Applications of HARMONI's pointing model

Using prior information to speed up calibrations

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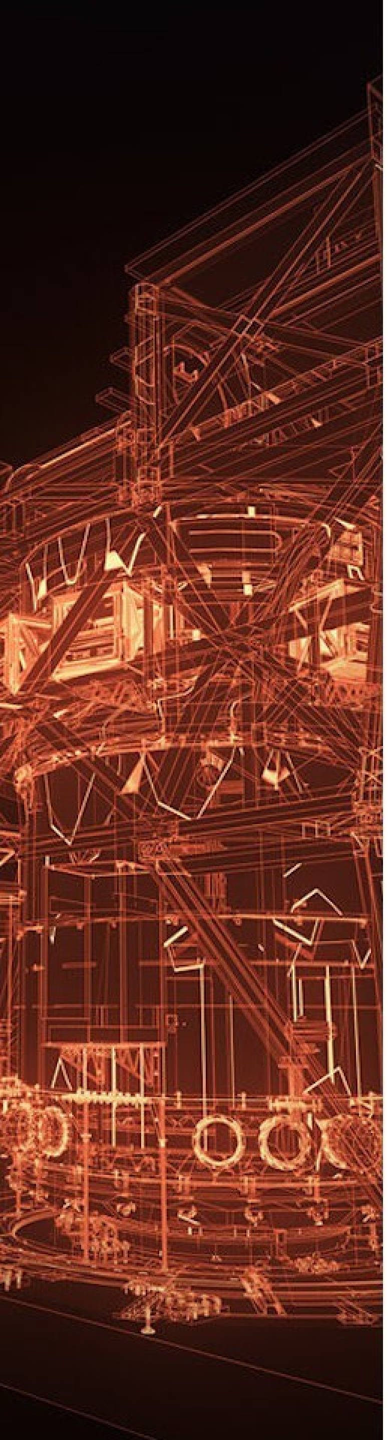
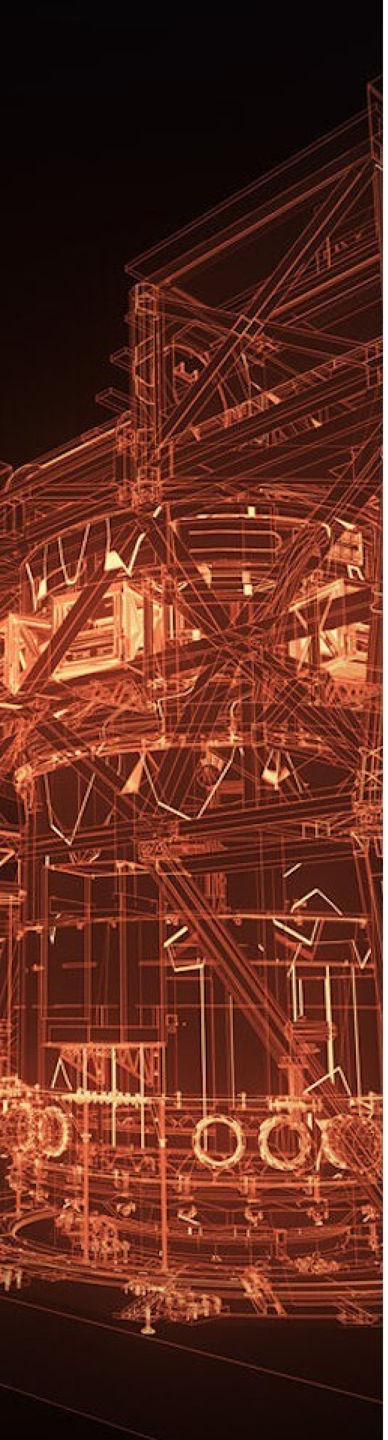


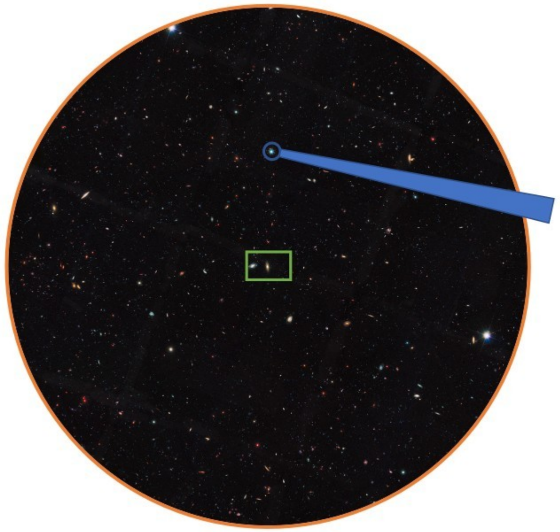
Introduction

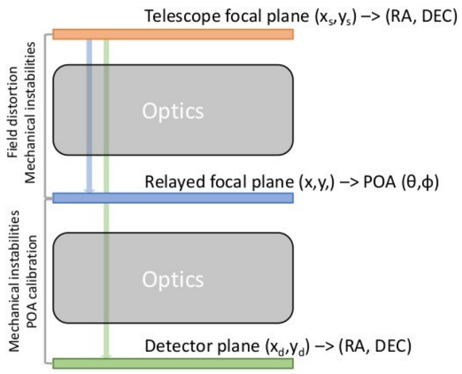
- HARMONI: Challenging angular resolution
  - ~10 mas FWHM (AO)
- Challenging positioning accuracy
  - 13 µm pixels →4 mas/pixel (Nyquist sampling)
- Instrument as-is: pointing error
  - **Pointing model** (for static contributions)
- The problem:
  - What does this model look like? How good is it? How do we fit it?
  - Is our knowledge of the instrument enough?
- The approach
  - An evolvable pointing simulator architecture: **harmoni-pm** (https://github.com/BatchDrake/harmoni-pm)



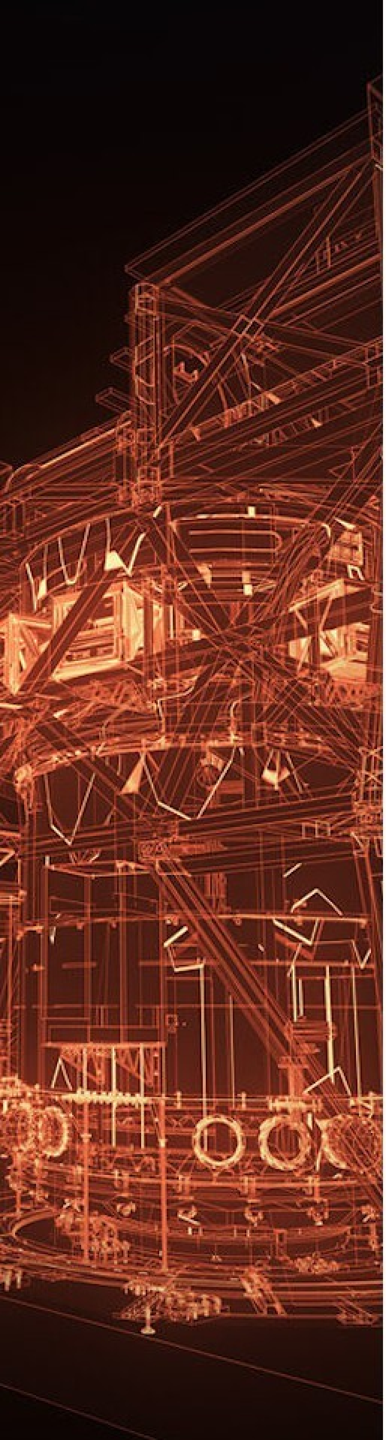
Pointing with HARMONI

Technical Field



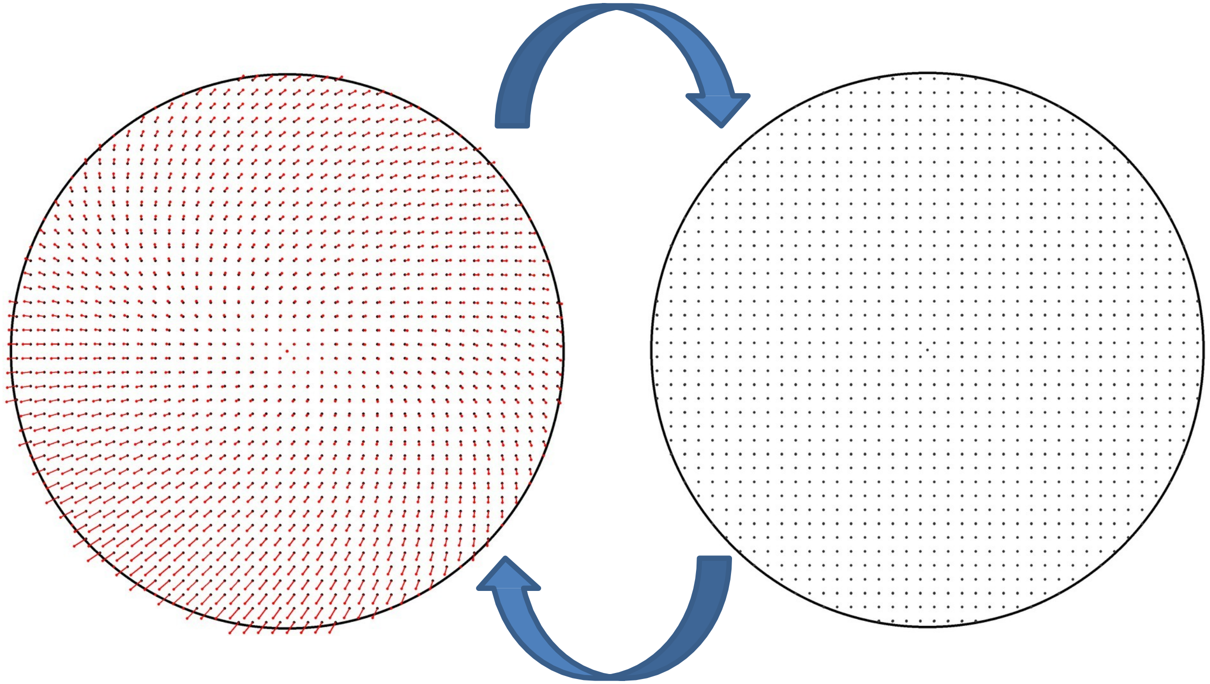


- Telescope’s focal plane is relayed to another 1:1 plane by means of **FPRS** optics
- Pick-Off Arm: measure position of stars in the **relayed** plane



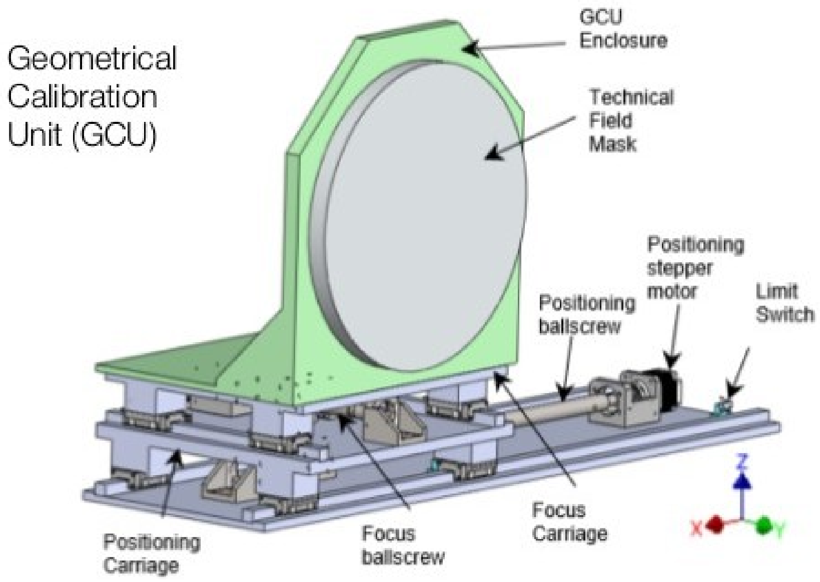
Pointing model in a nutshell

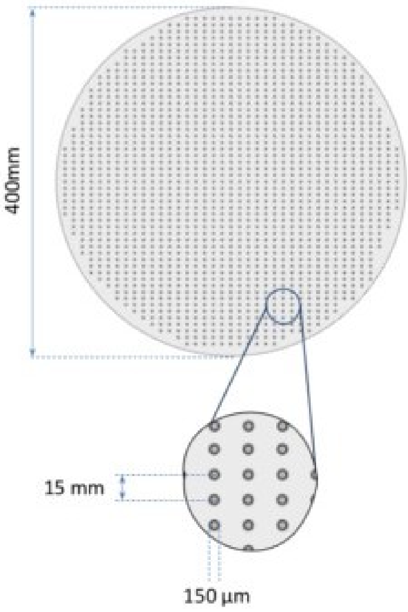
- Transform focal points into relayed points (search)
- Transform relayed points into focal points (error measurement)



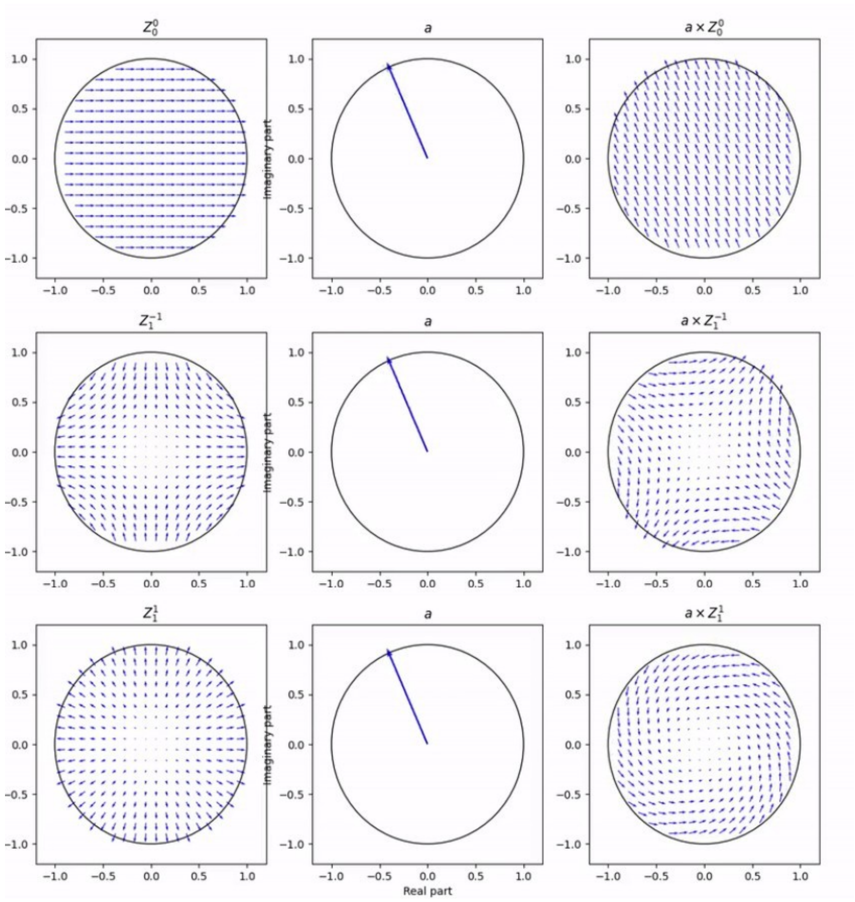
GCU and calibration mask

- Present well-known bright points into the focal plane to measure instrumental pointing errors



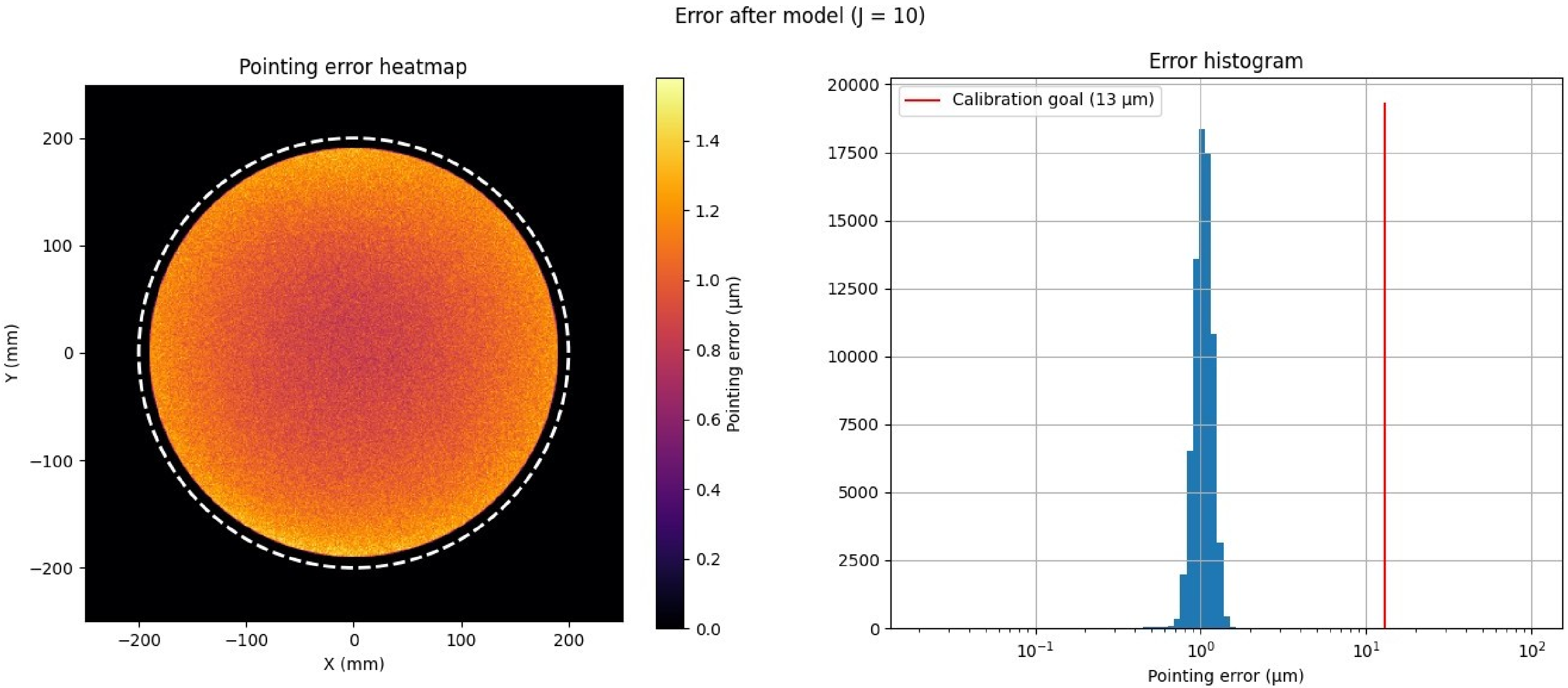


Pointing model formulation



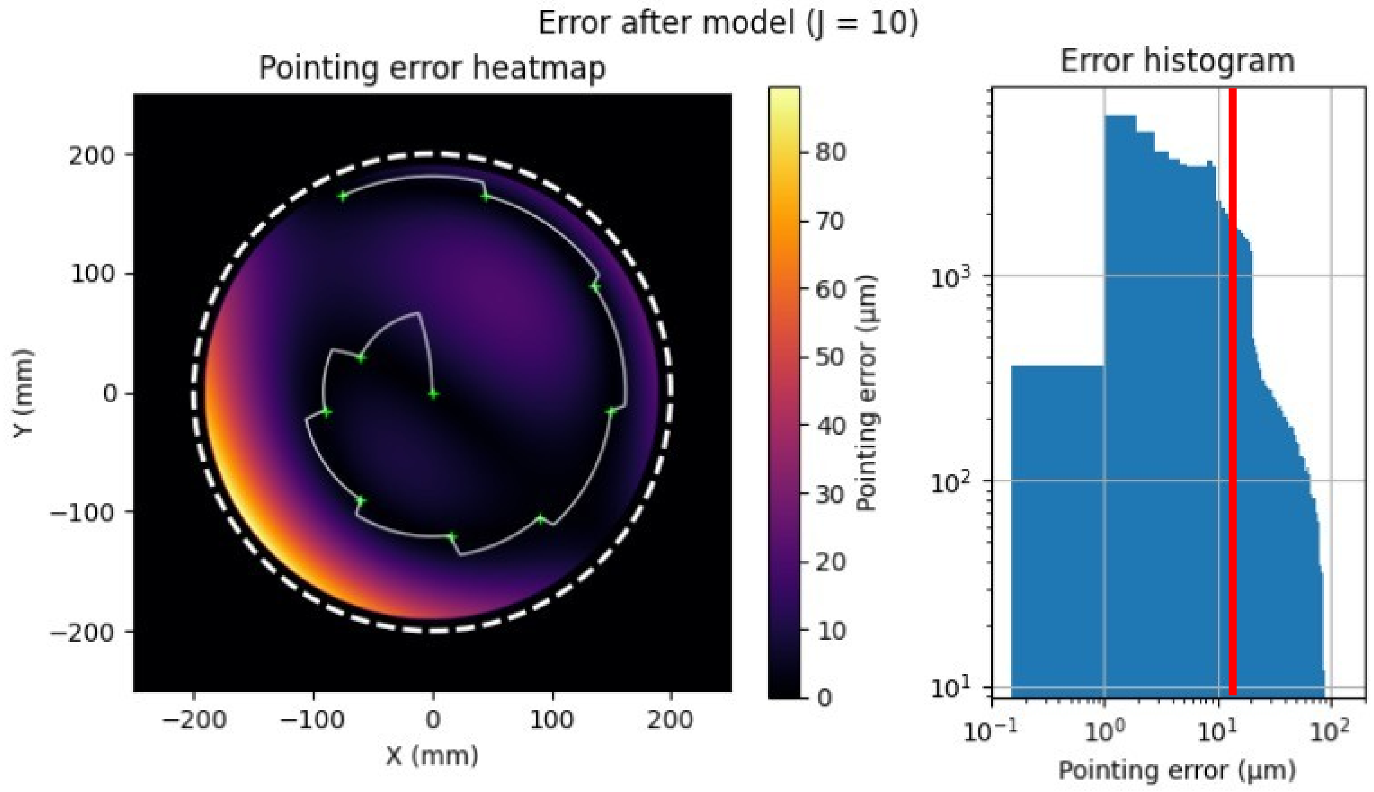
- Linear combination of complex Zernike polynomials
  - **Standard** (well documented)
  - **Orthogonal** (absence of information overlap)
  - **Meaningful** (each polynomial has physical interpretation)
- Can be related to the Fourier series

Results: minimum model complexity



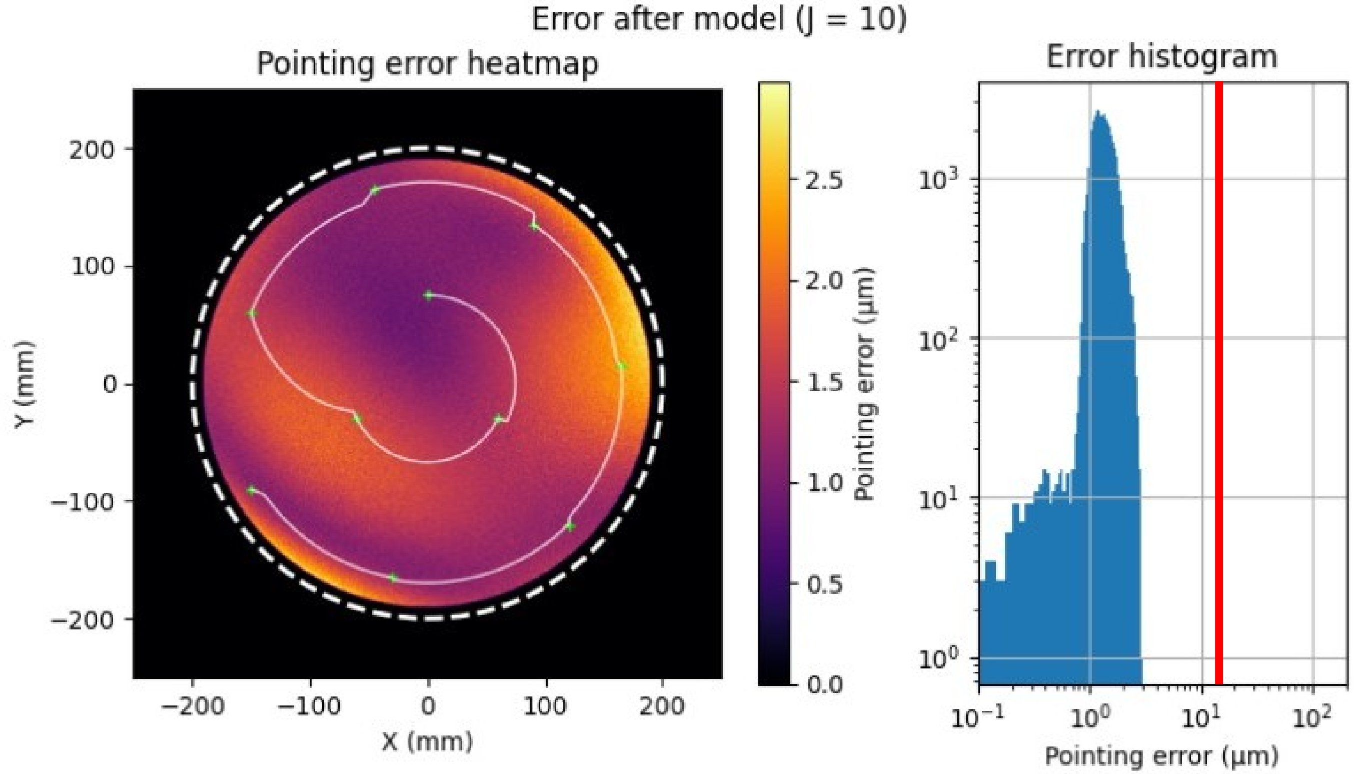
Results: calibration patterns

- Calibrating J = N = 10 with a **spiral** pattern produces **undersampled** regions in the relayed plane



Results: calibration patterns

- Calibrating J = N = 10 with a **concentrical** pattern results in a more evenly-distributed sampling of the pointing errors

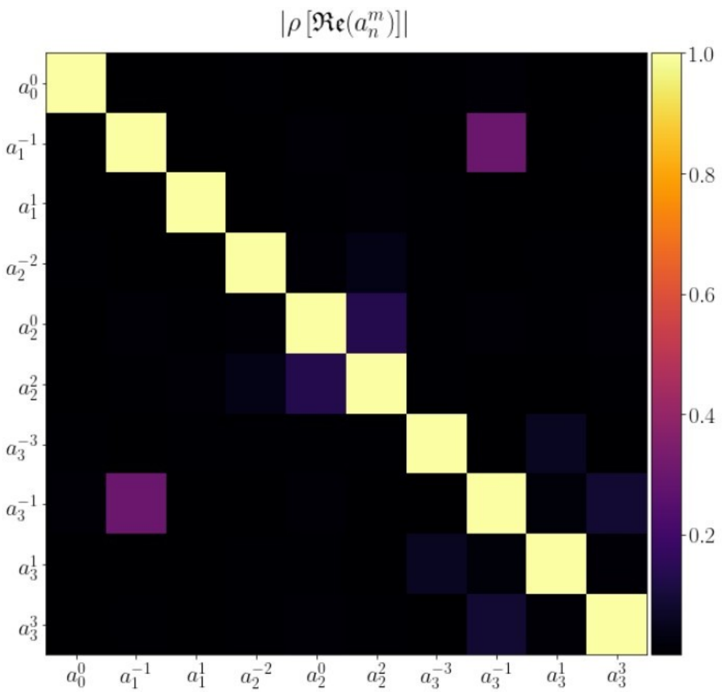


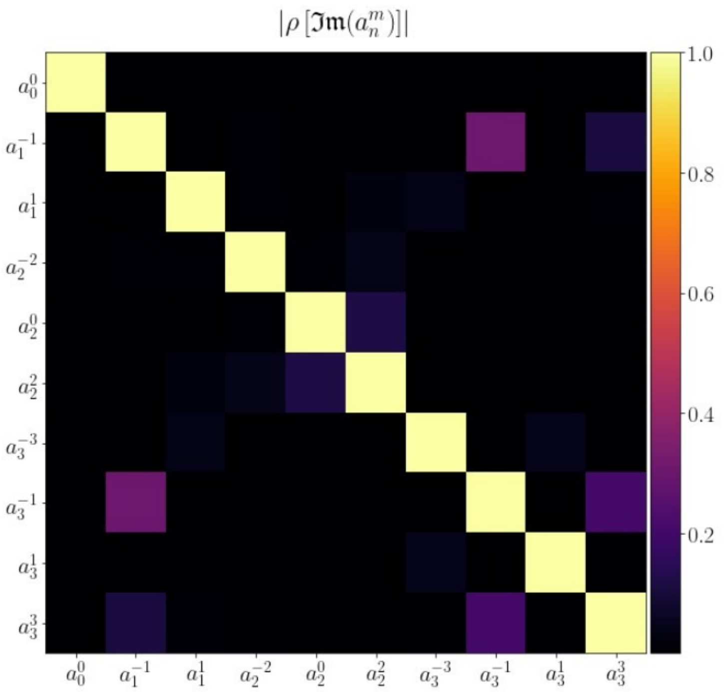
The Bayesian calibration problem

- Original formulation:
  - This is my set (**$N \geq J$**) of measured calibration points. *What is the set of model coefficients that **minimizes** the residual*?
- Bayesian formulation:
  - This is my set (**$N > 0$**) of measured calibration points, affected by measurement noise.
  - This is my set of prior probability distributions of the model coefficients.
  - *How are these distributions **updated** by the noisy measurements?*

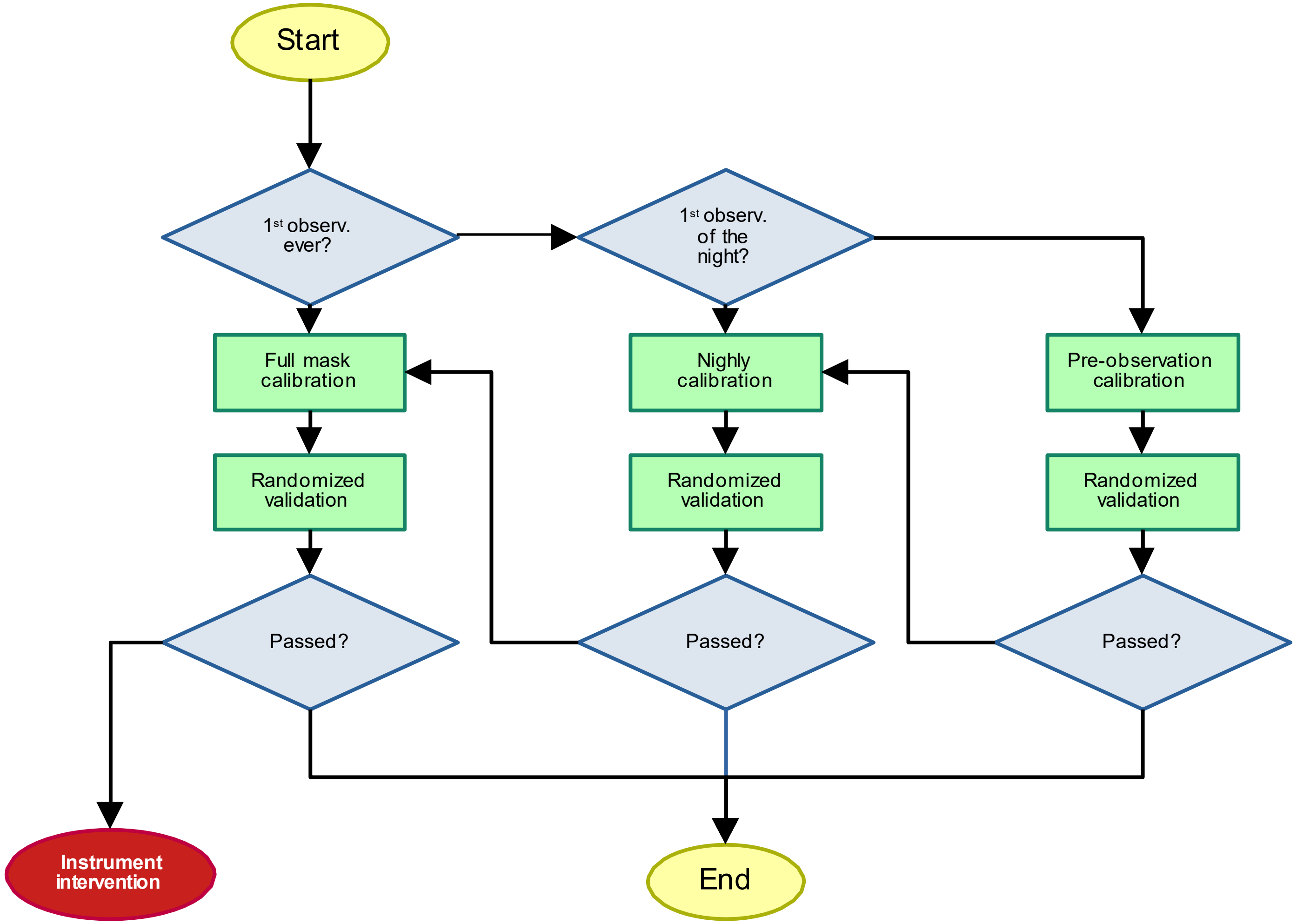
Optimizing the problem

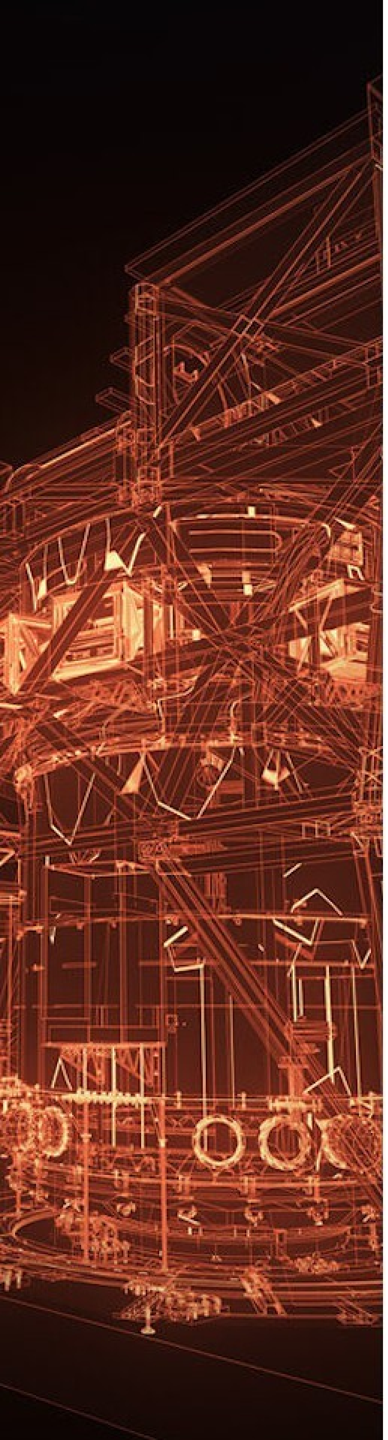
- Joint distributions of more than 3 variables are *hard*
- We have **20** variables (2 times 10)
  - Multivariate Gaussian: 20 means, ~**200** d.o.f in the cov. matrix
- Statistical independence → **separability** (20 variables, ~20 variances)





The calibration procedure





Conclusions

- **harmoni-pm** enables corrected and uncorrected pointing error simulations, while providing a highly flexible and extensible architecture
- **harmoni-pm** has proved to be a useful tool in constraining the pointing model complexity and optimizing the calibration strategy
- The **Bayesian formulation** allows to update the model with very reduced sets of calibration points, thus speeding up the calibration process