# A novel approach to interaction matrix calibration at THEMIS: accuracy analysis and extension to a temporal model

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Performance and stability of a closed-loop Adaptive Optics (AO) system are strongly related to the ability of the controller to model the response of the wavefront sensors to commands sent to the deformable mirrors. In most AO systems, this is modelled by the so-called Interaction Matrix (IM) which has to be calibrated.

While most AO systems calibrate the IM on an internal source, implementing the deformable mirror (DM) in the telescope requires more and more systems calibrate the IM on sky. But this difficulty brings advantages. For example, the calibration can take into account source specificities such as the elongation of laser guide stars or the structure of the solar granulation. Furthermore, if the calibration is done at the system full speed, temporal effects can also be calibrated, such as the temporal response of the DM.

This is the strategy followed on THEMIS AO, relying on original solutions for its wavefront sensing, its control, and its calibration, each one based on an inverse problem approach. We present in this work the interaction matrix calibration and we analyze the quality and features that can be obtained from this original approach.

In THEMIS AO, the IM is calibrated during open-loop observations of the sun granulation using a binomial random distribution of perturbation commands. The properties and benefits of this approach are analyzed. The uncertainties on the obtained IMs perfectly follow the theory. Data are compared to theory in Fig. 1 (left) showing noise decrease as $(\epsilon \sqrt{n_t})^{-1}$ with $n_t$ the number of measurements and $\epsilon$ the ratio between the standard deviations of the perturbation and of the turbulence.

For THEMIS AO, residual calibration errors suggest that a time dependent model of the IM is needed. To account for the temporal response of the DM in the controller, our calibration approach has thus been extended to fit an IM model consisting in a sequence of matrices. We show that, in practice, 2 components are sufficient and that the second IM matrix is well approximated by the first one times a simple factor. Figure 1 (right) shows the relative contribution of the 2-component IM fitted on THEMIS calibration data. Our time dependent IM model thus amounts to applying the static IM matrix to the current commands plus a fraction (11% here) of the previous commands. THEMIS calibration approaches and results are of importance for other high-frequency AO systems, particularly for High-Contrast AO systems.

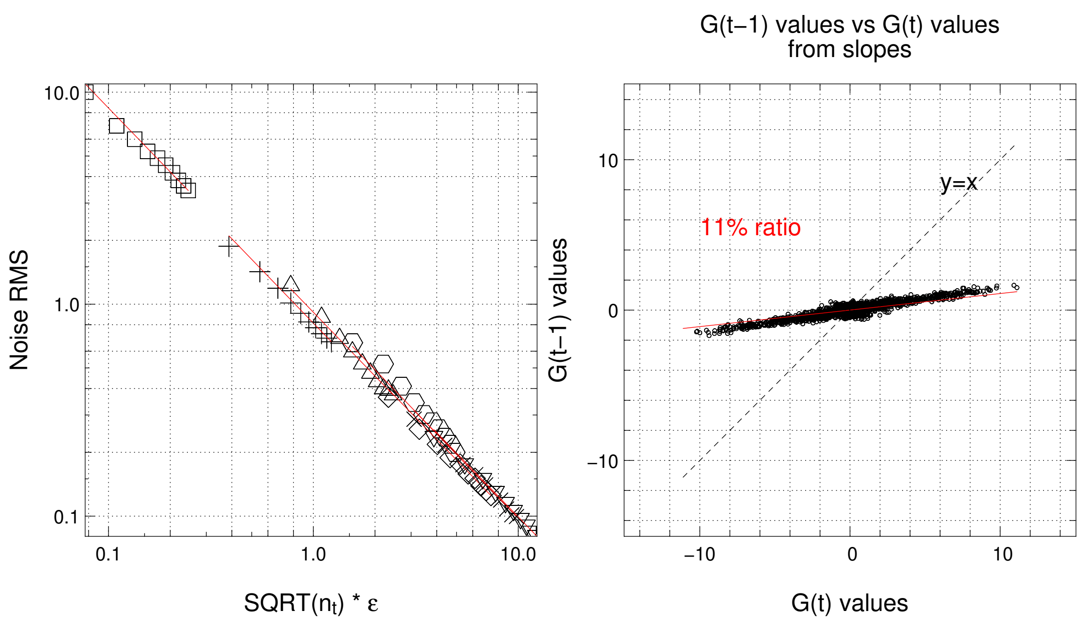


Figure 1: Left: Standard deviation of errors (a.u.) in Interaction Matrices calibrated at THEMIS depending on the number of frames used $n_t$ and the relative amplitude between perturbation and turbulence. Right: Elements of a calibrated static IM *vs* elements of the second-component matrix of a temporal IM model. On THEMIS, the second matrix contributes to 11% of the model.