Mem. S.A.It. Vol. 86, 450

Memorie della

Global (Multi Conjugated) Adaptive Optics and beyond

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Abstract. Multi Conjugated Adaptive Optics is nowadays a well established achievement marked by the short-lived MAD at the VLT, although it still lacks the benefits of being employed in instrumentations at 8m class telescopes, with the sole exception of GeMS at GEMINI. While the next obvious extension of MCAO is reppresented by GMCAO that is briefly described, I speculate on which could be the areas where development is needed or where some outstanding achievement could have the chance to make a further leap, if not a novel revolution, in the field of ground based astronomical instrumentation.

1. Introduction

MultiConjugated Adaptive Optics (MCAO) is a technique that has been introduced (Beckers 1989; Ellerbroek 1994) with the aim of solving one of the classical problems plaguing conventional Adaptive Optics (AO), namely the very limited size of the isoplanatic patch, where a significant correction can be achieved with the adoption of a single corrector, generally a Deformable Mirror (DM). MCAO, employing more than a DM, turned from concepts to drawings and then to reality (Marchetti et al. 2005; Rigaut et al. 2014; Neichel et al. 2014), both using conventional star-oriented wavefront sensing and three-dimensional wavefront sensing (Ragazzoni et al. 2000) employing multiple refractive pyramids (Ragazzoni 1996). References used has been both Natural Guide Stars (NGSs) and Laser Guide Stars (LGSs). It is remarkable that such a process encompassed more than two decades and, although we are supposed (and in fact we -as the Italian astronomical community working in the AO field- have done that) to write history rather than to limit ourself to read it (or to define the way, rather than to follow it, following Spyromilio's thoughts explained in this workshop), the next accomplishment -whatever it will look like- is likely to take a similar timescale. Furthermore, as conventional AO took then a similar time scale to evolve from technical experiments (and remarkable technical achievements, although on the sky) to real breaking astrophysical science, a similar process is going to take place in such augmented Field of View (FoV) approach. It is remarkable, in this context, the extremely productive outcome of MAD (Marchetti et al. 2008; Ragazzoni et al. 2008), offered in shared risk for a very limited amount of time, like a sample of a possible revolution that is still short to materialize. Global (MultiConjugated) Adaptive Optics, or GMCAO is just an extension of this and other techniques with the aim to correct a significant, but relatively small FoV, using however reference stars from a much larger surrounding patch in the sky. Although this is the proper technical definition, the strategic aim behind should be similarly clear, that is to attain a significant sky coverage with significant performances without the need for LGSs, ruling out the drawbacks in terms of cost, complexity and operability linked to the latter.

2. GMCAO state of the art

The basic idea behind GMCAO is that achieving a certain performance over a defined FoV will require more and more DMs as the corrected FoV gets larger. Once the effect of a DM are in some way "applied" to the WFS, these will "see" a compensated turbulence and the whole system will obey to the normal MCAO rules, while of course the correction is not actually being applied. This led to two concepts:

– The Virtual Deformable Mirrors, that are basically numerical realizations of what a physical DM should apply, and to apply this WF deformation to the outcome of the WFS. This however will lead the WFS not to work anymore around zero, not to be strictly in closed loop.
– This led to the introduction of the Very Linear (VL) WFS that is essentially some locally closed loop system that works only to the reference NGS taken into consideration. The dynamic range of the VL-AO is then dictated by the stroke of the employed local DM, and the sensitivity of the AO system is the one defined by the closed loop operation (so that, for instance, the well known gain of the Pyramid WFS in closed loop is retained (Ragazzoni & Farinato 1999).

The combination of these two concepts allow to describe a GMCAO system with the well known simulation techniques (Arcidiacono et al. 2004) used for the conventional MCAO approach. While GMCAO performances are described elsewhere we recently focussed on some astrophysical quantities that could be retrieved by such a system. Morphology of Galaxy cluster is one of the possible examples and work is being carried out through somehow detailed end-to-end simulations prodcuing synthetic frames as they would be collected by a GMCAO assisted E-ELT and assessing morphology statistics to evaluate the perturbation due to the imperfect AO correction.

3. What is beyond?

Future prediction is historically -and will remain forever- a difficult and mined field. So, while it would be pathetic to predict the future other than the two obvious and self-referencing contradicting statements (namely the first being "future will evolve much faster than any prediction" and the second being just the opposite statement) that turn out in retrospective to be always true to some extent (a very contorted way to say that predictions was wrong) I will try to point out four areas in which development could come (and in some I believe it will...) and that, if such a significant progress will happen, the probability that this would lead to a further deep change in the way we perform astronomical observations from the ground can be at hands.

3.1. Toward the ultimate wavefront sensing sensitivity

Do we actually reached the ultimate in terms of sensitivity of wavefront sensing? This parameter will define capabilities of AO systems in future, even when LGSs assisted, given the amount of efforts per return photons that has been well understood in the last times. On the NGS side there is plenty of proof that current WaveFront sensing does reach the optimum using constraints like the Heisenberg uncertainty principle, a notion that should lead us to think we are already very close to the ultimate limit. On one hand detectors with strictly zero Read Out Noise (RON) and no augmentation of Poissonian photon shot noise are getting closer, but we are still not there. A number of superconductive detectors that could become reality in the next decade and that promise to offer inherent spectral capability are still unemployed in WaveFront Sensing. Furthermore there are indications in other fields, especially in experimental quantum mechanics using just conventional light's photons, that there are areas where some research is doable. As we can "see" objects without actually having light hitting it (or, better, with such an amount of light vanishing toward zero) why should not it be possible to use the same concepts in order to make a giant (or just significant) leap in the ratio between photons required and information collected? So far the achievements obtained in recent times did not attack such a point, but just redistribute photons in a much smarter way. On the LGSs side the realm of possible actions is even larger. LGSs are so much different from point sources that rarely this has been used as a resource rather than a problem to overcome "massaging" data obtained in conventional way. The short lived era of z-invariant class of wavefront sensing is an example that still lacks to be completely explored.

3.2. Exploring the $S \approx 1$ era

If you look at any AO paper in the pre-XAO (or if you want in the pre-"pyramid fully achieved") era you will note that a reasonably good Strehl was of the order of $S = 0.3$. Furthermore, very often sky coverage is defined as the conditions allowing to achieve at least half of the full performance AO. In this case this would translate to a minimum achieved $S \approx 0.15$ that, just less than a decade ago, was regarded as a good and significant compensation of the turbulent atmosphere. While this has some meaning and will likely still have it in the ELTs era (the ratio of the peak to the halo becoming more and more strong with larger D/r_0) nowadays Strehls approaching the unity becomes conventional figure, not necessarily involving sophisticated exoplanetary instrumentation. Are we missing some ideas, concepts, or modes of operations assuming as paradigma that Strehl approaching the unity are routinely possible? The obvious example is represented by Wavefront Sensing that are plagues by wrap around effect, or that are based inherently on the amount of light falling in the central blob of the diffraction limited PSF, like several interferometric systems and the Smartt concept. Should we just revisit them reconsidering systems that have been discarded, or just labelled as unpopular, because getting a one order of magnitude smaller Strehl than the ultimate one was just requiring such vigorous achievement leaving these devices in the realm of academic ones, or should we explore in a much wider way in order to figure out if there are new, totally unexplored, ways or concepts that should take advantage of such a regime?

3.3. Engineering the PSF

For a combination of practical and fundamental reasons (galaxies at large z never shrink below a certain angular size), a PSF in which most of the energy is confined to a region of the order of 0.1arcsec (much smaller than tha average seeing, but also significantly larger than the diffraction limit of any next generation Extremely Large Telescope) would lead to a number of applications, especially in spectroscopy. Of course an obvious way to reach such a goal is to deploy a fully performant AO system and then to degrade artificially the PSF in order to match the requirement. This would be very inefficient way to achieve such a result. Partial AO is much less demanding both from the technical (number of actuators, size of the fast detector employed for the wavefront sensing) and fundamental (brightness of the reference, angular distance from the target, etc.) point of view. An AO approach in which a kind of partial AO, especially if this would translates into a much simpler apparatus able to work with relatively faint reference stars, leads to a sort of degraded PSF in a way that can be artificially engineered, would translates into a sort of "must" for AO assisted spectroscopy, at least in the extragalactic field. While we should recall that for 8m class telescopes the gain cannot be too much, for the ELTs there is no fundamental reason why such a concept could not exists. In principle some kind of WFS able to sense directly modes (these do exist) focusing on high order ones rather than to the low order, could suffice to the problem, but we are still missing a sort of practical way to achieve such a result in a more simple, direct and effective manner.

3.4. Correcting while going through

After an encouraging enthusiasm (and even some commercially available devices) with Liquid Cristal Devices (LCDs) as bi-dimensional digitally adressable wavefront retarder, the notion of flattening a distorted light wavefront has been left to different kinds of mirrors, such that is nowaday natural to assume that a compensating device is actually just a DM. There is no reason this should be the only available technology but today this is the case. Chromaticity and relatively low speed made the LCDs not of practical interest anymore, at least in the astronomical field and, coupled with the domination of the "till-today" era of NIR AO the concept of a "going through" wavefront compensator is probably not even being attacked in our laboratories. However the potential revolution offered by the development of such a futuristic device is paramount. Retrofitting existing telescopes and astronomical instrumentation would become one or two orders of magnitude simpler than what is currently required. MCAO with much more than 2 DMs, ops... I mean compensators, would become possible and viable. A white light fast and effective technology for such a device is non existing at the moment, maybe just because we are missing the right concept. Any successfull brain storming on the topic would have the chance to change the way we look at the AO into astronomy with respect to how we see it today. The recent experience on voice-coil actuated facesheet DMs (or Adaptive Secondary Mirror, ASM, as they are historically referred to sometimes) would explain us that the change of a paradigma on this topic is doable with the proper idea and a stubborn profusion of resources into the subject.

4. Conclusions

In order to have new answers you need new questions. AO, and especially wide field AO, whatever references are used, open such an uncharted territory in the parameter's space that is more likely to be short of answers rather than of questions. I just listed four challenges but several similar (and longer) lists could be formed. Remaining aligned with the spirit of the Spyromilio's thoughts as depicted during this workshop, we should avoid to focus solely on the engineering side of the existing concepts, but to create new engineering challenges to turn into reality novel concepts and new ideas. In the long term we risk to make a great leap and to avoid leaving dozens of engineers unemployed in the post ELTs era. Although this social perspective is here just speculative and provocatory, such a development would be extremely productive and requires today probably little more than human investment.

Acknowledgements. I am grateful to the whole AO Team that is working with me for the numerous, endless and fruitful discussions, including Maria Bergomi, Federico Biondi, Marco Dima, Jacopo Farinato, Marco Guilleuszik, Davide Greggio, Demetrio Magrin, Luca Marafatto, Elisa Portaluri, Valentina Viotto, and to the ESO and LBT colleagues for the uncountable discussions on the topic.

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