AO Tomography Workshop

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UK Astronomy Technology Centre

Royal Observatory

Edinburgh

Name	Affiliation	Presentation Title	Abstract
Dr. Nazim Bharmal	University of Durham	Introduction to AO tomography	This will be an overall introduction to tomography in AO, covering the various types and approaches with a bias towards astronomy but also opening up towards other disciplines.
Ms. Daniela Saxenhuber	Industrial Mathematics Institute JKU Linz	Fast iterative reconstruction methods in atmospheric tomography	Authors: Andreas Obereder (MathConsult GmbH), Ronny Ramlau (Industrial Mathematics Institute JKU Linz), Daniela Saxenhuber (Industrial Mathematics Institute JKU Linz) ELT AO systems have demanding computational requirements and depend on a sufficient reconstruction of the turbulence profiles in order to obtain a good correction. Due to steadily growing telescope sizes, there is a strong increase in the computational load for atmospheric reconstruction with current methods, first and foremost the MVM. The main goal of the novel iterative reconstruction methods presented in this talk is the comparability with the MVM method in quality as well as a significant reduction of computational cost. Instead of using one big matrix-vector system, one can decouple the problem in 3 steps: the reconstruction of the incoming wavefronts, the reconstruction of the turbulent layers (atmospheric tomography) and the computation of the best mirror correction (fitting step). The first step of this 3-step approach can be solved by the CuReD algorithm already tested on sky. For the atmospheric tomography problem, the Kaczmarz algorithm, the Gradient-based method and the CG method have been developed. These iterative reconstruction algorithms scale linearly and are, furthermore, highly flexible and well parallelizable. We will present quality results of our algorithms for the E-ELT setting on OCTOPUS, the ESO end-to-end simulation tool.
Mr. Mykhaylo Yudytskiy	Johann Radon Institute for Computational and Applied Mathematics (RICAM)	A finite element-wavelet hybrid algorithm for atmospheric tomography	Many of the next generation adaptive optics (AO) systems, such as the multi conjugate adaptive optics (MCAO), laser tomography adaptive optics (LTAO) and multi object adaptive optics (MOAO) depend on a sufficient reconstruction of the turbulence layers in order to obtain a good correction. As the dimension of these systems grows, current state of the art methods for atmospheric reconstruction become computationally heavy. In this talk we present the finite element-wavelet hybrid algorithm (FEWHA), an iterative approach, which combines wavelet-based techniques and conjugate gradient schemes to efficiently solve the problem of atmospheric tomography. The aim of our approach is to keep the qualitative performance of currently used methods, such as the MVM, but significantly reduce the computational cost. We present results of our algorithm with respect to quality in terms of numerical simulations on OCTOPUS, the ESO end-to-end simulation tool. Additionally, we present the speed results of our method compared to the MVM on an off-the-shelf computing system. This is a joint work with T. Helin and R. Ramlau.
Dr. Miska Le Louarn	ESO	Tomography simulations at ESO	In this talk, I will present the latest simulation results of tomography at ESO, in the framework of the E-ELT. I will focus on the impact of the Cn2 profile (both input in the simulation and reconstructed) and also present some early results on tip-tilt tomography.

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Mr. Juan Manuel Trujillo Sevilla	University of La Laguna	Tomographical application of CAFADIS plenoptic sensor	Modern MCAO systems used to be composed by several wavefront sensors working together feeding simultaneously several deformable mirrors. Consequently, the management of the adaptive system gets cumbersome: individual sensor callibration , loss of reference light due to the several beam splitters needed, bigger computation needed, ... In this work the plenoptic sensor is presented as an individual, compact and simple solution to get the tomographical distribution of turbulence layers in the atmospheres over the telescopes. Previous results related with plenoptic wavefront sensor have demonstrated it can be used to obtain depth distribution of a laser guide star(LGS) in real time, the wavefront phase maps at telescope's pupil (real data) and the tomographical turbulence ditribution using several natural guide stars (NGS). Here we present also the use of the plenoptic sensor to measure the tomographical wavefront distribution when an extended object is used as reference and science object at the same time. We also present, as an outside of AO application, our simulations on lightfield microscopy using a 3D transparent object composed by different reffraction index.
Mr. Yoshito Ono	Tohoku University	Numerical simulation of a new tomographic reconstruction method for wide FoR MOAO.	In order to increase the field of regard (FoR) of an Multi-Object Adaptive Optics (MOAO) systems, we propose a new tomographic reconstruction method. In the new method, we use atmospheric wind profiles and WFS measurements at previous time steps to increase the number of measured points of atmospheric turbulence for tomographic reconstruction. We will present the results of numerical simulation with the new tomography method applied to a 30m aperture telescope at Mauna Kea. The simulation shows the new method can achieve wave front error of 190 nm rms up to FoR of 5 arcmin and 250 nm rms up to FoR of 8 arcmin if we can estimate the wind direction and speed perfectly. In this new method, estimations of the wind direction and speed of each turbulence layer are necessary. We will also discuss the method to estimate wind direction and speed at each layer with the reconstructed atmospheric phases.
Dr. Aglae Kellerer	Durham University	Layer-oriented adaptive optics for solar astronomy	The future generation of telescopes will be equipped with multi-conjugate adaptive optical (MCAO) systems in order to obtain high angular resolution within large fields of view. MCAO comes in two flavors: star- and layer-oriented. Existing solar MCAO systems rely exclusively on the star-oriented approach. Adequate inference of the 3D turbulence from measurements along a few discrete directions is, however, a highly ill-conditioned problem, and large field-sizes are thus difficult to correct. The field size is therefore limited to approximately 60 arc seconds, while fields of several arc minutes are required to observe the formation and evolution of solar spots. I have recently proposed a layer-oriented approach for solar adaptive optics. In this approach, the wavefront distortions are averaged over a wide-field: the signal from distant turbulence is attenuated and the tomographic reconstruction is done optically. The main aim of this presentation will be to explain the proposed scheme in further detail.

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Dr. Matthias Rosensteiner	NRC Herzberg	The MCAO laboratory bench @ NRC Herzberg	NFIRAOS is the designated first light MCAO facility for the Thirty Meter Telescope. The MCAO laboratory bench at NRC Herzberg is a scaled down version of this instrument to support its development. The bench has four LGSs, three NGSs and two DMs. It includes several turbulence screens and can produce realistic spot elongation. The goals of the bench are the verification of the simulation predicting the performance of NFIRAOS; the development and demonstration of calibration procedures, correcting field-dependent Non-Common-Path Aberrations and PSF reconstruction; to test LGS tomographic Adaptive Optics under a variety of conditions. Further, the comparison of several tomographic reconstruction methods is anticipated. The bench is controlled via Matlab and is running at frame-rates between 1Hz and 15Hz.
Dr. Thomas Berkefeld	Kiepenheuer-Institut für Sonnenphysik	Tomography and first on-sky results of the MCAO at the 1.5m GREGOR solar telescope	The MCAO system for the 1.5m German solar telescope GREGOR has been installed at the telescope on Tenerife in November 2013, and, for the first time at a solar telescope, a control loop with 3 DMs has been closed successfully. The MCAO incorporates a tip tilt mirror and three DMs conjugated to 0, 8 and 25km which are the optimum heights for a typical Cn2-profile above Tenerife and a zenith distance of about 50-60 deg. Two correlating Shack Hartmann WFSs provide both the high spatial resolution required for sampling the strong ground layer turbulence (10cm subaperture size, 12 arcsec FoV) and the large field of view required for sampling the field dependent high altitude turbulence (50cm subaperture size, 19 field points covering the science FoV of 60 arcsec). The wavefront reconstruction that uses the data of the two WFSs to drive the three DMs is the key algorithm of the system. We present the system setup, the wavefront reconstruction scheme and first observational results.
Dr. Tim Morris	Durham University	Tomography with CANARY	CANARY is the world's only AO system dedicated to the investigation and characterisation of tomographic AO control. It has been performing tomographic AO correction on-sky since 2010 and is currently being upgraded to its final planned configuration containing four NGS WFSs, four LGS WFSs and two deformable mirrors, emulating the proposed MOAO configuration for the E-ELT. CANARY has provided a wealth of information and experience on how a tomographic AO system should (and should not) be designed and operated. Here we summarise and discuss the major issues affecting CANARY performance and how they can be addresed, during the system design, commissioning and operational phases.

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Dr. Benoit Neichel	Laboratoire d'Astrophysique de Marseille	Wide-Field Adaptive Optics for ground based telescopes: First science results and new challenges.	Over the 20 past-years, Adaptive Optics [AO] for astronomy went from a demonstration phase, to a well-proven and operational technique. Since the first astronomical AO systems were opened to the community in the early 1990s, numerous technical achievements have been accomplished, and it is now inconceivable to consider building a large telescope without AO. We are today at the beginning of a new step forward, with the birth of a revolutionary generation of AO systems called Wide Field AO [WFAO]. By using multiple Laser Guide Stars [LGS], WFAO significantly increases the field of the AO corrected images, and the fraction of the sky that can benefit from such correction. In this presentation, I will present GeMS, the Gemini Multi-Conjugate Adaptive Optics System, which is the first WFAO instrument offered to the community. After a brief review of the principles of AO and the extension to WFAO, we will see the first images and science results obtained by GeMS. Finally, we will see how instruments like GeMS are paving the way for the future generations of Extremely Large Telescopes [ELTs].
Dr. Alastair Basden	Durham	Mixed LGS/NGS tomographic real-time control using CANARY	I will present the real-time control system solution developed for the CANARY MOAO instrument, detailing experiences and lessons learned, what was done well, and what improvements could be made. The extension of this system to ELT-scale will be considered as well as future additions and modifications to allow pseudo-open-loop LTAO control and higher order operation.
Mr. Philip Rees	UK ATC	Welcome and Introduction	Local site specific information and an overview of the purpose of the OPTICON funding
Mr. Eric Gendron	Observatoire de Paris - LESIA	On-sky tomographic results and methods from the CANARY MOAO demonstrator	We will show results of tomographic compensation obtained on-sky with the CANARY MOAO demonstrator, using natural and laser guide stars. Using the on-sky data disengaged-loop, we are able to study the error breakdown and show that the terms are identical to simulations. We will focus on the decomposition of the tomographic error and study the reasons for errors in the model : varying Cn2(h) profile, uncertainty on layer positions, intrumental misregistration, etc.
Dr. Martin Booth	University of Oxford	Adaptive optics for microscopy	High resolution microscopy relies on the use of high quality optics with the goal of obtaining diffraction-limited operation. Yet in many cases this goal is not achieved as aberrations blur the focus and reduce the resolution and contrast of images. Aberrations can arise from imperfections in the optics, but are often introduced by refractive index variations in the specimen, particularly when imaging thick specimens. Adaptive optics was introduced into microscopy in order to overcome these problems. Various adaptive schemes have been developed for a range of different modalities including confocal, multiphoton and widefield microscopes with applications in the biological sciences and other areas. These methods are now being extended to more advanced methods in super resolution microscopes, which show greater sensitivity to aberrations. We will also consider some of the immediate challenges for adaptive microscopy, including anisoplanatic effects due to the complex structure of specimens.

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Dr. James Osborn	Durham University	On-sky validation of an Artificial Neural Network tomographic reconstructor with the Canary AO system	We present recent results from the initial testing of an Artificial Neural Network (ANN) based tomographic reconstructor (Carmen) on Canary, an Adaptive Optics demonstrator operated on the 4.2m William Herschel Telescope, La Palma. The reconstructor was compared with contemporaneous data using the Learn and Apply (L&A) tomographic reconstructor. We find that the fully optimised L&A tomographic reconstructor outperforms Carmen by approximately 5% in Strehl ratio or 15nm rms in wavefront error. We also present results for Canary in Ground Layer Adaptive Optics mode to show that the reconstructors are tomographic. The results are comparable and this small deficit is attributed to limitations in the training data used to build the ANN.