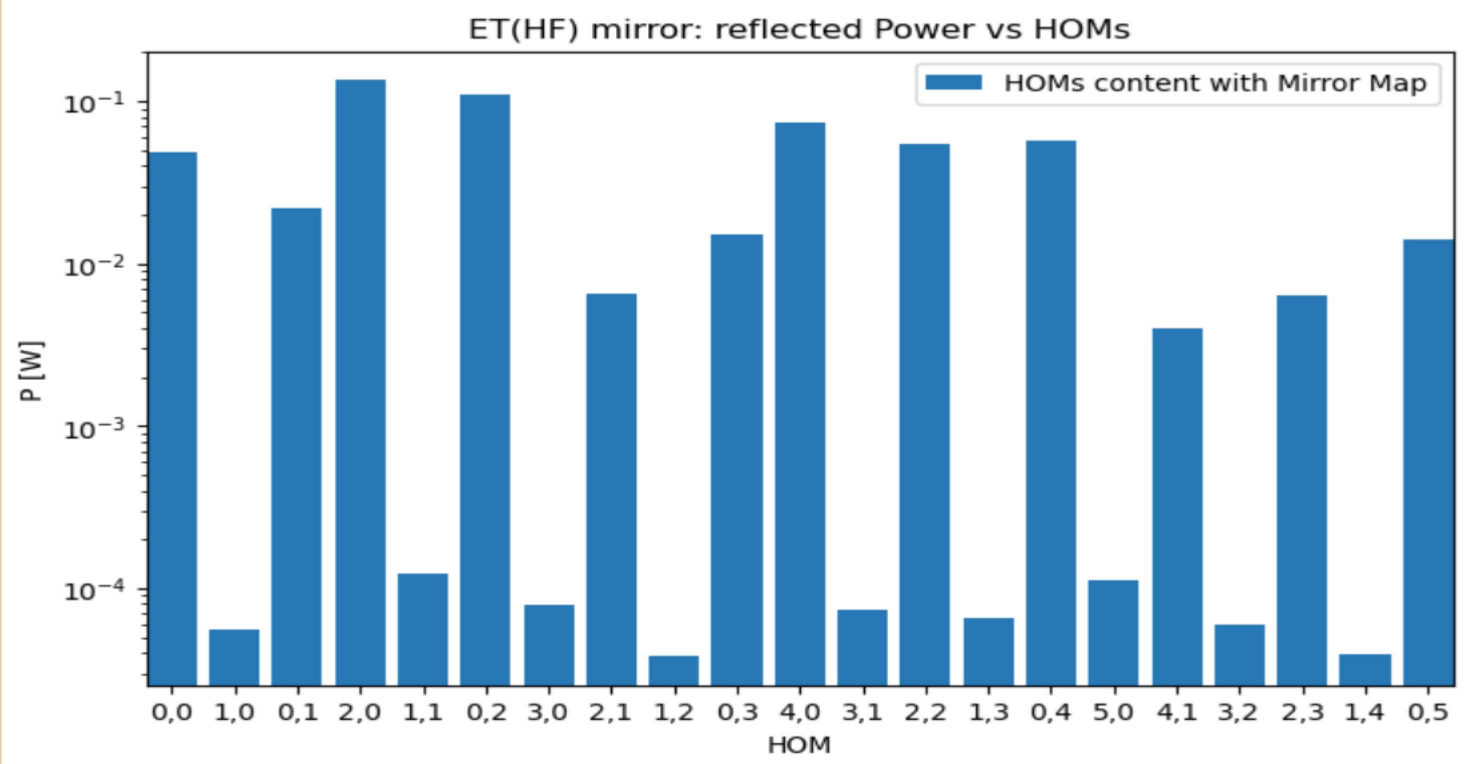
Fast Fourier Transformation (FFT):

FFT is an efficient algorithm to assess surface roughness. It provides an accurate evaluation of surface characteristics at various length scales, allowing for a quantitative characterization and detailed understanding and of surface properties.



Interferometer simulations:

Finesse is an open-source software [1,2,3] used to model the behavior of steady-state Gaussian beams within advanced interferometers. It leverages a model-based approach to accurately replicate beam distortions .
We use it as part of our evaluation process to test our Virtual Mirror Maps inside the ET optical model to analyze how the mirror surface distortions affect the detector HOMs content.



[1]: '*Frequency domain interferometer simulation with higher-order spatial modes*', A.Freise *et al.*Class.Quant.Grav. (2004)
[2]: '*Pykat:Python package for modelling precision optical interferometers*', D.D.Brown *et al.*, SoftwareX (2020).
[3]: '*Finesse 3*', D.D.Brown *et al.*, Nikhef (2023)

finesse.ifosim.org