MICADO Atmospheric Dispersion Corrector & Astrometry Study Review

On March 7, 2013 a review was held on the expected astrometric performance of MICADO, the *M*ulti-AO *I*maging *CA*mera for *D*eep *O*bservations, and the impact an Atmospheric Dispersion Corrector (ADC) might have on that performance.

The Review was convened in Dwingeloo by NOVA in order to develop insight into the feasibility to develop and build such ADC in the Netherlands under NOVA auspices. The insight is required by the NOVA Board for the discussion with the Instrument Steering Committee later this month.

The most pressing questions to be addressed by this review were:
- Can we build an ADC that meets the stringent requirements for MICADO astrometry?
- Is more study needed for such an ADC?

The review was attended by the Review Panel (Rudolf Le Poole, chair, and members Bernhard Brandl, Ric Davies, Mike Hartl and Josef Schubert), and Wilfried Boland, Eline Tolstoi, Gijs Verdoes Klein, Ramon Navarro, Lars Venema, Tibor Agócs, Remko Stuik,

Even after Gaia the science case is so impressive and exciting that it does not need to be addressed here.
During the review, the impact of adaptive optics on astrometric precision was discussed. All participants of the review agreed that this is an important issue that needs to be addressed in order to exploit the high performance of the ADC. The board urges both the MICADO consortium and NOVA members to consider how best to do this, including a continuation & extension of the analysis of MAD and GeMS data, as well as developing a more detailed description of the spatial and temporal power spectrum of distortions remaining in (MC-)AO corrected images.

This review focused on the significant component of the astrometric error budget which is given by the (time-variable) atmospheric dispersion, and in particular on how well that can be corrected by a well-designed and well-built ADC.
As target 10 µ-arcsec was retained as limit for ADC - induced defects in astrometric performance (after calibration and reduction). This degree of precision for the ADC is required in order to meet the 50µas total error budget.

The main question: ‘Is it realistic to design and build an ADC, that is required to achieve the targeted astrometric performance of MICADO?’ has led to a NOVA pilot study that was the main supportive evidence at the review. Its report ‘Achieving Full Astrometric Accuracy with MICADO and Requirements for the MICADO ADC’ was presented by its first author Remko Stuik with contributions of the co-authors Gijs Verdoes Klein and Ramon Navarro, and from Tibor Agócs.

Simulations were studied in parallel for two model ADC's, one located near an image plane close to the entrance window of MICADO, and one in a pupil plane in the AO system in front of MICADO. The possible locations not yet being well specified this was considered the best possible to develop insight in the achievable performance of an ADC for MICADO. Given the recently modified layout of MAORY it is presently not very clear whether the MICADO team has access to the pupil in MAORY in order to place an ADC; it might be possible that this must be remedied by inserting an ADC close to an image plane. The simulations were made for 'canonical values' for the atmospheric parameters (taken from a very representative day in July 2007, as available from the TMT site tests).

A discussion on the representativeness of these atmospheric parameters, and how well one would be able to adjust (drive the ADC) for the actual parameters made clear that these can be made known (by real-time measurements) with sufficient precision to reduce the impact of atmospheric dispersion to the ~1mas level. This is certainly enough for imaging purposes. The report also showed that an additional step, outlined below, is needed to reach the requirement for astrometry.

The impact of the two ADCs was simulated for optimally adjusted rotation of the ADCs. The imposed distortion of image geometry was evaluated as a function of zenith distance (up to 60 degrees) and as function of wavelength across the 4 bands (I, J, H, K). Both the distortions and the chromaticity thereof are about a factor 5 larger for the 'image plane' case than for the 'pupil plane' case.

To achieve the more precise performance given the specification, the study showed it would be necessary to perform post-processing of the observational data, making use of a physical model of the ADC that could, for a given set of atmospheric conditions (T, p, H) and the ADC status (T, rotation), predict the distortions from the ADC itself.

In some cases (especially shorter wavebands and higher airmasses), chromaticity would need to be accounted for in the physical model, but proper spectral typing of the targets "could in basically all cases reduce the resulting errors after proper correction to less than 10 micro arcseconds

Temperature proves rather a significant contributor possibly making thermal control of the ADC a valuable solution.
The temperature dependent part of distortions can amount to as much as 10 μ arcsec per degree Kelvin. The worry extends of course also to thermal influence on atmospheric parameters. However it is agreed that these effects can be modeled. Separate well placed thermometers (and barometers and hygrometers for that matter) should certainly help define corrections on the deviations from 'nominal deformations' to a lot better than required. Dynamic modeling of the temperature distribution in the ADC is recommended.

Finally also ‘make’ errors were evaluated for their impact on the description of the distortions, proving an influence that must not be overlooked. In particular wedge errors on the prisms may likely require that the rotation of the 2 prisms can be optimized independently rather than ‘just identical but opposite’ as was put into the simulations. Last minute simulations of this aspect proved that these 2 independent rotation angle optimizations could bring back the targeted residual spectral defects to below 100 micro arcseconds! In fact the make errors prove so significant, that both refined tolerancing and tests on the ‘as made’ parameters of the components need careful attention in the forthcoming developments.

Imaging:
It should be noted, that all the above described ‘defects’ all stay well below the size of the PSF at all (instantaneous) times. So only very long exposures (not foreseen, certainly not at full bandwidth) could possibly see slight PSF enlargements. Phrased differently: the imaging performance of the ADCs studied will be close to perfect.

All the considerations above lead to the following **conclusions**:

- The study team have performed a very informative study in a short time, which highlighted some key issues in designing and using an ADC to correct for atmospheric dispersion at the level of the relative astrometric precision required for MICADO. The top level conclusion of the study, with which the board concurs, is that no fundamental show-stopper has been identified, and it appears feasible to design and operate an ADC within the required error budget.

- It is premature to foresee today how much remaining ‘noise per unit time’ will limit the ultimate astrometric accuracy that can be reached by ‘regular observations’ after the break-in period of MAORY/MICADO. However we did not identify any trouble sources that will prevent sqrt(time) to bring in precisions of order few 10’s of μ arcseconds or even better.

- In the demonstration by simulation of expected performance of ADCs, even the very sub-optimally located ‘near image plane’ case there remained no identifiable showstoppers to aim wholeheartedly for final achievable precision of astrometry at the level of a few 10’s of μ arcseconds.

- For the latter ‘hopes’ to become reality a full design study seems indicated, where system analysis and detailed tolerancing shall help define possible difficulties and their mitigation.

- The start of such design study shall only marginally predate a new and complete definition of the interface with MAORY and ESO.

This brings us to the following **recommendations**:

- prior to allocating funds for the construction of an ADC, a design study to a 'Phase A level' for such a device (and its control strategy) as indicated in the conclusions above should be set up.

- As part of the process of developing a design, the following points (which could not be addressed within the restricted scope of the pilot study) should be specifically addressed: an intrinsic performance analysis (eg. impact of field rotation on distortion pattern); approach to performance verification; realistic opto-mechanical tolerances (sensitivity, feasibility, cost); optimization of the ADC (wrt materials, optical system, observing strategy, etc); trade-off of temperature modeling vs stabilization.

- Similarly, renewed simulations should be made in order to understand in more detail the feasibility of the physical model, which is so central to achieving the precision required. This should specifically include: how well a physical model can match the actual distortion induced by the ADC (including manufacturing tolerances, simplifications about the atmosphere, impact of uncertainties & errors); the effort required to implement such a model.

- MICADO includes a spectroscopic capability that will simultaneously cover a wavelength range of 0.8-2.5µm. It is not intended that the ADC be optimized for this, but it would be useful for the instrument design to understand to what level the ADC can correct such a broad wavelength coverage simultaneously.

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