Adaptive Optics for the Extremely Large Telescopes

Third edition

May 26^{th} - 31^{st} 2013. Firenze, Italy

Graphic art by: Marco Dima

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Foreword

The first two editions of the Adaptive Optics for the Extremely Large Telescopes (AO4ELT) conference held in Paris (France) in 2009 and in Victoria (Canada) in 2011 were clearly successes in all aspects. This is the third edition (AO4ELT3) taking place in in Florence (Italy) from May 26^{th} to May 31^{st}, 2013. The conference is organized by the Arcetri Astrophysical Observatory with support from LESIA (Paris Observatory).

The design of AO systems and related instrumentation for the planned ELT's has been strongly pursued over the last two years. The AO4ELT3 conference aims at gathering specialists to review and discuss the latest developments of the ELT's current design in terms of AO systems, related instruments and science goals. At the same time the conference will report on pathfinder projects planned or implemented on existing telescopes, including solar telescopes, which provide relevant results for the next ELT's design phase. Special attention will be given to key components and new ideas that have the potential to overcome the limitations of existing systems, in order to increase the scientific impact of the future ELT's.

More information about the conference can be found at:

`http://ao4elt3.sciencesconf.org`

The conference chairs:

Simone Esposito, Yann Clénet, Thierry Fusco, Norbert Hubin, Jean-Pierre Veran

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Topics

1. **ELT astronomy with AO**
2. **AO systems for ELTs**
3. **AO pathfinders and new ideas**
4. **AO numerical simulations and modeling**
5. **Wave-front sensing**
6. **Wave-front correctors**
7. **Laser guide star systems**
8. **System control and algorithms**
9. **Atmospheric turbulence and AO disturbance**
10. **Data post processing and optimization**

AO4ELT3 Timeline

Sunday May 26^{th}

15:00 **Registration & Poster setup**
18:00

18:00 **Welcome reception**

Monday May 27th

8:30	**Welcome**	
	ELT Astronomy with AO - I *[Chair: L. Simard]*	
8:40	Gael Chauvin	**The EELT View of the Circumstellar Environments [I]**
9:10	Isobel Hook	**The high redshift universe and cosmology [I]**
9:40	Giuseppe Bono	**A selection of science cases for the European ELT [I]**
10:10	Matthias Schoeck	Developing Performance Estimates for High Precision Astrometry with TMT
10:30	**Coffee Break**	
	AO systems for ELTs - I *[Chair: R. Davies]*	
11:00	Antonin Bouchez	**Preliminary Design of the Giant Magellan Telescope Adaptive Optics System [I]**
11:30	Brent Ellerbroek	**Adaptive Optics for the Thirty Meter Telescope [I]**
12:00	Remko Stuik	The two faces of the METIS Adaptive Optics system
12:20	Emiliano Diolaiti	Overview of the E-ELT MCAO module project
12:40	**Lunch**	
	AO pathfinders & new ideas - I *[Chair: B. Ellerbroek]*	
14:00	Benoit Neichel	**GeMS first science results [I]**
14:30	Tim Morris	**Multiple Object Adaptive Optics: Mixed NGS/LGS tomography [I]**
15:00	Markus Hartung	Final A&T stages of the Gemini Planet Finder
15:20	Norbert Hubin	The ESO Adaptive Optics Facility under Test
15:40	**Coffee Break**	
16:00	**Poster session**	
	Data post processing and optimization *[Chair: E. Diolaiti]*	
17:00	Olivier Martin	From CANARY to ELT: lessons learned in open-loop tomography
17:20	Frantz Martinache	Super resolution imaging with an ELT: Kernel-phase interferometry
17:40	Damien Gratadour	Practical issues with phase diversity for NCPA compensation resolved on the CANARY demonstrator
18:00	Laurent Jolissaint	PSF reconstruction for W. M. Keck and Gemini-North AO systems: practical experience with static aberration estimation using phase diversity on sky images, and last PSF-R results on Altair

Tuesday May 28th

Laser guide star systems *[Chair: F. Rigaut]*

8:30	Paul Hickson	**Properties of the mesospheric sodium region that impact AO [I]**
8:50	Andrei Tokovinin	GLAO in the visible, the SAM experience
9:10	Chadwick Trujillo	Altair at Gemini North: Full Sky Coverage Laser AO Correction at Visible Wavelengths
9:30	Ronald Holzloehner	Larmor-resonant Sodium Excitation for Laser Guide Stars
9:50	Thomas Pfrommer	Horizontal structure of mesospheric sodium
10:10	Sebastian Rabien	Performance Evaluation of Refocussed and Uplink Corrected Laser Guide Stars
10:30	Steffan Lewis	Upgrade of the ESO Laser Guide Star Facility
10:50	**Coffee Break**	

AO numerical simulations and modeling - I *[Chair: R. Conan]*

11:20	Christian Marois	Exoplanet Imaging with TMT: A Complete End-to-End TMT/NFIRAOS/IRIS Fresnel Simulation and a New LOCI SSDI Algorithm
11:40	Brent Ellerbroek	Evaluation of Astrometry Errors due to the Optical Surface Distortions in Adaptive Optics Systems and Science Instruments
12:00	Luc Gilles	Laser guide star Fourier tomography on extremely large telescopes
12:20	S. Mark Ammons	On-Sky Pathfinder Tests of Calibrated MCAO Astrometry and Implications for MCAO on ELTs
12:40	**Lunch**	

AO pathfinders & new ideas - II *[Chair: Y. Clénet]*

14:00	François Rigaut	**LGS MCAO systems experience in light of the ELTs [I]**
14:30	Olivier Guyon	**High Contrast Imaging: New Techniques and Scientific Perspectives for ELTs [I]**
15:00	Thierry Fusco	Integration of SAXO, the VLT-SPHERE eXtrem AO : final performance and lesson learned
15:20	Richard Dekany	First exoplanet and disk results with the PALM-3000 adaptive optics system
15:40	**Coffee Break**	
16:00	**Poster session**	

System control & algorithms - I *[Chair: R. Stuik]*

17:00	Enrico Fedrigo	**Trends on real time control for adaptive optics [I]**
17:30	Damien Gratadour	Building a reliable, scalable and affordable RTC for ELTs AO instruments
17:50	Ronny Ramlau	Fast iterative reconstructors for MCAO, MOAO and LTAO
18:10	Jean-Pierre Véran	NFIRAOS Real-Time Controller Trade Study

Wednesday May 29th

AO pathfinders & new ideas - III *[Chair: A. Bouchez]*

8:30	Armando Riccardi	**Adaptive telescope pathfinders for the ELTs: MMT, LBT, Magellan and VLT [I]**
9:00	Laird Close	**Into the Blue: AO Science in the Visible with MagAO and ELTs [I]**
9:30	Friedrich Woeger	**ATST and Solar AO state of art [I]**
10:00	Fabrice Vidal	GeMS: from the on-sky experimental system to science operation. The AO point of view.
10:20	**Coffee Break**	

Wave-front sensing - I *[Chair: T. Fusco]*

10:50	Philippe Feautrier, Gert Finger	**Visible and Infrared Wavefront Sensing detectors review [I]**
11:30	Jean-Pierre Véran	Improved tilt sensing in an LGS-based tomographic AO system
11:50	Cedric Plantet	On-sky validation of the LInearized Focal-plane Technique on GEMS
12:10	Simone Esposito	Natural Guide Star WFS for the GMT Preliminary Design
12:30	Baptiste Paul	COFFEE: Coronagraphic phase diversity improvements for high-order quasi-static aberrations compensation. Application to the SPHERE system
12:50	**Lunch**	

Atmospheric turbulence & AO disturbances *[Chair: M. Schoek]*

14:00	Elena Masciadri	MOSE: a feasibility study for the prediction of the optical turbulence and meteorological parameters at Cerro Paranal and Cerro Armazones
14:20	Angela Cortes	Analysis of the frozen flow assumption using GeMS telemetry data
14:40	Jean Marc Conan	Cn2 profile reconstruction with Shack-Hartmann slope and scintillation data: first on-sky results
15:00	Marc Sarazin	Defining reference turbulence profiles for E-ELT AO performance simulations
15:20	James Osborn	Stereo SCIDAR: Profiling atmospheric optical turbulence with improved altitude resolution
15:40	**Coffee Break**	

ELT Astronomy with AO - II *[Chair: C. Max]*

16:00	Giuliana Fiorentino	The space motion and stellar content of Galactic satellites seen with GeMS/GSAOI
16:20	Jacques Beckers	Adaptive Optics for the 8 meter Chinese Giant Solar Telescope
16:40	Philip Hinz	The LBT Interferometer: a high-resolution, high-contrast imager for a 23 m telescope
17:00	Sylvana Yelda	Astrometry in the Galactic center with TMT
17:20	Niranjan Thatte	HARMONI: the E-ELT's AO assisted first light integral field spectrograph

Wednesday May 29^{th} *(Continued)*

18:30
Visit to Palazzo Corsini
20:00

20:00
Social Dinner
23:00

Thursday May 30^{th}

AO systems for ELTs - II *[Chair: B. Neichel]*

8:30	Norbert Hubin	**Toward the Adaptive Optics for the 40 m class European ELT [I]**
9:00	Roberto Ragazzoni	Global MCAO aiming to the (whole) sky
9:20	Brian McLeod	The phasing system for the Giant Magellan Telescope
9:40	Thierry Fusco	The AO modes for HARMONI: from classical to Laser-assisted tomographic AO systems
10:00	Markus Kasper	Roadmap for PCS
10:20	Rodolphe Conan	Laser Tomography Adaptive Optics for the Giant Magellan Telescope
10:40	**Coffee Break**	

Wave-front correctors *[Chair: G. Herriot]*

11:10	Elise Vernet	The E-ELT M4 Adaptive Unit
11:30	Paul Bierden	MEMS Deformable Mirrors for Advanced AO Instrumentation
11:50	Daniele Gallieni	The new VLT-DSM M2 unit: construction and electro-mechanical testing
12:10	Runa Briguglio	Optical calibration and test of the VLT Deformable Secondary Mirror
12:30	**Lunch**	

Wave-front sensing - II *[Chair: M. Kasper]*

14:00	Thierry Fusco	Lab demonstration of the Zernike phase mask near-coronagraph quasi static aberrations sensor, ZELDA
14:20	Valentina Viotto	A study of Pyramid WFS behaviour under imperfect illumination
14:40	Olivier Guyon	Putting the non-linear Curvature Wavefront Sensor on the 6.5m MMT telescope
15:00	Fernando Quiros-Pacheco	Pyramid wavefront sensor performance with laser guide stars
15:20	Jean-Luc Gach	First results of a 2000+ frame per second OCAM2
15:40	**Coffee Break**	
16:00	**Poster session**	

AO numerical simulations and modeling - II *[Chair: J.P. Véran]*

17:00	Marcos van Dam	Wavefront Reconstruction for a Natural Guide Star Ground Layer Adaptive Optics System on the Giant Magellan Telescope
17:20	Hugh Thompson	Development and validation of vibration source requirements for TMT to ensure AO performance
17:40	Clémentine Béchet	Modeling wide-field wavefront sensing in solar adaptive optics and its effect on tomographic reconstruction
18:00	Manal Chebbo	Fast E2E simulation tools and calibration strategies for EAGLE on the E-ELT

Friday May 31st

ELT Astronomy with AO - III *[Chair: N. Thatte]*

8:30	Luc Simard	**Exploring the Full Cosmic Timeline with TMT [I]**
9:00	Patrick McCarthy	**Scientific Promise and Status of the Giant Magellan Telescope Project [I]**
9:30	Mathieu Puech	Simulations of high-z galaxy observations with an E-ELT/MOS
9:50	Jessica Lu	Astrometry with the Gemini Multi-Conjugate Adaptive Optics System
10:10	Fraser Clarke	High resolution science with SWIFT and PALM3K
10:30	**Coffee Break**	

System control & algorithms - II *[Chair: R. Myers]*

11:00	Mykhaylo Yudytskiy	Fast wavefront reconstruction with wavelet regularization for MCAO
11:20	Lianqi Wang	Design and Testing of GPU based RTC for TMT NFIRAOS
11:40	Niek Doelman	Reliable optimal control for ELT AO systems
12:00	Richard Myers	Real-time control system verification for ELT AO systems
12:20	Iuliia Shatokhina	P-CuReD – a fast wavefront reconstruction algorithms for XAO with pyramid WFS
12:40	**Lunch**	

AO pathfinders & new ideas - IV *[Chair: N. Hubin]*

14:00	S. Mark Ammons	Fourier-Based Predictive AO Schemes for Tomographic AO systems on ELTs
14:20	Gaetano Sivo	First on-sky validation of full LQG control with vibration mitigation on the CANARY MOAO pathfinder
14:40	Derek Kopon	Laboratory results and status update for Pathfinder, the LINC-NIRVANA ground-layer AO subsystem
15:00	Yutaka Hayano	Wide field adaptive optics and near-infrared instrument for Subaru Telescope
15:20	Katie Morzinski	Overview of High-contrast O/IR imaging with Magellan AO: Simultaneous images of an exoplanet host star with VisAO and Clio
15:40	Pierre Haguenauer	Adaptive Phase-Mask Coronagraph

List of Abstracts

1 ELT astronomy with AO

Invited

The high redshift universe and cosmology

Invited - N: 14217

Isobel Hook[1]

[1] University of Oxford

The ELTs, assisted by adaptive optics, will revolutionise observations of the high redshift universe. Using examples taken primarily from the science case of the E-ELT, this talk will cover prospects and requirements for studying distant galaxies and point sources at cosmological distances including gamma ray bursts, quasars and supernovae. The impact these observations will have on cosmology and our understanding of the early universe will be discussed.

A selection of science cases for the European ELT

Invited - N: 16374

Giuseppe Bono[1]

[1] Università di Roma Tor Vergata

We present a selection of science drivers for the European ELT. We will focus our attention on science cases connected with the two first light instruments (E-ELT CAM, E-ELT IFU). We will also discuss a few experiments,dealing with stellar populations in the nearby Universe, that are planned using the first generation of E-ELT instruments.

Exploring the Full Cosmic Timeline with TMT

Invited - N: 16445

Luc Simard[1]

[1] National Research Council Canada

The extremely large telescopes will revolutionize our understanding of the Universe at all epochs of our cosmic timeline. Space-time geometry, dark matter, supermassive black holes, galaxies, planetary systems and ultimately life are all areas of research where transformational discoveries are expected. The Thirty Meter Telescope will be equipped with a powerful suite of adaptive optics systems and science instruments that seek to realize this exciting scientific potential. I will use specific examples to highlight the richness of the TMT discovery space going from the first stars in the Universe all the way to our own Solar System.

Scientific Promise and Status of the Giant Magellan Telescope Project

Invited - N: 16453

Patrick McCarthy[1]

[1] GMT

I will review the scientific goals of the GMT project and the current technical status. Adaptive Optics is closely woven into the GMT science case, through high resolution and sensitive observations of a broad range of astronomical systems. The GMT will advance our knowledge in a range of contemporary science goals - from exo-planet imaging to first-light studies. The diverse AO modes supported by GMT - NGSAO, LTAO, and ground-layer correction - will provide a variety of high image quality capabilities as well as spectroscopy with enhanced sensitivity and spatial resolution. The GMT AO system is built around adaptive secondary mirrors with high actuator densities and heritage in the MMT, LBT, and Magellan AO systems. Fabrication of 8.4m off-axis primary mirror segments, the largest technical challenge, has now been demonstrated, with one segment completed and two in production. Site preparation work at Las Campanas is complete and designs for the enclosure and support facilities are advancing towards final design and fabrication.

The EELT View of the Circumstellar Environments

Invited - N: 17033

Gael Chauvin[1]

[1] Laboratoire de Planétologie de Grenoble

Considering the fantastic perspective offered by the upcoming generation of instruments of the EELT, a new observing domain will be opened for the exploration of the circumstellar environment. After placing the E-ELT in the context of current and future instrumentation and space missions, I will first briefly summarize the main properties and expected performances of the six currently known E-ELT instruments. I will then highlight the most interesting science cases from the disk-star interactions processes, the proto-planetary and debris disk characterization, the detection and characterization of exoplanets and their atmosphere to the rich environment of evolved stars. I will particularly insist on the unique observing constraints that will be obtained with the E-ELT.

Oral

Simulations of high-z galaxy observations with an E-ELT/MOS

Oral - N: 12389

Mathieu Puech[1]

[1] Galaxies, Etoiles, Physique, Instrumentation

I will present simulated observations of two important science cases of the 39m E-ELT, ie, the mass assembly in galaxies over z=2-5 and the detection of very high-z galaxies. These simulations are currently used to constrain the top level requirements of MOSAIC, which is a new MOS concept for the E-ELT. MOSAIC largely builds on two E-ELT instrument phase A studies, namely EAGLE, an MOAO-fed NIR multi-IFU spectragraph and OPTIMOS-EVE, a GLAO-limited fiber-fed NIR spectrograph. I will give a short summary of the MOSAIC study and detail how galaxy simulations are currently used to constrain the instrument conceptual design, and in particular simulations of the detection of UV interstellar lines in very distant (i.e.: $z > 6$) galaxies.

Adaptive Optics for the 8 meter Chinese Giant Solar Telescope

Oral - N: 12527

Jacques Beckers[1], Zhong Liu[2], Yuanyong Deng[3], Haisheng Ji[4]

[1] University of Arizona
[2] Yunnan Astronomical Observatory
[3] National Astronomical Observatories
[4] Purple Mountain Observatory

Solar ELTs enable diffraction limited imaging of the basic structure of the solar atmosphere. Magneto-hydrodynamic considerations limit their size to about 0.03 arcsec. To observe them in the near-infrared 8-meter class telescopes are needed. The Chinese Giant Solar Telescope, or CGST, is such a NIR solar ELT. It is a Ring Telescope with 8-meter outer diameter and a central clear aperture of about 6-meter diameter. At present various options for such a Gregorian type telescope are under study like a continuous ring made of segments or a multiple aperture ring made of 7 off-axis telescopes. The advantages of such a ring telescope is that its MTF covers all spatial frequencies out to those corresponding to its outer diameter, that its circular symmetry makes it polarization neutral, and that its large central hole helps thermal control and provides ample space for MCAO and Gregorian instrumentation. We present the current status of the design of the CGST. Our thinking is guided by the outstanding performance of the 1-meter vacuum solar telescope of the Yunnan Solar Observatory which like the CGST uses both AO and image reconstruction. Using it with a ring-shape aperture mask the imaging techniques for the CGST are being explored. The CGST will have Multi-Conjugate Adaptive Optics (MCAO). The peculiarities of Atmospheric Wavefront Tomography for Ring Telescopes are aided by the ample availability of guide stars on the Sun. IR MCAO-aided diffraction limited imaging offers the advantage of a large FOV, and high solar magnetic field sensitivity. Site testing is proceeding in western China, (e.g. northern Yunnan Province and Tibet). The CGST is a Chinese solar community project originated by the Yunnan Astronomical Observatory, the National Astronomical Observatories, the Purple Mountain Observatory, the Nanjing University, the Nanjing Institute of Astronomical Optics & Technology and the Beijing Normal University.

Astrometry with the Gemini Multi-Conjugate Adaptive Optics System

Oral - N: 13274

Jessica Lu[1], Benoit Neichel[2], François Rigaut[3]

[1] Institute for Astronomy, Hawaii
[2] Gemini Obs.
[3] Australian National University

GSAOI and GeMS has the potential to be a premier facility for precision astrometry due to the powerful combination of high spatial resolution and a large field of view at infrared wavelengths. Potential astrometric science cases cover a broad range of topics including exo-planets, star formation, stellar evolution, star clusters, nearby galaxies, black holes and neutron stars, and the Galactic center. Many of these areas cannot be addressed with HST or GAIA astrometry

due to insufficient resolution or lack of sensitivity at infrared wavelengths. Astrometric precisions of < 1 mas over the full GSAOI 85" field of view will enable many new experiments in these areas that have not been efficient or even possible with existing ground-based AO systems due to their limited fields of view. Preliminary analysis of GSAOI data suggests that these astrometric precisions can be reached, (Rigaut et al., 2012)). In this paper we push this analysis with deeper images, multi-epoch data and distortion calibration. A first error budget for the astrometry is derived, and we discuss the current limitations and improvements for future ELTs.

HARMONI: the E-ELT's AO assisted first light integral field spectrograph

Oral - N: 13308

Niranjan Thatte[1], Matthias Tecza[1], Fraser Clarke[1], Ian Bryson[2], Hermine Schnetler[2], Roland Bacon[3], Santiago Arribas[4], Evencio Mediavilla[5], Thierry Fusco[6]

[1] University of Oxford
[2] United Kingdom Astronomy Technology Centre
[3] Centre de Recherche Astrophysique de Lyon
[4] Centro de Astrobiologia
[5] Instituto de Astrofísica de Canarias
[6] Office National d'Etudes et Recherches Aérospatiales

HARMONI is one of two instruments forming the E-ELT's first light suite. It provides the core spectroscopic capability at visible and near-infrared wavelengths (0.47 to 2.45 microns), over a range of resolving powers from R(=lambda/Delta_lambda)~4000 to R~20000. The instrument is an image slicer based integral field spectrograph, obtaining simultaneous spectra of ~32000 spatial elements arranged in a contiguous field. Spatial pixel scales will range from diffraction limited (4 milli-arcsec) to seeing limited (50 x 25 milli-arcsec), assisted by SCAO and LTAO. Each exposure will yield a data cube of 256 x 128 x 4000 pixels, the long dimension being spectral. HARMONI is conceived as a work-horse instrument, that will support a broad range of science programs. HARMONI will excel at ultra-sensitive, diffraction-limited, spatially resolved, physical, chemical and kinematic studies of astrophysical sources. I will present an overview of the instrument's capabilities, and highlight the issues pertaining to adaptive optics: calibrating static non-common path errors, knowledge of the PSF, scientific trade-off between spaxel scale and sensitivity, etc.

The space motion and stellar content of Galactic satellites seen with GeMS/GSAOI

Oral - N: 13351

Giuliana Fiorentino[1], Alan Mc Connachie[2], Peter Stetson[2], Giuseppe Bono[3], Paolo Turri[2]

[1] INAF - Osservatorio Astronomico di Bologna
[2] Herzberg Institute of Astrophysics
[3] Università di Roma Tor Vergata

We will present the preliminary results of a very ambitious survey of Galactic satellites using GeMS/GSAOI to measure the proper motions of all globular clusters and Milky Way dwarf galaxies visible from the southern hemisphere. We obtained about 11 hours of Canadian GTO to carry out a pilot program with GSAOI@GemS. This pilot project proposes to measure the proper motions of six GGCs in order to analyse their orbital properties and internal dynamics using rst-epoch imaging from HST archival data (5 to 10 years temporal baseline). This project will also provide the deepest, most homogeneous, near infrared (J, Ks) photometric dataset for Galactic satellites that exists. We will additionally conduct a full photometric analysis of the stellar populations of these systems, a critical step towards the exploitation of the NIR for stellar populations analysis in the era of next generation facilities like the Extremely Large Telescopes. As part of this study, we will also provide a full characterization of the photometric and astrometric performance of the GeMS Multi Conjugate Adaptive Optics facility, a key requirement for the future scientic development of this technology.

Developing Performance Estimates for High Precision Astrometry with TMT

Oral - N: 13356

Matthias Schoeck[1], Tuan Do[2], Brent Ellerbroek[3], Gilles Luc[4], Glen Herriot[5], Leo Meyer[6], Ryuji Suzuki[7], Lianqi Wang[3], Sylvana Yelda[6]

[1] TMT Observatory Corporation
[2] Dunlap Institute, University of Toronto
[3] Thirty Meter Telescope
[4] TMT Observatory Corporation
[5] National Research Council Canada
[6] University of California Los Angeles
[7] TMT Project Office, National Astronomical Observatory of Japan

Adaptive optics on Extremely Large Telescopes will open up many new science cases or expand existing science into regimes unattainable with the current generation of telescopes. One example of this is high-precision astrometry, which has requirements in the range from 10 to 50 micro-arc-seconds for some instruments and science cases. Achieving these requirements imposes stringent constraints on the design of the entire observatory, but also on the calibration procedures, observing sequences and the data analysis techniques. This paper summarizes our efforts to develop a top down astrometry error budget for TMT. It is predominantly developed for the first-light AO system, NFIRAOS, and the IRIS instrument, but many terms are applicable to other configurations as well. Astrometry error sources are divided into 5 categories: Reference source and catalog errors, atmospheric refraction correction errors, other residual atmospheric effects, opto-mechanical errors and focal plane measurement errors. Results are developed in parametric form whenever possible. However, almost every error term in the error budget depends on the details of the astrometry observations, such as whether absolute or differential astrometry is the goal, whether one observes a sparse or crowded field, what the time scales of interest are, etc. Thus, it is not possible to develop a single error budget that applies to all science cases and separate budgets are developed and detailed for key astrometric observations. Our error budget is consistent with the requirements for differential astrometry of tens of micro-arc-seconds for certain science cases. While no show stoppers have been found, the work has resulted in several modifications to the NFIRAOS optical surface specifications and reference source design that will help improve the achievable astrometry precision even further.

Astrometry in the Galactic center with TMT

Oral - N: 13371

Leo Meyer[1], Sylvana Yelda[1], Andrea Ghez[1]

[1] University of California Los Angeles

We report on our work that analyzes in detail the astrometry performance of TMT's NFIRAOS/IRIS at our Galactic Center, where stars in orbit around the supermassive black hole are ideal probes of the curvature of space-time as predicted by General Relativity. This has the potential to test Einstein's theory in an unprecedented regime. The simulations fall into several distinct stages: first, a single-epoch set of simulated images of the Galactic Center (GC) is analyzed with respect to astrometric precision. Second, several epochs of observations are simulated taking into account the kinematic properties of the different stellar populations that exist in the GC. Third, the construction of an absolute reference frame is simulated, and the precision with which post-Newtonian effects in the orbits of short-period stars can be detected is determined. We use spatially variable points spread functions (PSF) that have been computed for the specific guide star constellation at the GC. Read-out and photon noise, thermal background as well as a model of the static distortion for the IRIS imager and the quadratic probe arm distortion are taken into account.

The LBT Interferometer: a high-resolution, high-contrast imager for a 23 m telescope

Oral - N: 13397

Philip Hinz[1]

[1] University of Arizona

The LBT Interferometer is a diffraction-limited AO-fed instrument, designed to utilize the Large Binocular Telescope as a 23 m imager. The instrument leverages the common-mount and integrated AO design of the LBT to provide sensitive and sharp images at thermal infrared wavelengths. The instrument has several modes of operation including standard imaging, low resolution spectroscopy, nulling interferometry, and coronagraphy. These modes require the LBTI to operate using adaptive optics and phase stabilization between the apertures. In this sense, the LBTI is very similar in scope to possible instruments for the planned ELT's. Commissioning of LBTI is currently in progress. Dual aperture AO performance has been demonstrated. Testing of phase stabilization is currently underway. We will describe the status of LBTI and early science with the system.

High resolution science with SWIFT and PALM3K

Oral - N: 13428

Fraser Clarke[1], Niranjan Thatte, Matthias Tecza, Ryan Houghton, Richard Dekany, Burruss Rick

[1] University of Oxford

SWIFT is a visible light (650-1000nm) integral field spectorgaph fed by the Palomar extreme adaptive optics system PALM3K. With a subaperture spacing of 8cm, PALM3K is capable of delivering diffraction limited performance even in the visible. With SWIFT providing spatially resolved spectroscopy at R=4000, this provides a truly unique facility for high resolution science in three dimensions. We present results from the first year of PALM3K+SWIFT science, including solar-system moons, giant planet atmospheres and asteroid surfaces. We also present an on-sky analysis of the capabilities of image slicer based integral field spectrographs to deliver the high contrast post-processing qualities needed for exoplanet direct spectroscopy. PALM3K+SWIFT also provide valuable experience of operating a small field of view instrument (1"x0.5") with a high performance AO system, and the lessons learned will provide valuable input to designing succesful and productive AO+Instrument combinations for ELTs

Posters

Extrasolar Planet imaging exploiting the LBT AO system + Pisces camera

Poster - N: 13015

Dino Mesa[1]

[1] INAF-OAPD

In the next future new instruments for the imaging of extrasolar planets (like e.g. SPHERE at VLT or GPI at Gemini) will be available. At the moment however, one of the best opportunity to image extrasolar planets consists in exploiting the very effective AO system at LBT. Our observations (during the commissioning period at the end of 2011) of the HR8799 planetary system with LBT + the Pisces camera demonstrated our capability to perfectly image all the four planets around that star exploiting the Angular Differential Imaging method.Following these encouraging results, we began a program for the observation of stars with known IR excess. Results for two stars (HIP101800 and HIP85157) were obtained in June 2012. No obvious candidate was found and very strict constraints were put to the mass of possible companions around these targets.

The Large Binocular Telescope as an early ELT

Poster - N: 13167

John Hill[1,2], Philip Hinz[2], David Ashby[1]

[1] Large Binocular Telescope Observatory
[2] University of Arizona, Steward Observatory

The Large Binocular Telescope (LBT) has two 8.4-m primary mirrors on a common AZ-EL mounting. The dual Gregorian optical configuration for LBT includes a pair of adaptive secondaries. The adaptive secondaries are working reliably for science observations as well as for the commissioning of new instruments. Many aspects of the LBT telescope design have been optimized for the combination of the two optical trains. The telescope structure is relatively compact and stiff with a lowest eigenfrequency near 8 Hz. A vibration measurement system of accelerometers (OVMS) has been installed to characterize the vibrations of the telescope. A first-generation of the binocular telescope control system has been deployed on-sky. Two instruments, LBTI and LINC-NIRVANA, have been built to take advantage of the 22.65-m diffraction baseline when the telescope is phased. This diffraction-limited imaging capability (beyond 20-m baseline) positions LBT as a forerunner of the new generation of extremely large telescopes (ELT). We discuss here some of the experiences ofphasing the two sides of the telescope starting in 2010. We also report some lessons learned during on-sky commissioning of the LBTI instrument.

Observations of BL Lac objects and QSOs with MAD

Poster - N: 13263

Elisabetta Liuzzo[1], Renato Falomo[2], Aldo Treves[3,4,5]

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[4] INFN
[5] Università dell'Insubria - Como

We used new adaptive optics near-IR observations obtained with the ESO multi-conjugated adaptive optics demonstrator (MAD) at the Very Large Telescope to perform a morphological and photometric study of three peculiar BL Lac objects and six QSOs. In all cases, MAD allow us to obtain images with the highest angular resolution (~0.12 arcsec) available up to now for these sources in the NIR. At first, we will report on a detailed study of jet properties of PKS 2201+044, and PKS 0521-365 which are two of the only three BL Lacs exhibiting prominent optical jets. As multifrequency observations are fundamental to constrain the physics of AGNs relativistic jets, MAD images were combined with HST, VLA, and Chandra archival data. We found a noticeable similarity in the morphology of the jets at all wavelengths. We constructed the spectral shape of the main jet knots which appear mostly dominated by synchrotron radiation. Then, we will present MAD observations performed for PKS 2155-304, one of the brightest BL Lac object in the sky and a very well studied target from radio to TeV bands. The main aim was to investigate its radio and NIR jet and its close environment. Thanks to our NIR images, we characterized the faint galaxies that form the poor group associated to the target. No radio emission is present for these galaxies, while an old radio jet at ~20 kpc from the nucleus of PKS 2155-304 and a jet-like structure of ~2 kpc (~1 arcsec) in the eastern direction are revealed. No counterparts of these radio jets are found in the NIR or in archival Chandra observations. Finally, we will show our preliminary results on the NIR MAD photometry and environment of some QSOs with redshift between 2 and 4.

Solar Adaptive Optics System for 1-m New Vacuum Solar Telescope

Poster - N: 13295

Changhui Rao[1], Lei Zhu[1], Naiting Gu[1], Xuejun Rao[1], Lanqiang Zhang[1]

[1] Institute of Optics and Electronics, Chinese Academy of Sciences

The 1-m New Vacuum Solar Telescope (NVST), located at Full-shine Lake Solar Observatory, Kunming, Yunnan, is the largest solar telescope in China recently. A 37-elemnt low-order solar adaptive optics (AO) system had been developed and installed on the telescope in 2011, and AO-corrected high resolution solar images were obtained at wavelength 430.5nm, 705.7nm and 1555nm simultaneously. The low-order AO system can yield diffraction limited images only in the near infrared under good seeing and in the visible under excellent seeing, which cannot satisfy the requirement of Solar Physics study. A high-order AO system, which consists of a fine tracking loop with a tip/tilt mirror and a correlation tracker, and a high-order correction loop with a 127-element deformable mirror, a correlating Shack-Hartmann wavefront sensor and a real-time controller, is under development. A multi-conjugate adaptive optics (MCAO) experiments are also carried on the telescope. This paper summarizes the progress of the solar adaptive optics in China and presents the observational results of the low-order AO system. The design of the high-order AO system and MCAO experimental prototype are given.

The HARMONI SCAO system: science cases and main trade-offs for diffraction limited integral field spectroscopy at the E-ELT

Poster - N: 13342

Matthias Tecza, Thierry Fusco[1], Niranjan Thatte[2], Fraser Clarke[2], Hermine Schnetler[3], Harmoni Consortium

[1] Office National d'Etudes et Recherches Aérospatiales

[2] University of Oxford

[3] United Kingdom Astronomy Technology Centre

HARMONI is one of two first light instruments for the E-ELT. It is an adaptive optics assisted integral field spectrograph offering a range of spectral resolving powers and a range of spatial scales from unprecedented diffraction limited to seeing limited. Two adaptive optics systems are foreseen to be used with HARMONI: Laser Tomography AO (LTAO) with large sky coverage at moderate Strehl ratios of ~50%, and Single Conjugate AO (SCAO) offering 70-80% Strehl ratios using on-axis natural guide stars. In this paper we present a preliminary analysis of the SCAO science cases that led to the requirements for the HARMONI SCAO module as well as simulations and trade-offs of SCAO features. Among others this includes the size of the patrol field, whether to include a coronagraph and a atmospheric dispersion corrector, the limiting magnitudes of the guide star, and guiding on extended objects.

On the potential for visible diffraction-limited ELT astronomy around natural guide stars

Poster - N: 13401

Richard Dekany[1]

[1] Caltech Optical Observatories

ELTs offer an immense SNR gain for background-limited observations at the recovered diffraction limit. This is particularly true at visible wavelengths, where D/r0 ~ 200, enabling unprecedented ability to explore the key periods of reionization, massive galaxy assembly, and maximum star formation. Considering the trade-off between isoplanatic correction and the extended aureole of bright natural guide stars, we demonstrate the accessibility of ELTs to a signficant solid angle of visible diffraction-limited sky.

Astrophotonics and AO: a powerful combination for new instruments

Poster - N: 13650

Christian Schwab[1]

[1] Yale University

Astrophotonics is an emerging field, harnessing the enormous developments in photonic technologies over the past decade. It is providing novel ways to conceive and build astronomical instrumentation, in particular by applying single mode devices to the guiding and conditioning of light. A key step to enable the use of single mode technology was the demonstration of efficient, so called photonic lanterns, devices to convert a multimode input to a number of single mode outputs. This alleviates the problem of coupling starlight directly into a single mode fiber, which has been notoriously inefficient in the past. An AO system is indispensable to provide a PSF matched to the lantern input, and keep the number of modes within practical limits. Once in the single mode domain, instruments can be compact, extremely stable and highly integrated. This in turn can provide the next step in instrument performance, in particular in highest precision spectroscopy and interferometry. Thus, the combination of AO facilities with astrophotonics leverages the strengths of both technologies for the design of powerful, new instruments. We will present some existing and future astrophotonic devices, like photonic lanterns, OH-suppression Fiber Bragg Gratings, and beam combiners, and discuss the requirements for AO facilities.

Laboratory tests of planet signal extraction in high contrast images

Poster - N: 13701

Pierre Baudoz[1], Johan Mazoyer[1], Raphael Galicher[1]

[1] Laboratoire d'études spatiales et d'instrumentation en astrophysique

Understanding the formation, evolution and surprising diversity of exoplanetary system is recognized as one of the few major challenges of current astrophysics. While a large number of planets are discovered thanks to techniques like radial velocity and transits, only a few of them have clear measurements of their atmospheric components. Besides, these latter have been studied on transiting planets with very short orbits. Study of planets at larger separations requires direct imaging, which has enabled detection of a handful of exoplanets. This number will dramatically increase with the arrival in 2013 of SPHERE and GPI instruments that will give access to a large class of self-luminous young exoplanets. Characterization of mature planets or even massive rocky planets is expected for the next generation of planet finders that will be installed on Extremely Large Telescopes (ELT).On ELT, even with Adaptive Optics (AO) working at their best, using smart wavefront sensor and correction strategy, it is expected that the residual speckles in the images will still be a factor 100 brighter than the planet signal. This level composed of slow quasi static speckles not detected by the wavefront sensor and the rapidly varying wavefront errors that cannot be corrected by the AO loop frequency. Solutions are actually studied to calibrate these speckles and make sure that we can differentiate them from planet signal. One of the best solution is to use the signal of focal plane wavefront sensors that can help suppressing the quasi-static speckles but also help to extract the planet signal in the final images.After describing the benefit of focal plane wavefront sensor for data extraction, we will describe our laboratory test bench which uses the Self-Coherent Camera as focal plane wavefront sensor. The principle of the data processing used to extract the planet signal will be presented together with laboratory results on very high contrast images.

2 AO systems for ELTs

Invited

Adaptive Optics for the Thirty Meter Telescope

Invited - N: 13199

Brent Ellerbroek[1]

[1] TMT Observatory Corporation

This paper provides an overview of the progress made since the last AO4ELT conference towards developing the first-light AO architecture for the Thirty Meter Telescope (TMT). The Preliminary Design of the facility AO system NFIRAOS has been concluded by the Herzberg Institute of Astrophysics. Work on the client Infrared Imaging Spectrograph (IRIS) has progressed in parallel, including a successful Conceptual Design Review and prototyping of On-Instrument WFS (OIWFS) hardware. Progress on the design for the Laser Guide Star Facility (LGSF) continues at the Institute of Optics and Electronics in Chengdu, China, including the final acceptance of the Conceptual Design and modest revisions for the updated TMT telescope structure. Design and prototyping activities continue for lasers, wavefront sensing detectors, detector readout electronics, real-time control (RTC) processors, and deformable mirrors (DMs) with their associated drive electronics. Highlights include development of a prototype sum frequency guide star laser at the Technical Institute of Physics and Chemistry (Beijing); fabrication/test of prototype natural- and laser-guide star wavefront sensor CCDs for NFIRAOS by MIT Lincoln Laboratory and W.M. Keck Observatory; a trade study of RTC control algorithms and processors, with prototyping of GPU and FPGA architectures by TMT and the Dominion Radio Astrophysical Observatory; and fabrication/test of a 6x60 actuator DM prototype by CILAS. Work with the University of British Columbia LIDAR is continuing, in collaboration with ESO, to measure the spatial/temporal variability of the sodium layer and characterize the sodium coupling efficiency of several guide star laser systems. AO performance budgets have been further detailed. Modeling topics receiving particular attention include performance vs. computational cost tradeoffs for RTC algorithms; optimizing performance of the tip/tilt, plate scale, and sodium focus tracking loops controlled by the NGS on-instrument wavefront sensors, sky coverage, PSF reconstruction for LGS MCAO, and precision astrometry for the galactic center and other observations.

Toward the Adaptive Optics for the 40 m class European ELT

Invited - N: 16558

Norbert Hubin[1]

[1] ESO

This paper will provide an overview of the activities being carried out by ESO for the development of new Adaptive Optics capabilities for the Very Large Telescope and for the European Extremely Large Telescope. This paper will also focus on the progresses, challenges and remaining risks of the AO key technologies and concepts.

Preliminary Design of the Giant Magellan Telescope Adaptive Optics System

Invited - N: 17195

Antonin Bouchez[1]

[1] Giant Magellan Telescope Organization

The Giant Magellan Telescope adaptive optics system will be an integral part of the telescope, providing laser guide star generation, wavefront sensing, and wavefront control to every instrument currently planned on the 25.4 m diameter GMT. The AO system will provide three observing modes: Natural Guidestar, Laser Tomography, and Ground Layer. All three modes will use a segmented adaptive secondary mirror to deliver a high-throughput, corrected beam directly to the instruments. The Natural Guidestar mode will provide extreme AO performance, with a total wavefront error of 160 nm RMS in median conditions. The Laser Tomography mode uses 6 lasers and a single off-axis natural guidestar to deliver 280 nm RMS wavefront error at the science target, over 50% of the sky at the galactic pole. The Ground Layer mode uses 4 natural guidestars on the periphery of the science field to tomographically reconstruct and correct the ground-layer turbulence, significantly improving the image quality of all wide-field instruments. We will describe the AO system preliminary design, predicted performance, and the remaining challenges as we move towards a start of construction in 2014.

Oral

Laser Tomography Adaptive Optics for the Giant Magellan Telescope

Oral - N: 12521

Rodolphe Conan[1], Brady Espeland[1], Simon Parcell[1], Marcos Van Dam[2], Antonin Bouchez[3], Piotr Piatrou[1]

[1] The Australian National University
[2] Flat Wavefronts
[3] GMTO

Laser tomography adaptive optics (LTAO) will allow Extremely Large Telescope to get nearly diffraction limited images over a large fraction of the sky.For such systems, the sky coverage is limited by the number of natural guide star (NGS) suitable to estimate the tip and tilt (TT) modes of the atmosphere.The LTAO system of the Giant Magellan Telescope is using a single NGS which detector is located within the instrument. A deformable mirror (DM) in open–loop corrects the anisoplanatism error of the NGS wavefront.The DM command is derived from an off-axis tomographic reconstruction using the measurements from the Laser Guide Star wavefront sensors.The paper describes the tomography algorithm, a minimum variance reconstructor in the wavefront sensor space.The detail of the control architecture is shown including the TT, the focus and the truth sensors.As a conclusion, we will report on the expected sky coverage and performance of the system.

Roadmap for PCS

Oral - N: 12804

Markus Kasper[1], Dimitri Mawet[2], Christophe Verinaud[3]

[1] ESO-Garching
[2] ESO-Chile
[3] IPAG

Presently, dedicated instruments at large telescopes (SPHERE for the VLT, GPI for Gemini) are about to discover and explore self-luminous giant planets by direct imaging and spectroscopy. The next generation of 30m-40m ground-based telescopes, the Extremely Large Telescopes, have the potential to dramatically enlarge the discovery space towards older giant planets seen in reflected light and ultimately even a small number of rocky planets. The E-ELT Planetary Camera and Spectrograph (PCS) serves this purpose. Building on the heritage of the EPICS phase-A study, this contribution presents revised requirements, a possible instrument concept, performance analysis as well as the R&D necessary to realize the instrument.

Global MCAO aiming to the (whole) sky

Oral - N: 13252

Roberto Ragazzoni[1], Jacopo Farinato[1], Maria Bergomi[1], Marco Dima[1], Davide Greggio[1], Demetrio Magrin[1], Luca Marafatto, Valentina Viotto

[1] INAF - Osservatorio di Padova

Global Multi Conjugated Adaptive Optics is a novel concept technique introduced a few years ago that aim to compensate the turbulence in a MCAO manner in a Field of View (much) smaller than the one used for WaveFront sensing. This can be accomplished along lines similar to MOAO, using extremely linear wavefront sensing. The aim of the technique is to reach sky coverages figures that are in competition with MCAO systems based on artificially generated LGSs. This can be accomplished through a combination of techniques without compromising linearity toward sensitivity. The current status of the concept development is reviewed, the possible demonstration experiments to prove the concept on the sky are outlined along with the first estimation of the expected performances and sky coverage.

The phasing system for the Giant Magellan Telescope

Oral - N: 13318

Brian McLeod[1], Antonin Bouchez[2], Scott Acton[3]

[1] Smithsonian Astrophysical Observatory
[2] GMTO
[3] Ball Aerospace

In this presentation we give an overview of the components of the Giant Magellan Telescope AO system that are responsible for keeping the telescope phased. The segmented nature of both the primary and secondary mirrors, combined with the relatively large size of the gaps between the segments, makes phasing a difficult problem. The phasing components include a dispersed Hartmann sensor, edge sensors for the primary and secondary mirror segments, and phase sensitive AO wavefront sensors. We will show on-sky results from a prototype dispersed Hartmann sensor deployed at the Magellan Clay telescope.

The AO modes for HARMONI: from classical to Laser-assisted tomographic AO systems

Oral - N: 13333

Thierry Fusco[1]

[1] Office National d'Etudes et Recherches Aérospatiales

HARMONI is a visible and near-infrared integral field spectrograph for the E-ELT. It needs to work at diffraction limited scales. This will be possible thanks to two adaptive optics systems, complementary to each other. Both systems will make use of the telescope's adaptive M4 and M5 mirrors. The first one is a simple but efficient Single Conjugate AO system (good performance, low sky coverage), fully integrated in HARMONI itself. The second one is a Laser Tomographic AO system (medium performance, very good sky coverage). We present the overall design of the SCAO system and discuss the complementary between SCAO and LTAO for HARMONI. The development process allowing to efficiently going from SCAO to LTAO is described. In that respect, the rational for wave front sensor choices is presented as well as the first preliminary conclusions.

Overview of the E-ELT MCAO module project

Oral - N: 13380

Emiliano Diolaiti[1]

[1] INAF-OABo

MAORY is the Multi-Conjugate Adaptive Optics (MCAO) module for the European Extremely Large Telescope (E-ELT). It is designed to feed the E-ELT high angular resolution camera. Both the MCAO module and the camera are currently included in the telescope's first light instrumentation set. The MCAO module is required to relay the telescope focal plane to the client instrument and to compensate the wavefront errors due to atmospheric turbulence and other effects such as telescope windshake. The performance is optimized on the wavelength range 0.8-2.4 μm over an angular field of view of about 1 arcminute. In the current baseline design, wavefront correction is performed by the telescope's adaptive mirror M4 and tip-tilt mirror M5 and by two post-focal deformable mirrors integrated in the MCAO module and conjugated to high altitude turbulent layers. Wavefront sensing is performed by a Laser Guide Star (LGS) wavefront sensor using 6 Sodium artificial sources, complemented by a Natural Guide Star (NGS) wavefront sensor using 3 natural stars. The NGS wavefront sensor is devoted to the measurement of the orders of wavefront aberration that the LGS wavefront sensor alone cannot measure in a reliable way, such as tip-tilt, focus, low/medium orders induced by the Sodium layer density profile variations coupled with instrumental effects. The MCAO system architecture is based on a robust closed loop approach, ensuring reliable peak performance as well as high sky coverage. An overview of the baseline design and expected performance of the MCAO module is given. The on-going activities in preparation for the project phase B are described.

The two faces of the METIS Adaptive Optics system

Oral - N: 13447

Remko Stuik[1], Stefan Hippler[2], Andrea Stolte[3], Bernhard Brandl[1], Lars Venema[4], Rainer Lenzen[2], Eric Pantin[5], Joris Blommaert[6], Alistair Glasse[7], Michael Meyer[8]

[1] Leiden Observatory, Leiden University
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[3] Argelander Institut för Astronomie
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[5] CE Saclay DSM/IRFU/SAp, Service d'Astrophysique
[6] Institut voor Sterrenkunde, K.U. Leuven
[7] UK Astronomy Technology Center
[8] Institute of Astronomy, ETH Zurich

METIS, the Mid-infrared E-ELT Imager and Spectrometer is foreseen to be the third instrument on the European Extremely Large Telescope (E-ELT) and the only instrument to provide high sensitivity imaging and spectroscopy to the E-ELT. In order to reach the maximum resolution and sensitivity, an adaptive optics system is required. The science drivers for METIS are versatile, ranging from high contrast imaging of exo-planets and debris disks to wide field imaging of extended features both inside as well as outside our own galaxy. In order to serve all these science cases with the best possible performance, a dual AO solution is foreseen for METIS; an internal SCAO system will provide the highest possible performance for on-axis sources, while a LTAO system will provide excellent performance over a larger field of view and for targets without a bright guide star present. This paper describes the requirement, the trade-offs and the expected performance of the two AO solutions, focusing on the applicability to the various science cases of METIS.

Posters

The opto-mechanical design of the LTAO WFS for the Giant Magellan Telescope

Poster - N: 12835

Kristina Uhlendorf[1], Brady Espeland[1], Rusty Gardhouse[1], Rodolphe Conan[1], Antonin Bouchez[2]

[1] Research School of Astronomy & Astrophysics, The Australian National University
[2] Giant Magellan Telescope Observatory Corporation

The Giant Magellan Telescope presents an unique astronomical facility with seven 8.4 m diameter primary mirrors matched by seven adaptive secondary mirrors (ASM). The ASMs will be controlled by several Adaptive Optics systems; one of them is the Laser Tomography Adaptive Optics (LTAO) system. A key component in any design of a LTAO system is the Laser Tomographic Wavefront Sensor (LTAO WFS). The LTAO WFS Assembly consists of six optically equal 60x60 Shack-Hartmann WFS aligned to the six Laser Guide Stars (LGS). Changing telescope elevation and changes in the mean altitude of the sodium layer result in a varying back focal distance and F-number. Therefore, very accurate focus compensation and pupil size adjustment, combined with very high requirements for pupil stability and optical performance, are the main challenges for opto-mechanical design of the LTAO WFS Assembly. We are presenting a compact solution developed during the LTAO preliminary design phase. In our design, the six LGS wavefront sensors use the same focus and zoom stage. Besides the presentation of the optical performance, we will show the results of the tolerancing, the alignment concept and the mechanical realisation.

Near-infrared optimised wavefront sensing for ELT-class instrumentation: Lessons from the VLTI-GRAVITY adaptive optics system

Poster - N: 13187

Sarah Kendrew[1], Stefan Hippler[1], Casey Deen[1], Pengqian Yang[1], Neil Zimmerman[1], Wolfgang Brandner[1], Yann Clenet[2], Frank Eisenhauer[3]

[1] Max Planck Institut för Astronomie
[2] Observatoire de Paris
[3] Max Planck Institut för extraterrestrische Physik

GRAVITY is an adaptive optics-assisted 2nd generation instrument for the VLT Interferometer. Combining 4 Auxiliary or Unit Telescope beams, it will provide high precision astrometry (of order 10 μas) and phase-referenced interferometric imaging at 4 mas resolution in the near-infrared K-band. The project includes the development of a NIR-optimised adaptive optics system, including new Shack-Hartmann wavefront sensors (WFS) and real-time control, to be deployed at each Unit Telescope. The GRAVITY Coudé Infrared Adaptive Optics system (CIAO) will see the first on-sky implementation of the newly developed ESO/Selex SAPHIRA detectors, which provide low-noise readout at high speeds, ideally suited to NIR adaptive optics applications. We show here performance simulations for the GRAVITY wavefront sensors, demonstrating the substantial improvement in sensitivity provided by the SAPHIRA detectors, and describe our first practical experience in the lab. Our findings suggest that such IR-optimised WFS with such detectors are an attractive option for infrared ELT-class instruments, enabling the use of fainter guide stars than is possible with current IR WFS with no penalties in speed and limited additional opto-mechanical complexity over optical WFS.

Integrated Optic Segment Piston Sensor for the GMT

Poster - N: 13236

Francis Bennet[1], Kristina Uhlendorf[1], Rusty Gardhouse[1], Rodolphe Conan[1], Brady Espeland[1], Antonin Bouchez[2]

[1] Research School of Astronomy and Astrophysics, ANU
[2] Giant Magellan Telescope Organization

Integrated optic segment piston sensor (IOPS) for the Giant Mag- ellan Telescope (GMT) uses single mode laser written waveguides to measure segment piston of the GMT primary mirrors. Light in the H-band (from 1.5 to 1.6 μm) incident on each segment originating from an off-axis guide star is coupled into separate laser written single mode waveguides in a fused silica substrate. Light from neighbouring segments is interfered in several coupling regions where waveguides are in spatial proximity allowing coupling, in order to produce an inter- ference signal at the output. The output signal magnitude is directly related to the phase difference at the waveguide input, originating from the segment piston. IOPS is located in the on-instrument wavefront sensor of the GMT, which includes a deformable mirror for low order Zernike mode cor- rection. Residual image motion (tip-tilt modes) in the on-instrument wavefront sensor are measured by a tip-tilt sensor in the K-band. Small residual tip-tilt modes caused by atmospheric dispersion at the IOPS input will reduce performance significantly as these modes are seen by IOPS as segment piston. This aliasing effect also exists for higher order modes, but with a reduced magnitude. The input of IOPS is dithered by a small amount with a steering mirror. The corresponding drop in reference signals from each segment allows for the detection and correction of tip-tilt modes at the IOPS input to less than 5 nm. Segment piston sensitivity of less than 35 nm RMS is achieved with Strehl at the IOPS input greater than15% with a detector integration time of 7.5 seconds and dithered input.

Optical design of MAORY turbulence simulator

Poster - N: 13251

Matteo Lombini[1], Emiliano Diolaiti[1], Adriano De Rosa[2]

[1] INAF-OABo
[2] INAF-IASFBo

MAORY, the foreseen multi conjugate adaptive optics module for the Extremely Large Telescope, has the goal to relay the telescope focal plane achieving a high and uniform correction of the atmosphere induced wavefront aberrations, over a 2 arcmin field of view in a large fraction of the sky. The aberrated wavefronts are planned to be measured by 6 Sodium laser guide stars, arranged symmetrically over a 2arcmin circular field of view, and by 3 natural guide stars in a searching field of view up to 2.6 arcmin while the wavefront will be corrected by means of the telescope embedded adaptive mirror M4 and two post focal deformable mirrors. At the end of the integration phase performance tests of MAORY adaptive correction capability must be carried out. We present in this paper the optical design of a turbulence generator that will feed MAORY entrance focal plane with laser and natural guide stars having realistic time varying aberrated wavefronts. The focal plane diameter (~500mm) and the distance between the natural guide and the laser guide star focal plane positions (4-6 meters) discourage a monolithic design of the turbulence generator. Our approach consists in separating the optical paths of the different sources in order to use smaller and thus more feasible components. The time varying atmospheric turbulence at several altitudes over the telescope is carried out placing before the pupil stop few phase screens on moving stages. A set of mirrors focuses both the natural and laser stars at the expected positions of the real sources, preserving the telescope optical parameters as the exit pupil position, focal ratio, field curvature, etc. The laser guide stars and 7 natural guide stars, one on axis and 6 at 1arcmin off-axis, can be simulated with diffraction limit size. The optical layout and a preliminary tolerance analysis are shown.

Avoiding to trade sensitivity for linearity in a real world WFS

Poster - N: 13259

Demetrio Magrin[1], Jacopo Farinato[1], Davide Greggio[2], Roberto Ragazzoni[1], Maria Bergomi[1], Marco Dima[1], Luca Marafatto[2,1], Valentina Viotto[1]

[1] INAF-OAPD
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In the framework of the European ELT design, partially open-loop MCAO systems, coupled with virtual DMs, have been proposed to achieve AO correction using solely NGSs, to be selected in a FoV as wide as allowed by the Telescope optical design. This concept is called Global MCAO. The conceptual design of a very compact wavefront sensor, exploiting the just mentioned concept and characterized by a dynamic range limited by the stroke of the Deformable Mirror and by a limiting magnitude performance typical of a closed loop coherent wavefront sensor, have been presented in the past. We present here an updated and more detailed study of the Very Linear WFS, which includes a synoptic study concerning its optical design, investigating also possible conceptual opto-mechanical realization of a probe capable to co-exist with the currently foreseen E-ELT LGS probes. We also present a conceptual opto-mechanical design of a Global MCAO pathfinder, to be possibly installed on a 8-m class telescope, which might be a precursor of the E-ELT system, realized in a way to perform Low Layer correction for example at the VLT.

Systems Engineering - Transforming Adaptive Optics Experiments and Models into Operational Available Products

Poster - N: 14102

Hermine Schnetler[1]

[1] UK Astronomy Center

Most instruments on the European Extremely Large telescope (E-ELT) will require correction of the incoming beam so as to eliminate the effects of turbulence and to be able to fully utilise the potential of fine spatial resolution available due to the large primary mirror. For example the first light single channel IFU Spectrograph will require a laser tomography adaptive optics system while the multi-object spectrograph, which utilises the full telescope field of view will benefit from a multi-object adaptive optics topology. The two most important aspects to ensure the operational availability of instruments that rely on a fully working adaptive optics system are: (a) to understand the impact of the large number of adaptive optics parameters on the overall performance of the instrument and (b) to ensure that the operational concept of the adaptive optics system is feasible and that all the functions required are implemented with a minimum number of components. Especially it will be very important to make sure that the calibration and alignment requirements and procedures are simple, easy to perform and not overly time-consuming. It will also be of the utmost importance to manage and control all the instrument's critical performance parameters over the full environmental operational range of the instrument. This paper describes how the rigour of systems engineering will be applied to take simulation and on-sky test results to define a product specification which captures the performance requirements. Similarly, the paper will show how systems engineering processes can be deployed to realise a product which is fit for purpose with high operational availability.

3 AO pathfinders and new ideas

Invited

Into the Blue: AO Science in the Visible with MagAO and ELTs

Invited - N: 13387

Laird Close[1], Jared Males[1], Derek Kopon[1], Victor Gasho[1], Kate Follette, Philip Hinz[1], Katie Morzinski[1], Alan Uomoto[2], Tison Hare[2], Armando Riccardi[3], Simone Esposito[3], Alfio Puglisi[3], Enrico Pinna[3], Lorenzo Busoni[3], Carmelo Arcidiacono[3], Marco Xompero[3], Runa Briguglio[3], Fernando Quiros-Pacheco[3], Javier Argomedo[4]

[1] Steward Observatory
[2] OCIW
[3] INAF - Osservatorio di Arcetri
[4] ESO

The Magellan Clay telescope is a 6.5m Gregorian telescope located in Chile at Las Campanas Observatory. We have fabricated an 85 cm diameter aspheric adaptive secondary with our subcontractors and partners, MagAO passed acceptance tests in spring 2012, and the entire System was commissioned from Nov 17 to Dec 7, 2012. This secondary has 585 actuators with $<$ 1 msec response times (0.7 ms typically). We fabricated a high order (585 mode) pyramid wavefront sensor (similar to that of LBT's FLAO). The relatively high actuator count allows moderate Strehls to be obtained in the visible (0.63-1.05 microns). We have built an CCD science camera called "VisAO". On-sky long exposures (60s) achieve 30% Strehls at 0.62 microns (r') with the VisAO camera in 0.5" seeing with bright R $<$ 8 mag stars. These relatively high optical wavelength Strehls are made possible by our powerful combination of a next generation ASM and a Pyramid WFS with 200-400 controlled modes and 1000 Hz loop frequencies. To minimize non-common path errors and enable visible AO the VisAO science camera is fed by an advanced triplet ADC and is piggy-backed on the WFS optical board itself. Despite the ability to make 25 mas images we still have ˜4 mas of resolution loss to residual vibrations. We will discuss what the most difficult aspects are for visible AO on ELTs scaling from our experience with MagAO.

ATST and Solar AO state of art

Invited - N: 13652

Thomas Rimmele[1], Friedrich Woeger[1]

[1] National Solar Observatory

The 4 meter aperture Advanced Technology Solar Telescope (ATST) is an ELT for solar astronomy, and as such will address a broad range of science questions that require its AO system to operate in several different observing scenarios. We review the science drivers that lead to the most demanding ATST AO system requirements, such as high Strehl ratios at visible wavelengths, MCAO correction, and photon starved, extended FOV wavefront sensing using large, faint structures at the limb of the Sun. Within the context of exisiting high-order AO systems for solar telescopes we present an overview over the current ATST AO system design and capabilities. Finally, we will describe the widely used post-facto image processing techniques of AO corrected solar imaging and spectroscopic data that are required to achieve the desired spatial resolution especially at the short end (380 nm) of the visible spectrum over ATST's full FOV. We will lay out how these techniques will be supported in the AO system to help ATST achieve its scientific goals.

GeMS first science results

Invited - N: 13993

Benoit Neichel[1], François Rigaut[2], Fabrice Vidal[1], Rodrigo Carrasco[1], Claudia Winge[1], Peter Pessev[1], Andrew Serio[1], Gustavo Arriagada[1], William Rambold[1], Javier Luhrs[1], Maxime Boccas[1], Celine D'Orgeville[2], Vincent Fesquet[1], Ariel Lopez[1], Chadwick Trujillo[3], Ramon Galvez[1], Gaston Gausachs[1], Tomislav Vucina[1], Vanessa Montes[1], Cristian Urrutia[1], Cristian Moreno[1], Claudio Marchant[1], Sarah Diggs[1], Matthieu Bec, Gelys Trancho, Fabian Collao[1]

[1] Gemini Observatory
[2] The Australian National University
[3] Gemini North Observatory

After 100 nights of commissioning, GeMS started science operations last December 2012.In this presentation, we come-back on all the steps that were necessary to bring this complex machine from integration, to an on-sky demonstrator and finally to a science instrument. Some of the key steps, like integration into the observatory operational scheme, are described in more details and we present the overall system performance and on-sky efficiency.Finally, we show some of the first science results out of GeMS, illustrating the unique capabilities of this new Gemini's facility.

Multiple Object Adaptive Optics: Mixed NGS/LGS tomography

Invited - N: 15023

Tim Morris[1], Eric Gendron[2], Alastair Basden[1], David Henry[3], Zoltan Hubert[4], Gaetano Sivo[5,6], Damien Gratadour[2], Fanny Chemla[4], Arnaud Sevin[2], Matthieu Cohen[2], Eddy Younger[1], Fabrice Vidal[7], Urban Bitenc[1], Andrew Reeves[1], Nazim Bharmal[1], Henri-François Raynaud[8,6], Caroline Kulcsar[6], Jean-Marc Conan[5], Jean-Michel Huet[4], Denis Perret[4], Colin Dickson[3], David Atkinson[3], Tom Baillie[3], Andy Longmore[3], Stephen Todd[3]

[1] Durham University
[2] Laboratoire d'études spatiales et d'instrumentation en astrophysique
[3] Royal Observatory Edinburgh
[4] Observatoire de Paris - Site de Meudon
[5] Département d'Optique Théorique et Appliquée
[6] Laboratoire Charles Fabry de l'Institut d'Optique
[7] Gemini Observatory
[8] Laboratoire de Traitement et Transport de l'Information

Open-loop adaptive optics has been successfully demonstrated on-sky by several groups, including the fully tomographic MOAO demonstration made using CANARY. MOAO instrumentation such as RAVEN will deliver the first astronomical science and other planned instruments aim to extend both open-loop AO performance and the number of corrected fields. Many of these planned systems rely on the use of tomographic open-loop LGS wavefront sensing. Here we present results from the combined NGS/LGS tomographic CANARY system and then compare the NGS- and LGS-based tomographic system performance. We identify the major system performance drivers, and highlight some potential routes for further exploitation of open-loop tomographic AO.

Adaptive telescope pathfinders for the ELTs: MMT, LBT, Magellan and VLT

Invited - N: 16354

Armando Riccardi[1]

[1] INAF - Osservatorio di Arcetri

In the '80s the introduction of active control of telescope mirror shape and collimation errors - induced by gravity, thermal and wind disturbances - started the 'active telescope' era and allowed building and operating the current generation of 8-10m telescopes with excellent optical performances. The maturity of adaptive optics allows to produce a similar technological step integrating adaptive optics in the telescope design and moving from active to 'adaptive telescopes'. The technological step is particularly advantageous for ELTs where disturbances on such large structures require a correction bandwidth that moves from the typical active to the adaptive regime. Adaptive optics is also the most interesting observing modality for ELTs and its integration in the telescope by design allows to serve all the focal stations with a reduction of complexity and an increase of efficiency on the instrument side. This paper reviews the past and present activities on the adaptive telescope technology in the framework of the current generation of 6-8m telescopes as pathfinders for ELTs. Current adaptive telescopes have the common characteristics of substituting a rigid secondary with a deformable one: the adaptive secondary mirror (ASM), providing an actuator pitch, projected on M1, in the range 20-30cm. The review will start from the first on-sky experience with the 6.5m MMT telescope on 2001, to the activity of the 2x8.4m LBT: the first adaptive telescope by design and pushing the performance to be real diffraction limited in NIR with its First Light Adaptive Optics (FLAO) system. The review ends with the most recent activity on the 6.5m Magellan Telescope, implementing an LBT-like ASM, and the 8.2m VLT with the largest ASM ever built.

High Contrast Imaging: New Techniques and Scientific Perspectives for ELTs

Invited - N: 16504

Olivier Guyon[1]

[1] SUBARU Telescope

High contrast imaging techniques have advanced considerably in the last decade. Their development is motivated by the scientific perspective of directly imaging and characterizing exoplanets with ground-based and space-based telescopes, with a long term goal of identifying signs of biological activity on rocky planets in the habitable zones of nearby stars. I will show that detection of ~1e-8 contrast planet at ~1 to 2 l/D separation may be achievable with ELTs with a combination of high performance coronagraphy, high sensitivity extreme-AO, and speckle residual calibration.This performance level will reveal a large sample of giant planets, and allow their spectroscopic characterization. More interestingly, I will show that habitable planets around nearby M-type stars are ideal targets for ELTs. Thanks to the ELTs' high angular resolution, the small angular size of the habitable zone around these targets is well resolved, and the planet-to-star contrast is favorable thanks to the relatively faint stellar brightness. I will show how a modern adaptive optics techniques (high sensitivity wavefront sensing, time-lag compensation in AO control loop, focal plane speckle calibration) will enable such detections.I will conclude that through direct imaging and spectroscopic characterization of rocky planets in the habitable zones of nearby M-type stars, ELTs can provide scientific evidence for (or against) the presence of life outside our solar system. Technologies requiring further maturation to enable these observations will be discussed.

Focal Plane Wavefront Sensing with a self-coherent camera

Invited - N: 18647

Raphael Galicher[1], Jacques Robert Delorme, Pierre Baudoz[2], Johan Mazoyer[2]

[1] University of Paris Diderot
[2] Observatoire de Paris

Characterization of exoplanets with long orbital periods requires direct imaging which is challenging. The objective is the suppression of the light of the star that is 10^4 to 10^10 times brighter than its planet which is at less than 1". Coronagraphs were proposed to suppress the stellar light but their performance is strongly limited by wavefront aberrations that induce stellar speckles in the science image. Adaptive optics correct for most of the atmospheric turbulence but quasi-static aberrations still remain because of flexures with pointing, optical aberrations of moving optics, and so on. Classical adaptive optics cannot calibrate the quasi-statics because of differential aberrations between the science image and the wavefront sensing image. Since 2006, our team works on a self-coherent camera (SCC) that estimates both phase and amplitude aberrations from the science image. The SCC creates a reference beam that interferes with the speckles in a Fizeauscheme and spatially modulates them in the science image. Demodulating the signal, we retrieve the complex amplitude of the electric field in the science image and use a deformable mirror to enhance the contrast in a dark hole. We obtained contrasts as high as 1e-8 between 4 and 15 l/D in laboratory but chromatism may be an issue working with large bandwidths. At the AO4ELT3, I will present a new version of the SCC (numerical simulations and laboratory results) that may overcomethis limitatiion.

LGS MCAO systems experience in light of the ELTs

Invited - N: 19339

François Rigaut[1]

[1] Australian National University

In light of the experience gained with the Gemini Multi-conjugate AO system GeMS, I will review design, performance, and operational points relevant to the upcoming ELTs. This talk will encompass the system in its globally, including the AO bench,Laser Guide Star Facility and integration into the observatory infrastructure. I will show preliminary results of the first scienceprograms, go through a somewhat detailed error budget and will comment on lessons learned.

Oral

Adaptive Phase-Mask Coronagraph

Oral - N: 13183

Nicolas Schuhler[1], Bourget Pierre[1], Mawet Dimitri[1], Haguenauer Pierre[1]

[1] European Southern Observatory

High contrast imaging of extra-solar planets and close environments of bright astrophysical objects in general, such as stars or active galactic nuclei, is a challenging task. ELTs and their dedicated AO systems will provide unprecedented high angular resolution. Coronagraphs techniques will allow taking advantage of this resolution, however the technical challenges for coronagraphs are significant (intrinsic contrast, ability to perform over broad wavelength range, inner working angle (IWA)) and their design shall be carefully thought to ensure that the capability offered by ELTs are used at maximum potential. Accessing small IWA is considered as an edge as it provides substantial scientific and technical advantages. One of the difficulties of accessing small IWA is that coronagraphs become very sensitive to low-order aberrations such as tip-tilt. Our original approach of adaptive phase-mask coronagraph aims at integrating the small IWA capability and the mitigation of sensitivity to low-order aberrations within the coronagraph itself. Our concept is applicable to both low and high Strehl regimes, corresponding to current and next generation AO systems. The adaptive coronagraph can adapt dynamically, in quasi real time, to adjust to the observing conditions (seeing, AO correction performances) to deliver a stable and optimized contrast at the science image level.

GeMS: from the on-sky experimental system to science operation. The AO point of view

Oral - N: 13276

Fabrice Vidal[1], Benoit Neichel[1], François Rigaut[2], Rodrigo Carrasco[1], Claudia Winge[1], Peter Pessev[1], Andrew Serio[1], Gustavo Arriagada[1], William Rambold[1], Javier Luhrs[1], Maxime Boccas[1], Celine D'Orgeville[2], Vincent Fesquet[1], Ariel Lopez[1], Chadwick Trujillo[1], Ramon Galvez[1], Gaston Gausachs[1], Tomislav Vucina[1], Vanessa Montes[1], Cristian Urrutia[1], Cristian Moreno[1], Claudio Marchant[1], Sarah Diggs[1], Matthieu Bec[3], Gelys Trancho[3], Fabian Collao[1]

[1] Gemini Observatory
[2] Australian National University
[3] Giant Magellan Telescope Org. Corp.

Two years after its first light in 2011, GeMS, the Gemini Multi conjugate adaptive optics System is currently in the science verification process. From the Adaptive Optics (AO) point of view it means we started the long process of performance stabilization, optimization and automation. We present the tools that have been developed recently to understand the on-sky system behaviour. In particular thanks to a new telemetry software we dispose of a unique AO data set of Wave Front Sensors slopes and Deformable Mirrors commands synchronised to the wide field science images. We discuss of this unprecedented amount of data recorded during the last 60 nights of commissioning ranging from summer to winter, variable seeing conditions, Cn2 Profiles and Sodium return... In order to manage this huge amount of data, we also developed a processing software now working in quasi real time that help us to optimize the GeMS performance during the science verification operation. We discuss about how such a tool is useful to converge towards the performance stability, performance optimization and automation of the 20 loops and offloads between the instrument and the telescope. Finally we present a detailed error budget and conclude on the long ending story of the GeMS commissioning.

First exoplanet and disk results with the PALM-3000 adaptive optics system

Oral - N: 13289

Richard Dekany[1], Rick Burruss[2], J. Chris Shelton[2], Ben Oppenheimer[3], Gautam Vasisht[2], Stanimir Metchev[4], Jennifer Roberts[2], Jonathan Tesch, Tuan Truong[2], Jennifer Milburn[1], David Hale[1], Christoph Baranec[1], Sergi Hildebrandt[2], Matthew Wahl[4], Chas Beichman[2], Lynne Hillenbrand[5], Rahul Patel[4], Sasha Hinkley[5], Eric Cady[2], Ian Parry[6]

[1] Caltech Optical Observatories
[2] Jet Propulsion Laboratory [NASA]
[3] American Museum of Natural History
[4] Stony Brook University
[5] Department of Astronomy, California Institute of Technology
[6] Cambridge University

We describe the status of the PALM-3000 adaptive optics facility instrument for the Hale telescope at Palomar Observatory. Since first light in June 2011, PALM-3000 has made significant advances in both performance and sensitivity. Using Strehl ratio as our performance metric, we present results in 64x64 and 32x32 wavefront sensor pupil sampling modes on a range of guide stars from V ˜ 3 to 12. We describe our automated reconstructor pipeline tool, which incorporates pupil illumination and an optimal-estimator Baysian approach which serve to boost faint guide star performance. We conclude by presenting initial high-contrast circumstellar disk results from the PHARO vector vortex coronagraph and exoplanet spectra from the P1640 integral field spectrograph.

Overview of High-contrast O/IR imaging with Magellan AO: Simultaneous images of an exoplanet host star with VisAO and Clio

Oral - N: 13307

Katie Morzinski[1], Jared Males[1], Laird Close[1], Philip Hinz[1], Derek Kopon[1], Kate Follette, Timothy Rodigas[1], Ya-Lin Wu[1], Vanessa Bailey[1]

[1] Steward Observatory

The 6.5m Magellan Clay telescope's adaptive secondary AO system, MagAO, successfully completed its first commissioning run in Fall 2012, and will complete its second commissioning run in Spring 2013. With a high actuator density and a sensitive pyramid WFS, MagAO achieves down to ˜100 nm rms WFE on bright guide stars in good (0.5" V band seeing conditions) at Las Companas Observatory in Chile. MagAO's infrared camera, Clio, has a comprehensive suite of narrow and broad band filters that allow direct imaging of faint companions from 1-5 um. I will present first-light results from Clio, including images of an exoplanetary system. High-contrast imaging is an important goal of AO for ELTs, and results from MagAO/Clio are the next step along that path — particularly true for the GMT which is located very close to the Magellan site.

Wide field adaptive optics and near-infrared instrument for Subaru Telescope

Oral - N: 13324

Yutaka Hayano[1], Ikuru Iwata[1], Shin Oya[1], Masayuki Akiyama[2], Yosuke Minowa[1], Tadayuki Kodama[1], Kentaro Motohara[3], Tomoyasu Yamamuro[4], Tomonori Usuda[1], Ichi Tanaka[1], Daigo Tomono[1], Testuo Nishimura[1], Takashi Hattori[1], Hiroshi Terada[1], Naruhisa Takato[1], Koki Takiura[1], Yoshito Ono[2], Nagayoshi Ohashi[1], Hideki Takami[5], Masanori Iye[5], Nobuo Arimoto[1]

[1] Subaru Telescope, National Astronomical Observatory of Japan
[2] Tohoku University
[3] The University of Tokyo
[4] OptCraft
[5] National Astronomical Observatory of Japan

Future AO system and new near-infrared (NIR) instrument for Subaru Telescope have been considered since 2009. The working group has been formed in 2011 to set forward a feasibility study for this future plan. The working group selected a GLAO system with wide-field NIR camera and spectrograph as the best future instrument candidate, since it is expected to strengthen Subaru's wide-field observing capability along with optical wavelength instruments such as Hyper Suprime-Cam. Two major science goals have been defined for this instrument with GLAO. One is to reveal the entire picture of galaxy evolution by analyzing morphology, mass distribution, internal dynamics, metallicity and other physical parameters of large ensemble of galaxies as well as effects of nuclear activity and of outskirt environments. Another goal is to discover the most distant galaxies, i.e, those at redshift larger than 7.5, using narrow bandpass filters. Those galaxies should disclose the very early phase of galaxy formation and the cosmic reionizaion. We are also carrying out system analysis of GLAO and wide-field NIR instrument. Preliminary performance simulation of GLAO system at Subaru Telescope showed that uniform image size across more than 15 arc-minutes of field-of-view can be achieved. Additionally, we have started technical feasibility study for manufacturing critical components of GLAO, such as a deformable secondary mirror and high power laser system, for installing them to Subaru Telescope. Conceptual optical design of wide-field NIR instrument at Cassegrain focus is underway. Design parameters have been widely scanned and compromised. Most challenging issues are optimization of a size of deformable secondary mirror and focal ratio of Subaru Telescope, splitting into several field-of-views due to a size limit of optical materials required for NIR instruments. We will present some possible solutions to achieve >10 arc-minutes field-of-view while maintaining image quality to be achieved with GLAO.

Integration of SAXO, the VLT-SPHERE eXtrem AO : final performance and lesson learned

Oral - N: 13327

Jean-François Sauvage[1,2], Cyril Petit[1], Thierry Fusco[1,3], Anne Costille[3]

[1] Département d'Optique Théorique et Appliquée
[2] Institut de Planétologie et d'Astrophysique de Grenoble
[3] Observatoire Astronomique de Marseille Provence

The direct imaging of exoplanet is an up to date instrumental challenge, as well as a scientific exciting goal. Contrary to indirect methods, the study of exoplanet's own light witnesses for biomarkers presence in their atmosphere. Observing such a faint object close to its bright host star requires dedicated instrumental observation from the ground. SPHERE and GPI are two of these instruments, currently on final AIT phase, for a very first light during this year. Both instruments developed during the last 5 years are composed of extremely high performance AO system (XAO) able to compensate for the optical deformation caused by the turbulence of earth atmosphere. Moreover, the final performance of such a system is limited by the static light residuals present in the imaging focal plane, caused by uncorrected static optical aberrations. The direct imaging of exoplanet therefore also requires to perform self-calibration in order to attenuate these residual and enhance the coronagraphic extinction. This paper presents the final ongoing AIT results of the SPHERE instrument, and mainly focuses on XAO aspects. An exhaustive view of last SAXO performance in lab is shown. In particular, such improvement as the Optimised Modal Gain, optimized Kalman filtering of vibration, and Garbage collection are the key point to reach the final performance. The behavior of the instrument with realistic turbulence strength, wind speed, flux conditions are studied. The self-calibration module, based on phase diversity measurement of NCPA, demonstrates the ultimate performance of the instrument, in term of flux extinction and future scientific results.

Laboratory results and status update for Pathfinder, the LINC-NIRVANA ground-layer AO subsystem

Oral - N: 13347

Derek Kopon[1], Al Conrad[1], Thomas Bertram[1], Tom Herbst[1], Martin Kürster[1], Juergen Berwein[1], Roberto Ragazzoni[2], Jacopo Farinato[2], Valentina Viotto[2], Maria Bergomi[2], Ralf-Rainer Rohloff[1], Harald Baumeister[1], Fulvio De Bonis[1], Ralph Hofferbert[1], Alessandro Brunelli[2], Carmelo Arcidiacono[3], Jörg-Uwe Pott[1], Peter Bizenberger[1], Florian Briegel[1], Daniel Meschke[1], Lars Mohr[1], Xianyu Zhang[1], Frank Kittmann[1]

[1] Max Planck Institut för Astronomie
[2] INAF - Astronomical Observatory of Padova
[3] Istituto di Astrofisica Spaziale e Fisica cosmica - Bologna

The full LINC-NIRVANA instrument will be one of the most complex ground-based astronomical systems ever built. It will consist of multiple subsystems, including two multi-conjugate ground layer AO systems (MCAO) that drive the LBT adaptive secondaries, two mid-high layer AO systems with their own Xynetics 349 actuator DM's, a fringe tracker, and a beam combiner. In order to mitigate risk, we take a modular approach to instrument testing and commissioning by decoupling these subsystems individually. The first subsystem tested on-sky will be one of the ground-layer AO systems, part of a test-bed known as the Pathfinder. The Pathfinder consists of a 12-star pyramid WFS that drives one of the LBT's adaptive secondaries, a support structure known as "The Foot," and the infrared test camera (IRTC),

which is used for acquisition and alignment. The 12 guide stars are acquired by moveable arms called "star enlargers," each of which contains its own optical path. The Pathfinder will be shipped from MPIA in Heidelberg, Germany to the LBT mountain lab on Mt. Graham, Arizona in February. The system will be unpacked, assembled in the LBT clean room, and internally optically aligned. We present the results of our system tests, including star enlarger alignment and system alignment. We also present our immediate plans for on-sky closed loop tests on the LBT scheduled for early Fall. Because plans for all ELTs call for ground layer correction, the Pathfinder provides valuable preliminary information not only for the full LINC-NIRVANA system, but also for future advanced MCAO systems.

First on-sky validation of full LQG control with vibration mitigation on the CANARY MOAO pathfinder

Oral - N: 13353

Gaetano Sivo[1,2], Caroline Kulcsar[1], Jean-Marc Conan[2], Henri-François Raynaud[1,3], Eric Gendron[4], Alastair Basden[5], Fabrice Vidal[4], Tim Morris[5], Serge Meimon[2], Cyril Petit[2], Damien Gratadour[4], Olivier Martin[4], Zoltan Hubert[4], Gérard Rousset[4], Nigel Dipper[5], Gordon Talbot[5], Eddy Younger[5], Richard Myers[5]

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[3] Laboratoire de Traitement et Transport de l'Information
[4] Laboratoire d'études spatiales et d'instrumentation en astrophysique
[5] Durham University, Department of Physics

Many concepts of Wide Field AO (WFAO) systems are under development, especially for Extremely Large Telescopes (ELTs) instruments. Multi-Object Adaptive Optics (MOAO) is one of these WFAO concepts, well suited to high redshifts galaxies observations in very wide Field of View (FoV). CANARY is the on-sky pathfinder for MOAO operated at the William Herschel Telescope (WHT, La Palma, Spain) since 2010. We have demonstrated that Linear Quadratic Gaussian (LQG) control was an appealing strategy in this context [Sivo-SPIE2012], which moreover provides optimal performance (in the sense of minimum residual phase variance) with respect to the chosen models . It is based on a unified formalism that allows accounting for multi WaveFront Sensors (WFSs) channels, both on Laser Guide Stars (LGSs) and NGSs, and for various disturbance sources (turbulence, vibrations). We present the very first on-sky IR images recorded with full LQG AO. This world premiere has been obtained this summer 2012 at WHT on the CANARY demonstrator. Two AO configurations have been tested: single-conjugated AO and multi-object AO with NGS and NGS+LGS. These results demonstrate the practical implementation of LQG control for tomographic AO, as well as the efficiency of our strategy for vibration identification and filtering on tip-tilt. These very successful results are analyzed in terms of performance, and the influence of turbulence conditions and control tuning parameters is discussed. Note that this very first demonstration has been made possible thanks to a close collaboration between the CANARY teams (Durham University, Observatoire de Paris LESIA-GEPI, IOGS/L2TI-UP13, ONERA, UK ATC, ING).

Fourier-Based Predictive AO Schemes for Tomographic AO systems on ELTs

Oral - N: 13400

S. Mark Ammons[1], Lisa Poyneer[1], Donald Gavel[2], Bruce Macintosh[1], Renate Kupke[2], Claire Max[2], Connie Rockosi[2], Srinath Srikar[3], Alex Rudy[3], Benoit Neichel[4]

[1] Lawrence Livermore National Laboratory
[2] University of California Observatories
[3] University of California Santa Cruz
[4] Gemini Observatory

Modeling and predicting the evolution of wavefront errors in AO systems holds great potential for reducing temporal error terms for ELTs. We present an update of a UCSC-LLNL collaboration funded by the University of California to test Fourier-based predictive schemes on-sky with the upgraded ShaneAO system on the 3-meter telescope at Lick Observatory and to develop improved multi-guide star predictive schemes for widening the field of view of MCAO and MOAO systems. We discuss the extension of Fourier-based predictive AO schemes to multi-layer, multi-guide star tomographic AO systems anchored through simulation and analysis of testbed data from an MCAO/MOAO testbed at UCSC. Tracking organized, frozen-flow wind motion in the separate layers of a multi-guide star system is complicated by tomographic blind mode errors that blur phase information between atmospheric layers. To surpass this problem, we only perform wind identification in regions of the metapupil sampled by more than one guide star, where height resolution is ideal, and only modify phase estimates in regions of the metapupil sampled by one guide star, where height resolution is poor. We show with simulations of a tomographic, 5-LGS AO system on an ELT that this technique improves layer phase estimates by 5-11%, translating into potential gains in MOAO field of regard of up to 30%. We apply our multi-guide star predictive technique to GEMS MCAO telemetry and discuss implications for MCAO/MOAO systems on ELTs.

Final A&T stages of the Gemini Planet Finder

Oral - N: 16014

Markus Hartung[1], Bruce Macintosh, Donald Gavel[2], Lisa Poyneer[3], Dimitri Savransky[3], Sandrine Thomas[4], Daren Dillon[5], Naru Sadakuni[5], Kent Wallace[6], Jeffrey Chilcote[7], Marshall Perrin[8], Jerome Maire[9], Fredrik Rantakyro[10], Stephen Goodsell[10]

[1] Gemini Observatory
[2] University of California Observatories
[3] Lawrence Livermore National Lab.
[4] NASA Ames Research Center
[5] University of California, Santa Cruz
[6] Jet Propulsion Laboratory
[7] University of California Los Angeles
[8] Space Telescope Science Institute
[9] Dunlap Institute for Astronomy & Astrophysics, Univ. of Toronto
[10] Gemini South Telescope

The Gemini Planet Finder (GPI) is currently in its final Acceptance & Testing stages at the University of Santa Cruz, California. GPI is an XAO system based on a tweeter & woofer architecture (43 & 9 actuators across the pupil), with the tweeter being a Boston Michromachines 64^2 MEMS device. The XAO AO system is tightly integrated with a Lyot apodizing coronagraph. Acceptance has started in February 2013. After the conclusive acceptance review shipment is scheduled mid 2013 to ensure readiness for commissioning at the Gemini South telescope on Cerro Pachon, Chile, end of 2013, matching the summer window of the southern hemisphere. According to current estimates the 3 year (~800 allocated hours) planet finding campaign might discover, image, and spectroscopically analyze 20 to 40 new exo-planets.Final acceptance testing of the integrated instrument can always emerge a number of unforeseen challenges as we are eventually using cold chamber and flexure rig installations. The latest developments will be reported. Also, we will give an overview of GPI's lab performance, the interplay between subsystems such as the calibration unit (CAL) with the AO bench. (The CAL principal purpose is to maintain a clean and centered XAO PSF on the coronagraph.) We report on-going optimizations on the AO controler loop to filter vibrations and last but not least achieved contrast performance applying speckle nulling. Furthermore, we will give an outlook of possible but challenging future upgrades as the implementation of a predictive controler or exchanging the conventional 48x48 SH WFS with a pyramid. With the ELT area arising, GPI will proof as a versatile and path-finding testbed for AO technologies on the next generation of ground-based telescopes.

The ESO Adaptive Optics Facility under Test

Oral - N: 16254

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The Adaptive Optics Facility project has received most of its subsystems in Garching and the ESO Integration Hall has become the central operation location for the next phase of the project. The main test bench ASSIST and the 2nd Generation M2-Unit (hosting the Deformable Secondary Mirror) have been granted acceptance late 2012. The DSM will now undergo a series of tests on ASSIST to qualify its optical performance which launches the System Test Phase of the AOF. The tests will validate the AO modules operation with the DSM: first the GRAAL adaptive optics module for Hawk-I in natural guide star AO mode on-axis and then its Ground Layer AO mode. This will be followed by the GALACSI (for MUSE) Wide-Field-Mode (GLAO) and then the more challenging Narrow-Field-Mode (LTAO). We will report on the status of the subsystems at the time of the conference but also on the performance of the delivered ASSIST test bench, the DSM and the 20 Watt Sodium fiber Laser pre-production unit which has validated all specifications before final manufacturing of the serial units. We will also present some considerations and tools to ensure an efficient operation of the Facility in Paranal.

Posters

Layer-oriented adaptive optics for solar telescopes

Poster - N: 13213

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Future extremely large solar telescopes will be equipped with multi-conjugate adaptive optics (MCAO) systems. Up to now, solar MCAO uses exclusively a star-oriented approach, which is a natural extension of a conventional AO system. The field size is then limited to approximately 60 arc seconds, while fields of several arc minutes are required to observe the formation and evolution of solar spots. The Sun, however, is an ideal target for a layer-oriented MCAO system because the wavefront distortions can be sensed continuously over the entire field-of-view. Interestingly, in a layer-oriented approach, the correction is improved with increasing field-sizes. A practical implementation, however, meets current technological limits in terms of detector sizes and read-out frequencies. We will present first results on a layer oriented solar MCAO system, obtained via numerical simulations.

Validation of the AOF calibration strategy on the MAD bench

Poster - N: 13215

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The UT4 of ESO's VLT will soon be turned into an adaptive telescope thanks to the Adaptive Optics Facility (AOF) project. This new configuration induces new challenges for the control and calibration of the Adaptive Optics (AO) of the telescope, and can be seen as a pathfinder for the E-ELT. One of the main issues is the addition of a Deformable Secondary Mirror (DSM). In that context, the Interaction Matrix (IM), which establishes the link between the varying shape of the DSM and the measurements provided by the Wavefront Sensors (WFS), cannot be measured on an artificial source anymore, because there is no intermediate focal plane before the Deformable Mirror (DM). In addition, mis-alignments are likely to happen between the DSM and the WFSs. The resulting mis-registrations of the IM will induce a decrease of the AO performances. The baseline for the AOF is to use a Pseudo-Synthetic IM (PSIM), computer-generated and tuned with measured system parameters. IM measurement on turbulence is kept as a backup solution. The mis-registrations are identified in closed-loop without introduction of additional perturbation. If the system gets too mis-aligned, the PSIM is then numerically updated, taking these mis-registrations into account, and a new command matrix is uploaded in the system. This paper presents laboratory test bench results that helped validating some of the key aspects of the IM calibration strategy for the AOF. Tests were performed on ESO's MAD bench in SCAO, GLAO and LTAO mode.

Preliminary studies into the reduction of dome seeing using air curtains

Poster - N: 13227

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We report on an initial experimental evaluation of using laminar flow aircurtains for reducing turbulence. We demonstrate that the turbulentflow induced seeing can be very significantly reduced by using an aircurtain to isolate the two sides of an aperture, thus avoiding mixingof air and the associated turbulence. A computationalfluid dynamics model is used to investigate the potential that thismethod has for reducing dome seeing in current and future astronomicaltelescopes, and results are presented. We hypothesise that if such air curtains are used on a telescope then AO system requirements canbe relaxed, and we detail future experiments that we are intending tocarry out.

PULSE: Palomar Ultraviolet Laser for the Study of Exoplanets

Poster - N: 13275

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PULSE is a new concept to augment the currently operating 5.1-m Hale PALM-3000 exoplanet adaptive optics system with an ultraviolet Rayleigh laser and associated wavefront sensor. By using an ultraviolet laser to measure the high spatial and temporal order turbulence near the telescope aperture, where it dominates, one can extend the faintness limit of natural guide stars needed by PALM-3000. Initial simulations indicate that very-high infrared contrast ratios and good visible-light adaptive optics performance will be achieved by such an upgraded system on stars as faint as mV = 16-17 using an optimized low-order NGS sensor. This will enable direct imaging searches for, and subsequent characterization of, companions around cool, low-mass stars for the first time, as well as routine visible-light imaging twice as sharp as HST for fainter targets. PULSE will reuse the laser and wavefront sensor technology developed for

the automated Robo-AO laser system currently operating at the Palomar 60-inch telescope, as well as take advantage of pending optimization of low-order NGS wavefront sensing and planned new interfaces to the PALM-3000 real-time reconstruction computer. A copy of the Robo-AO laser will be installed in the prime focus cage of the 5.1-m, and a new ultraviolet high-order wavefront sensor, fed by an ultraviolet dichroic, will be installed in the space above the PALM-3000 optical bench near the calibration sources. The laser measurements will drive the 3,388 active element high-order deformable mirror in open-loop, while an adaptive optics sharpened faint natural source will be measured by the current PALM-3000 wavefront sensor in its lowest spatial sampling mode, with commands sent in closed-loop to the 241 active element low-order deformable mirror. The natural guide star loop corrects for both the relatively weak low-order high-altitude turbulence as well as functioning as both the tip-tilt and low-bandwidth 'truth' sensor loops in a traditional laser adaptive optics system.

High-contrast O/IR imaging with Magellan AO: Simultaneous images of an exoplanet host star with VisAO and Clio

Poster - N: 13286

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The Magellan Adaptive Optics (MagAO) system saw first light in November 2012 at Las Campanas Observatory on the 6.5m Magellan (Clay) telescope. Here we present an introduction to MagAO's visible wavelength diffraction limited imager, VisAO. VisAO delivers Strehl ratios greater than 30% from 0.62 microns (r') through 1 micron, where Strehl is even higher, and achieved resolutions as small as 21 milli-arcseconds. There are several design considerations which allow VisAO to achieve such good performance on a large telescope, and these will have important implications for ELT AO systems. We took advantage of the excellent performance of MagAO/VisAO to conduct high contrast observations of an exoplanet host star in the optical. We also provide a brief overview of some of the other diffraction limited science from VisAO.

Optical Set-Up and Design for Solar Multi-conjugate Adaptive Optics at the 1.6m New Solar Telescope, Big Bear Solar Observatory

Poster - N: 13313

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The Sun is an ideal target for the development and application of Multi-Conjugate Adaptive Optics (MCAO). A solar MCAO system is being developed by the Big Bear Solar Observatory, for the 1.6m New Solar Observatory, with the purpose of extending the corrected science field of view to 1.00Arcmin. A preliminary optical set-up, design and optical performance for such a system is presented and discussed here.

New strategy for cophasing extremely large telescopes with multiple AO corrected apertures made of circular mirrors

Poster - N: 13315

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To achieve the ultimate resolution of future ELTs, the segments of their primary mirrors must be perfectly aligned. This paper present wavefront sensing technique using focal plane images that allows to perform piston measurements and correction between all the segments. We investigate this possibility for new types of telescopes including AO correction independently for each of their segments prior to cophasing the segments. In this context we propose to derive the segment phase error using the inverse approach knowing the segment positions and the single aperture Airy function. We demonstrate that a natural star can be used successfully by a multiwavelength focal-plane image sensor to cophase in real time a telescope composed of sixty large segments.

Concept for Solar Multi-Conjugate Adaptive Optics at Big Bear Observatory

Poster - N: 13316

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Solar observations are performed over an extended field of view and the isoplanatic patch over which conventional adaptive optics (AO) provides diffraction limited resolution is a severe limitation. The development of multi-conjugate adaptive optics (MCAO) for the large aperture solar telescopes ranging from 1.6 to 4 metres diameters is extremely important. The Sun is an ideal object for the development of MCAO since solar structure provides multiple "guide stars" in any desired configuration. We propose a concept for a new MCAO system at Big Bear Observatory. This MCAO system uses three deformable mirrors conjugated to the telescope entrance pupil and to two layers in the upper atmosphere. We present the detailed analysis of the performance of this system for large range of elevations as required in solar observations by using the Fractal Iterative Method (FrIM), which incorporates wide field correlating Shack-Hartmann wavefront sensors.

Infrared Differential Imager and Spectrograph for SPHERE: Performance Status with Extreme Adaptive Optics before shipment to ESO/VLT

Poster - N: 13317

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SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research) is a second generation instrument for the VLT optimized for very high-contrast imaging around bright stars. Its primary science goal is the detection and characterization of giant planets, together with observation of circumstellar environment. The infrared differential imager and spectrograph (IRDIS), one of the three science instruments for SPHERE, provides simultaneous differential imaging in the near infrared, among with long slit spectroscopy, classical imaging and infrared polarimetry. IRDIS is designed to achieve very high contrast with the help of extreme-AO (Strehl > 90%), coronography, exceptional image quality (including non-common-path aberrations compensation), very accurate calibration strategies and very advanced data processing for speckle suppression. In this paper, we report on the latest experimental characterizations of IRDIS performed with extreme adaptive optics (SAXO) under various seeing conditions before the preliminary acceptance in Europe.

Robotic visible-light laser adaptive optics

Poster - N: 13321

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Robo-AO is the first autonomous laser adaptive optics system and science instrument operating on sky. With minimal human oversight, the system robotically executes large scale surveys, monitors long-term astrophysical dynamics and characterizes newly discovered transients, all at the visible diffraction limit. The average target-to-target operational overhead, including slew time, is a mere 86 s, enabling up to ~200 observations per night. The first of many envisioned systems has finished 51 nights of science observing at the Palomar Observatory 60-inch (1.5 m) telescope, with over 5,600 robotic observations executed thus far. The system will be augmented in late 2013 with a low-noise wide field infrared camera, which doubles as a tip-tilt sensor, to widen the spectral bandwidth of observations and increase available sky coverage while also enabling deeper visible imaging using adaptive-optics sharpened infrared tip-tilt guide sources. Techniques applicable to larger telescope systems will also be tested: the infrared camera will be used to demonstrate advanced multiple region-of-interest tip-tilt guiding methods, and a visitor instrument port will be used to evaluate visible-light single-mode and photonic fibers to feed compact spectrographs.

High precision astrometry using a diffractive pupil on segmented mirror telescopes and MCAO distortion calibration

Poster - N: 13322

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Atmospheric effects that limit the astrometric measurements from the ground are significantly diminished as the telescope aperture increases (Ammons et al., 2012). As a result, future ELTs offer unprecedented capabilities to achieve astrometric accuracies in the order of 40μas (MICADO). However, this can only be obtained, and even improved, if the telescope and adaptive optics system distortions can be calibrated over long periods of time. Future telescopes will be larger and have a greater number of optical surfaces that can suffer from bending and misalignment. Adding diffractive features on the primary mirror (Guyon et al 2012), a technique currently being studied for several space missions, could calibrate distortions induced by non-systematic changes on the optical train of any optical surface not conjugated to the pupil, including MCAO system DMs. This work discusses the feasibility of applying this concept to segmented mirror telescopes and assesses the effect of relative motion between the segments. It also presents a compatibility study of the simultaneous use of high contrast imaging and wide field astrometry using a diffractive pupil. Finally, it also analyzes a simpler solution in which the diffractive grid is placed on a relayed pupil before an MCAO system to calibrate the distortions induced by long-term drifts on high altitude conjugated DMs.

Predictive Control on LBT Adaptive Optics Data: Laboratory Tests

Poster - N: 13329

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Predictive algorithms have been already successfully applied and tested in many servo loop systems. In particular an ARMA based approach has been tested in MCAO simulations, demonstrating a significant improvement of the overall performances.In this contribution we present new results from the hardware implementation of our FORS algorithm, an ARMA-based closed loop control code, which we tested on real LBT Adaptive Optics data.Pros and cons of this control scheme are discussed, in light of the high demands in the performance of adaptive optics systems for the forthcoming ELT class of telescopes.

A linear relationship of pupil plane complex amplitudes and rooftop sensor measurements

Poster - N: 13335

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We consider a conventional rooftop sensor (variation of the pyramid wavefront sensor) with no beam modulation. The sensor produces four pupil images using a beam splitter and two perpendicular roof prisms or comparable components. We present a formalism showing a linear relationship between the pupil plane complex amplitudes and the sensor measurements. This formalism is then investigated further to find out its potential to reconstruct the wavefront at a very high resolution using numerically efficient algorithms. Performance comparisons are shown for the EPICS extreme AO at its 42 meter E-ELT design.

High Contrast Imaging with an Arbitrary Aperture: application of the Active Correction of Aperture Discontinuities to ELTs

Poster - N: 13373

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We discuss the application of a new method to achieve high-contrast images with Extremely Large Telescopes. Our approach relies on using two sequential Deformable Mirrors to compensate for the large amplitude excursions in the telescope aperture due to secondary support structures and/or segment gaps. In this configuration the parameter landscape of Deformable Mirror Surfaces that yield high contrast Point Spread Functions is not linear, and non-linear methods are needed to find the true minimum in the optimization topology. We solve the highly non-linear Monge-Ampere equation that is the fundamental equation describing the physics of phase induced amplitude modulation. We determine the optimum configuration for our two sequential Deformable Mirror system and show that high-throughput and high contrast solutions can be achieved using realistic surface deformations that are accessible using existing technologies. We name this process Active Compensation of Aperture Discontinuities (ACAD). We quantify the performances of this technique on various ELTs geometries. We illustrate its application when seeking to maintain high contrast in the configuration for which some of the primary mirror's segments might be missing.

Discret Aperture Mapping (DAM), a new high frequency optical filter for high contrast imaging

Poster - N: 13389

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A challenging study for high resolution and high-contrast imaging is the detection and the characterization of planets in the habitable zone. The problem of detection in imaging is due to both the contrast ratio and the tiny separation between the hosting star and the exoplanet. Certainly, many techniques in high-contrast imaging will have to be optimized simultaneously to enhance the detection treshold and to probe the candidates for life. In this context, the objective is to demonstrate the technical faisability and to get scientific returns with a new concept called Discret Aperture Mapping or DAM (Patru et al. 2011). DAM is a new interferometric technique allowing high contrast imaging over a narrow field of view imaged by the present class of mono-pupil telescopes equipped with adaptive optics (AO). DAM consists in mapping the telescope pupil to provide a correct sampling of the spatial frequency content of the telescope. DAM can be realized by an afocal double lenslet array array (BIGRE-DAM, Antichi et al. 2011), or by a single-mode fiber combiner (Fibered-DAM, Patru et al. 2008). The spatial filtering used in interferometry allows to subdivide the entrance pupil of a large telescope into many coherent sub-pupils, so that the intra-sub-pupil residual phase is averaged out. On the other side, frequencies higher than the deformable mirror sampling one are not corected by AO impling aliasing effect and a strong impact of Fresnel propagation on the compensated wavefront up to the final focus (Antichi et al. 2010). DAM is then a high frequency optical filter able to remove part of the AO residuals and to remove most of the halo in the image. It may improve the contrast limit to explore the inner region of new stellar systems (disk, exoplanet). We show here first simulation results on the DAM concept.

Discret Aperture Mapping with a BIGRE-DAM: First laboratory results

Poster - N: 13390

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Discret Aperture Mapping (Patru et al. 2011) - or DAM - is a new pupil remapping technique that may enhances the high angular resolution and the high contrast imaging capabilities of a large telescope equipped with an Adaptive Optics (AO). DAM provides a high-Strehl image thanks to a simple and passive optical component, composed of an afocal double lenslet array (BIGRE, Antichi et al. 2009. DAM, conveniently applied onto an image of the telescope pupil, sub-divides the pupil in many spatially filtered sub-pupils (Antichi et al. 2011). This pwork deals with the first laboratory results on a testbed aimed at verifying the BIGRE-DAM optical concept with visible light. We focus our attention on the on-axis point spread function properties of BIGRE-DAM, on the aliasing effects as a function of the off-axis position of the object. The results show a good comparison between experience and simulation. They validate the quality of the optical component to use it on sky. They show the simplicity and the great potential of BIGRE-DAM as a useful technique in high contrast imaging application. The next objectif will be to test a DAM with an AO, first in laboratory and then on sky, so as to demonstrate the interest of DAM coupled with the new class of AO-assisted intruments, e.g. SPHERE and ERIS at the VLT.

SCExAO as a precursor to an ELT exoplanet direct imaging instrument

Poster - N: 13396

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[1] SUBARU Telescope

The Subaru Coronagraphic Extreme AO (SCExAO) instrument consists of a high performance Phase Induced Amplitude Apodisation (PIAA) coronagraph combined with an extreme Adaptive Optics (AO) system operating in the near-infrared (H band). The extreme AO system driven by the 2000 element deformable mirror will allow for Strehl ratios>90% to be achieved in the H-band when it goes closed loop. This makes the SCExAO instrument a powerful platform for high contrast imaging down to angular separations of the order of 1 lambda/D and an ideal testbed for exploring coronagraphic techniques for ELTs. In this paper we report on the recent progress in regards to the development of the instrument, which includes the addition of a visible bench that makes use of the light at shorter wavelengths not currently utilized by SCExAO and closing the loop on the tip/tilt wavefront sensor. We will also discuss several exciting guest instruments which will expand the capabilities of SCExAO over the next few years; namely CHARIS which is a integral field spectrograph as well as VAMPIRES, a visible aperture masking experiment based on polarimetric analysis of circumstellar disks. In addition we will elucidate the unique role extreme AO systems will play in enabling high precision radial velocity spectroscopy for the detection of small companions.

New developments at MPIA in Heidelberg to make AO more sensitive and more precise

Poster - N: 13430

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In my contribution, I will review our recent efforts in the field of ELT-scale AO hardware and control. Instrumentational background is our lead of the MCAO-supported Fizeau imager LINC-NIRVANA for the LBT, and co-development of the SCAO module of the E-ELT firstlight camera MICADO. The presented instrumentation research supports our main scientific goals: improvement of AO performance of faint extragalactic imaging and high precision astrometry, to detect black holes and dark matter in stellar clusters and dwarf galaxies. The presented selection will include(i) recent success to measure the LBT main mirror vibrations in real-time to the 5% precision level with a dedicated accelerometer system and advanced modeling(ii) passive and active resonance suppression of large, fast actuators(iii) modeling and measuring mirror vibrations without starlight to improve limiting magnitudes(iv) optical calibration of MICADO imaging aberrations to achieve a regular, repeatable differential, astrometric precision of 50uas.

Field tests of elongated Na LGS wavefront sensing for the E-ELT

Poster - N: 13437

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Wavefront sensing using extremely elongated Sodium Laser Guide Stars (LGS) is a key concern for the design of a number of first generation ELT AO modules. One of the main challenges is the mitigation of the effects induced by extreme elongation on the wavefront measurements. Before the final design studies of the E-ELT instruments, a Na LGS wavefront (WF) sensing on-sky field experiment at this scale is strategic and mandatory to provide spatial and temporal wavefront measurements on a true LGS, subject to the atmospheric and mesospheric variability. The fine comparative analysis of such data with synchronously acquired WF measurements on a NGS will be unique to test a number of algorithms, configurations for spot sampling and truncation and WF reconstruction schemes including multi-LGS configurations. We propose to use CANARY, the Multi-Object AO demonstrator installed at the WHT (4.2m) . CANARY is now equipped with a Rayleigh LGS and also provides several natural guide star WFS. It shall be adapted to the Na LGS to provide the same pupil sampling than the NGS WFS for direct comparison. A compact, transportable laser system, such as the WLGSU developed at ESO, positioned at a varying distance from the WHT will be used to provide off-axis launching (up to 40m), simulating the whole range of LGS spot elongations obtained on the E-ELT. In addition, this experiment will include varying rate Sodium profiling and open and close-loop operations including offloads from profiling. In this paper, we present the objectives and the design of the proposed experiment and detail our strategy in terms of experimental setup and data reduction. A global error budget for the whole experiment is derived and spin-offs for the adequate dimensioning of E-ELT LGS-AO modules WFS are demonstrated.

The possible upgrades of SPHERE eXtreme AO : improving the detectivity toward the next generation of planet finders on ELT

Poster - N: 13493

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SAXO is the eXtreme Adaptive Optics system at the heart of the SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research in Europe) system. This challenging second-generation instrument for the ESO VLT is dedicated to the direct detection and spectral characterization of extra-solar planets. In this respect, SPHERE relies on its extreme adaptive optics system but also on various coronagraphic devices and on a suite of focal instruments providing imaging, integral field spectroscopy and polarimetry capabilities in the visible and near-infrared spectral ranges. The eXtreme AO SAXO shall thus provide to the scientific instruments a flat wavefront corrected from all the atmospheric turbulence and internal defects. While SAXO AIT are in their final stage and results on SAXO performance are presented, we propose to come back on the lessons learned from these AIT. It is indeed a most interesting moment in the life of a project to have a look back on what has been specified, numerically simulated, and what has been really implemented in the end and the associated performance. Either motivated by instrumental limitations and constraints or by trade-offs between performance and operability, some significant upgrades have been proposed for SAXO, particularly concerning wavefront sensing, control laws, non-common path aberrations estimation and compensation or calibration tools. We propose a critical analysis of these modifications and discuss possible upgrades that could benefit to any AO system.

The LBT Experience of Adaptive Secondary Mirror operations for Routine Seeing- and Diffraction-limited Science Operations

Poster - N: 14612

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The Large Binocular Telescope (LBT) is unique in that it is currently the only large telescope (2 x 8.4m primary mirrors) with permanently mounted adaptive secondary mirrors (ASMs). These ASMs have been used for regular observing since early 2010 on the right side and since late 2011 on the left side. They are currently regularly used for seeing-limited observing as well as for selective diffraction-limited observing and are required to be fully operational every observing night. By comparison the other telescopes using ASMs, the MMT and more recently Magellan, using fixed secondaries of seeing-limited observing and switch in the ASMs for diffraction-limited observing. We will discuss the night-to-night operational requirements for ASMs specifically for seeing-limited but also for diffraction-limited observations based on the LBT experience. These will include preparation procedures for observing (mirror flattening and resting as examples); hardware failure statistics and how to deal with them such as for the actuators; observing protocols; and current limitations of use due to the ASM technology such as the minimum elevation limit (25 degrees) and the hysteresis of the gravity-vector induced astigmatism. We will also discuss the impact of ASM maintenance and preparation on science observing time and describe our experience of the systems' performance and calibration reliability.

Results using the Improved Active Optics Algorithm for the Large Binocular Telescope Using Source Extractor and an On-The-Fly Reconstructor

Poster - N: 14614

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To efficiently use Adaptive Optics (AO) systems on large telescopes it is necessary to have a well collimated telescope for which an Active Optics (aO) system is required. Algorithms for aO systems share a lot in common with those for AO systems. For the Large Binocular Telescope (LBT) the AO system comprises a 12x12 Shack-Hartmann (SH) wavefront sensor which is comparable to those in at existing telescope for used for AO. The aO collimation for seeing limited operation at the LBT was recently upgraded from a center-of-weight (CoW) and static reconstructor algorithm to a Gaussian fitting and dynamic reconstructor algorithm. For each new observational target AO collimates the telescope optics in order to provide the optimal science image quality at the desired instrument focal plane. The previous algorithm used center-of-weight to identify the sub-aperature centroids needed for the wavefront reconstruction. It could require four to five iterations, each lasting ~50 seconds, to achieve collimation. The new algorithm uses Source Extractor*, and usually collimation is reached in two to three iterations, saving ~50 to 100 seconds per target, which translates directly to an increase in science time. In addition, the delivered image quality using this new algorithm is more robust to changes in seeing conditions, guide star brightness and the loss of wavefront information due to missing SH spots caused by a highly aberrated wavefront or a vignetted pupil. The advantage of this new algorithm is that a dynamic reconstructor can be use when SH spots are either missing or non-detectable. The reconstructor using the center-of-weight algorithm would yield an incorrect solution because all sub-aperatures, including those with missing signal, were included in the wavefront reconstruction. The new reconstructor is dynamic because it change as

the number of illuminated sub-aperatures change as detected by Source Extractor. We will present a brief description of the AO system used at the Gregorian focal stations at the LBT, discuss the original CoW algorithm, describe the new Source Extractor approach and present the on-sky results of these two methods demonstrating the improved collimation time, increased stability and robustness to missing wavefront information of the new approach.

Current status of Raven, a MOAO science demonstrator for Subaru telescope

Poster - N: 15991

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Raven is a Multi-Object Adaptive Optics (MOAO) scientific demonstrator which will be used on-sky at the Subaru observatory from 2014. Raven is currently being built and tested at the University of Victoria AO Lab. This paper presents an overview of the optomechanical design and the software architecture of Raven, and gives the current status of this project. Raven includes three open loop wavefront sensors (WFSs), a laser guide star WFS and two figure/truth WFSs. Two science channels containing deformable mirrors (DMs) feed light to the Subaru IRCS spectrograph. Central to the Raven is a Calibration Unit which contains multiple sources, a telescope simulator including two phase screens and a ground layer DM that can be used to calibrate and test Raven in the lab. Preliminary results on calibration and open-loop AO correction using a tomographic reconstructor are presented.

4 AO numerical simulations and modeling

Oral

Wavefront Reconstruction for a Natural Guide Star Ground Layer Adaptive Optics System on the Giant Magellan Telescope

Oral - N: 12295

Marcos Van Dam[1], Antonin Bouchez, Rodolphe Conan

[1] Flat Wavefronts

In this paper, we present a wavefront reconstruction paradigm for NGS GLAO systems. The conventional approach to reconstructing the wavefront for LGS GLAO systems is to have a number of LGSs in a ring outside the science field and simply average the individual wavefronts. This approach is not well-suited to NGS GLAO because the stars have an irregular distribution and varying magnitudes. In this paper, we derive covariance matrices for the wavefronts is different directions and the measurement noise. Using these covariance matrices, we are able to find the minimum-variance reconstructor and estimate the residual wavefront as a function of location in the field. This can be used to determine which guide stars produce the best correction. End-to-end simulations in YAO are run, with pseudo-open loop control, to estimate the expected performance of the NGS GLAO system for the Giant Magellan Telescope.

Fast E2E simulation tools and calibration strategies for EAGLE on the E-ELT

Oral - N: 13221

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Refined simulation tools for wide field AO systems (such as MOAO, MCAO and LTAO) on ELTs present new challenges. Increasing the telescope diameters and the new higher-resolution applications on planned AO systems makes many existing codes useless due to the huge number of operations to be performed at each step of the AO loop process. This computational burden requires new approaches in the computation of the DM voltages from WFS data. The classical matrix inversion and the matrix vector multiplication have to be replaced by a clever iterative resolution of the Maximum A Posteriori (MAP) criterion. In this paper we present different control law performances based on a refined E2E tool developed to deal with these specific ELT challenges. It is based on an iterative resolution of the linear model with high number of degrees of freedom and includes new concepts of filtering and coupling between LGS and NGS to effectively manage modes such as tip / tilt and defocus in the entire process of tomographic reconstruction. We present new strategies to calibrate an MOAO system on the frame of the EAGLE project: a flagship instrument for the future E-ELT combining all the experience gained from the current generation of AO systems. Such an AO system requires a full modelisation of the interaction matrices. For those reasons we present a new concept to deal with differential pupil and field rotations such as the measurement of the influence functions of both the deformable M4 mirror and individual MOAO DMs.

Evaluation of Astrometry Errors due to the Optical Surface Distortions in Adaptive Optics Systems and Science Instruments

Oral - N: 13285

Brent Ellerbroek[1], Glen Herriot[2], Ryuji Suzuki[3], Schoeck Matthias[1]

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The objectives for high precision astrometry on ELTs will be challenging, with requirements in the range from 10 to 50 micro-arc-seconds for some instruments and science cases. Reducing and correctly calibrating the systematic and quasi-static errors introduced by optical surface distortions will be an important part of meeting these goals. In a recently submitted paper, we described an analytical Fourier domain model for evaluating these effects as the sum of three terms: (i) under-sampling errors, due to measuring the effects of static surface distortions using a finite number of discrete reference sources; (ii) unknown beam wander across the static surface distortions due to line-of-sight jitter or boresighting errors, and (iii) quasi-static errors due to slowly varying surface distortions. In this paper, we apply these methods to evaluating this term in the astrometry error budgets for the TMT Infrared Imaging Spectrograph (IRIS) and the facility AO system, NFIRAOS. The inputs to this exercise include the original top-down allocations for this error term, the original optical surface specifications for IRIS and NFIRAOS as derived earlier on the basis of wavefront error requirements, our assessment of the feasible density and positioning accuracy for an array of calibration

sources, and the expected beam wander due to tip/tilt jitter and bore-sighting errors between NFIRAOS and IRIS. The astrometry error computed for these initial parameters was considerably larger than the top-down allocation due to the contributions from the NFIRAOS double-pane entrance window, which is close to the system's input focal plane. The error can be reduced to fall within the allocation by defining tighter, but still feasible, specifications for these elements. We also evaluated the astrometry errors due to quasi-static drift of the figures of the NFIRAOS deformable mirrors, and determined that they are acceptable for RMS wavefront distortions of up to about 30 nm RMS.

Development and validation of vibration source requirements for TMT to ensure AO performance

Oral - N: 13362

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In order for TMT to deliver the required AO image quality, sources of vibration throughout the observatory need to be characterized and tabulated. A table of sources has been developed including the location of each source and an estimate of the force amplitude in key frequency bands. Sensitivity to vibration has been determined using a finite element model of the system. This model includes the main optical elements, the individual mirror segment supports, and the telescope structure. Soil stiffness estimated by ground-penetrating radar is included with a model of the support building, enclosure and telescope pier foundations. Frequency dependent models of the AO, active optics and mount control systems are included allowing end-to-end assessment of vibration sources on AO corrected image quality. Effects on image jitter caused by relative rigid body motion of main optical elements are distinguished from effects caused by dynamic motion of individual primary mirror segments. These results have been used to develop allocated requirements on source amplitudes in each frequency band, and isolation systems required at various locations both in the support building and enclosure and on the telescope structure. A program of validation of these requirements is described including measurement of comparable sources and comparable transmission paths. A scheme for verification of these combined models of transmission paths and installed sources to be conducted during observatory assembly and integration is described.

Modeling wide-field wavefront sensing in solar adaptive optics and its effect on tomographic reconstruction

Oral - N: 13377

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The planned 4-meter diameter of the European Solar Telescope (EST) is aimed at providing high spatial resolution and large photon collecting area, in order to understand in particular the mechanisms of magnetic coupling in the chromosphere and the photosphere. To reach its goals in visible and near-infrared, the EST is designed with a multi-conjugate adaptive optics (AO) of similar complexity as the ones featured for the Extremely Large Telescopes. In addition, the EST MCAO has to face a particularity of solar AO systems : the wavefront sensing on extended sources with measurement fields of about 10" in size. Reviewing recent literature and together with an independent analysis, we investigate the impact of this extended-field sensing in the AO for large solar telescopes. Classical sensing modeling and reconstruction performance are analyzed thanks to simulations, showing the difficulty to correct high altitude turbulence. We study a modified direct model of this extended-source sensing, with the specific goal of improving the tomographic reconstruction. The impact on EST expectable performance is then evaluated with end-to-end simulations of the MCAO system, involving Octopus simulator and the Fractal Iterative Method (FRiM-3D) for tomography.

On-Sky Pathfinder Tests of Calibrated MCAO Astrometry and Implications for MCAO on ELTs

Oral - N: 13399

S. Mark Ammons[1], Eduardo Bendek[2], Olivier Guyon[3], Christian Marois[4], Benoit Neichel[5], Raphael Galicher[6], Bruce Macintosh[1]

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[5] Gemini Observatory
[6] Observatoire de Paris

MCAO systems on ELTs should deliver the best available relative astrometric precision from the ground, which may be sufficient to detect exo-earths orbiting nearby brown and red dwarfs (< 0.03 mas). Yet despite the success of AO astrometry on large telescopes, we still do not understand the systematic errors that may dominate long-term astrometric stability with MCAO, such as dynamic optical distortion and differential atmospheric refraction (DAR). We present results from two on-sky pathfinders intended to characterize long-term systematic errors in MCAO systems and discuss implications for MCAO on ELTs. The first is an astrometric monitoring program of bright stars in 2013A on the GEMS LGS MCAO system. We isolate the effects of dynamic optical distortion by using narrow filters to counter atmospheric refraction and observing sparse fields to avoid crowding errors. We characterize the magnitude of long-term optical drift in GEMs as well as the dependency on the number of NGSs used. The second pathfinder is an on-sky test of the diffractive pupil concept on a 1-meter telescope at Lick Observatory, theorized to calibrate changing optical distortion with diffracted light from the target star (Guyon et al. 2012). These data indicate PSF modeling systematics of one thousandth of the star FWHM (1 mas) for individual stars, but we show that averaging the many diffracted PSFs reduces this error and other flat-fielding errors to the ˜0.5 mas level. We show that the diffractive pupil stabilizes the instrumental distortion to at least the precision of the experiment (˜1 mas over 3'). We simulate the astrometric performance of a hybrid MCAO + diffractive pupil system on ELTs. The diffracted PSFs include an anisoplanatic term, increasing PSF modeling errors, but the sum of all random errors (CDAR, DAR, DTTJ, S/N) can be better than 0.01 mas for 5 minute exposures for K < 15 stars.

Exoplanet Imaging with TMT: A Complete End-to-End TMT/NFIRAOS/IRIS Fresnel Simulation and a New LOCI SSDI Algorithm

Oral - N: 13450

Christian Marois[1], Carlos Correia, Jean-Pierre Veran

[1] National Research Council Canada

The first exoplanet imaging science at TMT will be performed with NFIRAOS and IRIS. Following the TMT+NFIRAOS high-contrast work presented by our team at AO4ELT2, the complete optical path, now including the IRIS prescription, as been simulated with PROPER. A 1h equivalent sequence of quasi-static polychromatic data cubes is generated at H-band with a simulated AO-corrected atmosphere. The achievable contrast is analyzed using a new optimal LOCI algorithm that is specialized in subtracting polychromatic data cubes. Contrasts of the level of GPI are expected, while higher contrasts will require a dedicated high-contrast imaging instrument. I will present the overall updated simulations, describe how the time-evolving aberrations are generated and show the typical contrasts we should be achieving at first light with NFRIAOS/IRIS. I will also briefly describe the new SSDI LOCI algorithm.

Laser guide star Fourier tomography on extremely large telescopes

Oral - N: 13487

Luc Gilles[1], Paolo Massioni, Caroline Kulcsar, Henri-François Raynaud, Brent Ellerbroek

[1] Thirty Meter Telescope Observatory Corporation

This paper discusses performance and cost of two computationally efficient Fourier-based tomographic wavefront reconstruction algorithms for wide field laser guide star adaptive optics. The first algorithm is the iterative Fourier Domain Preconditioned Conjugate Gradient (FDPCG) algorithm developed by Vogel et. al. [Yang, Vogel and Ellerbroek, Appl. Opt. 45, 5281 (2006)], combined with pseudo open loop control (POLC). FDPCG's computational cost is proportional to N*log(N), where N denotes the dimensionality of the tomography problem. The second algorithm is the distributed Kalman filter (DKF) developed by Massioni et. al. [Massioni, Kulcsar, Raynaud and Conan, JOSA A 28, 2298 (2011)], which is a non-iterative, spatially invariant controller. When implemented via Fast Fourier Transforms (FFTs), DKF's cost is also proportional to N*log(N). Both algorithms are capable to estimate spatial frequency components of the residual phase beyond the wavefront sensor (WFS) cutoff frequency thanks to regularization prior information, thereby reducing WFS spatial aliasing at the expense of more computations. We present performance and cost analyses for the laser guide star (LGS) multi-conjugate adaptive optics (MCAO) system under design for the Thirty Meter Telescope (TMT), and a brief sensitivity analysis of the DKF algorithm with respect to uncertainties in the wind profile prior information. Due to its non-sequential nature and high degree of parallelism, the DKF algorithm is particularly well suited for real-time implementation on inexpensive off-the-shelf Graphics Processing Units (GPUs).

Posters

End-to-end simulations of E-ELT instrument performance

Poster - N: 12496

Miska Le Louarn[1]

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In this contribution, we will present the latest simulation results obtained with the Octopus end-to-end simulation tool for the E-ELT's AO instruments. These simulations include effects such as the spot-truncation on the LGS-wavefront sensors on tomographic AO systems (LTAO and MCAO) - which has an impact on the necessary number of CCD pixels on the LGS WFS. Another effect that is investigated, using the Frim reconstructor, is the impact of a thick spider on LTAO performance. Finally, we also investigate the limiting magnitude of natural guide star(s) in a laser tomography system.

Sky coverage for Adaptative optics : an analytical expression

Poster - N: 12528

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The correction of the wavefront in adaptive optics usually requires the existence of a natural reference star. This depends on the density of stars in the sky, which is called the sky coverage in literature. However it is known that even such a star exists, it could not be detected, this effect depends on the instrument used and the quality of the atmosphere in which we operate. Indeed, the sky coverage depends on the density of stars, the instrumental parameters and atmospheric parameters. In this work, we will establish an analytical formula of the sky coverage taking into account all the above-mentioned parameters. That formula gives a more general definition of sky coverage, instead of that related only to the density of stars in the sky. Thus, we can know, for a given equipement and a given site, if we have enough reference stars or not before any installation.

ELT AO simulations on a laptop with YAO

Poster - N: 13173

François Rigaut[1], Marcos Van Dam[2]

[1] Francois Rigaut
[2] Marcos van Dam

Adaptive Optics systems are at the heart of the coming Extremely Large Telescopes generation. Given the importance, complexity and required advances of these systems, being able to simulate them faithfully is key to their success, and thus to the success of the ELTs. The type of systems envisioned to be built for the ELTs cover most of the AO breeds, from NGS AO to multiple guide star Ground Layer, Laser Tomography and Multi-Conjugate AO systems, with typically a few thousand actuators. This represents a large step up from the current generation of AO systems, and accordingly a challenge for existing AO simulation packages. This is especially true as, in the past years, computer power has not been following Moore's law in its most common understanding; CPU clocks are hovering at about 3GHz. Although the use of super computers is a possible solution to run these simulations, being able to use smaller machines has obvious advantages: cost, access, environmental issues. By using optimised code in an already proven AO simulation platform, we were able to run complex ELT AO simulations on very modest machines, including laptops. The platform is YAO. In this paper, we describe YAO, its architecture, its capabilities, the ELT-specific challenges and optimisations, and finally its performance. As an example, execution speed ranges from 5 iterations per second for a 6 LGS 60x60 subapertures Shack-Hartmann Wavefront sensor Laser Tomography AO system (including full physical image formation and detector characteristics) up to over 30 iterations/s for a single NGS AO system.

Frequency-based design of Adaptive Optics systems

Poster - N: 13218

Guido Agapito[1], Giorgio Battistelli[2], Daniele Mari[2], Daniela Selvi[2], Alberto Tesi[2], Pietro Tesi[3]

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The problem of reducing the effects of wavefront distortion and structural vibrations in ground-based telescopes is dealt with within a modal-control framework. The proposed approach aims at optimizing the parameters of a given modal stabilizing controller with respect to a performance criterion which reflects the residual phase variance. The cost functional to be minimized is quadratic and is defined on a sampled frequency domain. This framework makes it possible to account for turbulence and vibration profiles of arbitrary complexity (even empirical power spectral densities from data), while the controller order can be kept at a desired value. Moreover it is possible to take into account additional requirements, as robustness in the presence of disturbances whose intensity and frequency profile vary with time. The proposed design results in solving a quadratic programming problem, for which there exist several

standard optimization techniques. The optimization starts from a given stabilizing controller which can be either a non-model-based controller (in this case no identification effort is required), or a model-based controller synthesized by means of turbulence and vibration models of limited complexity. In this sense the approach can be viewed not only as alternative, but also as cooperative with other control design approaches. The results obtained by means of an end-to-end simulator are shown to emphasize the power of the proposed method.

First end-to-end AO simulation results to dimension the ELT-CAM/MICADO SCAO mode

Poster - N: 13240

Yann Clenet[1], Damien Gratadour[1], Eric Gendron[1], Gérard Rousset[1], Arnaud Sevin[1]

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We present here first results of end-to-end simulations done to dimension the SCAO mode that will be included in ELT-CAM/MICADO, the E-ELT first light imager. These simulations have been done using a GPU based Monte Carlo model providing almost real-time performance at the E-ELT scale (several hundred iterations per second). The simulations will address the SCAO performance evaluation in terms of observing conditions and wavefront sensor concepts. We also present the performances of this GPU-based software compared to classical, CPU-based, end-to-end AO simulation software.

Parameterising E-ELT AO PSFs for detailed science simulations for HARMONI

Poster - N: 13269

Simon Zieleniewski[1], Niranjan Thatte[2]

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With the first ELTs around the corner it is becoming ever more important to determine observational strategies and assess the prospective success of observing programs prior to making the observations. To this end, scientific simulations need to become more refined to understand the criteria required for a specific science case. We address the science simulations for HARMONI, an AO assisted first light integral field spectrograph (IFS) for the E-ELT. AO PSFs vary markedly as a function of wavelength and type of AO system used, so there is need to create detailed PSFs across all IFS wavelength channels for accurate simulations. Detailed AO simulations have shown that for LTAO on the E-ELT, Strehl ratios can vary from 0.5E-3 in V-band up to 0.5 in K-band. Using a single PSF for an entire datacube (especially with large instantaneous wavelength coverage) could introduce misleading features into simulated observations using HARMONI. We have developed a method to parameterize detailed PSFs using analytical models, which can then be interpolated as a function of wavelength. This allows us to create accurate, but computationally inexpensive, AO PSF datacubes for HARMONI simulations. This shall be developed to cover LTAO, SCAO and GLAO/no-AO PSFs for a range of observing parameters.

Preliminary performance analysis of the Multi-Conjugate AO system of the EST

Poster - N: 13272

Icíar Montilla[1], Clémentine Béchet[2], Maud Langlois[2], Michel Tallon[2], Manuel Collados[3]

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The European Solar Telescope (EST), a 4-meter diameter world-class facility, has been designed to measure the properties of the solar magnetic field with great accuracy and high spatial resolution. For that reason, it incorporates an innovative built-in Multi-Conjugate Adaptive Optics system (MCAO), featuring 4 high altitude DM's. It combines a narrow field high order wavefront sensor, providing the information to correct the ground layer, and a wide field lower order sensor to control the higher altitude mirrors. Using sensors collecting wide field of view information has several implications, i.e. it averages wavefront information from different sky directions, making the Strehl ratio to drop for low elevation observations. So far these effects have not been studied in MCAO. We analyze this effect by using the Fractal Iterative Method (FrIM), which incorporates a wide field Shack-Hartmann, and we performed end to end simulations of the EST MCAO system to analyze the performance of this system for a large range of elevations, as required in solar observations, and depending on the asterism geometry and number and height of DM's, in order to find the best system configuration.

Updated Sky Coverage Estimates for the TMT Facility AO System NFIRAOS

Poster - N: 13284

Wang Lianqi[1], Gilles Luc[1], Brent Ellerbroek[1]

[1] TMT Observatory Corporation

AO system performance for observations of particular science fields is constrained by the availability of bright, nearby guide stars for accurate wavefront measurements. "Sky coverage" is the probability of finding such stars. Sky coverage is a function of seeing, zenith angle, the guide star density function, and the desired level of AO performance. Estimating sky coverage for the laser guide star (LGS) multi-conjugate AO system NFIRAOS is not straightforward, since NFIRAOS employs multiple natural guide stars (NGSs) to measure tip/tilt and plate scale (or tilt anisoplanatism) image distortion modes. We have previously described how the "split tomography" method used in NFIRAOS for the LGS- and NGS-controlled wavefront modes enables efficient Monte Carlo simulations for large numbers of random asterisms, which can be used to express sky coverage as a cumulative probability density function. Sky coverage can then be parameterized vs. galactic latitude and longitude, assuming (for example) that targets are observed at a particular hour angle relative to transit. This paper outlines refinements made to our NFIRAOS sky coverage estimates over the past year. Updated and more detailed models for the TMT pupil function and the surface distortions in all telescope, NFIRAOS, and instrument optics have been implemented. Results generated for a variety of different control algorithm implementations show non-negligible differences in performance. Sodium layer range variations are now simulated explicitly, including the spatial variations between separate LGS and the partial cross-coupling between range variations and plate scale modes in the NGS wavefront sensors. Sky coverage has been improved, particularly at high zenith angles, by extending the wavefront sensing spectral passband to the Ks band. Further improvements appear feasible by two candidate refinements to the control algorithms: "Selective sharpening," which improves the Strehl ratio for each NGS image, and "Minimum variance split tomography," which optimizes the basis of NGS-controlled modes separately for each asterism.

Multiscale modeling for the simulation of not completely frozen flow turbulence

Poster - N: 13297

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Models typically used to simulate the influence of atmospheric turbulence on ground telescope observations are usually based on the frozen flow hypothesis. However, the frozen flow model of the atmosphere is valid at time scales of the order of tens/hundreds of milliseconds. This paper generalizes a previous model for turbulence simulation to ensure reliable tests of AO system performance in realistic working conditions. The proposed method relies on the use of two simulation models: First, the part of turbulence that shows a coherent flow at short time scales is simulated by means of a multiscale autoregressive-moving average model, which allows to efficiently simulate (with computational complexity O(n)) the coherent evolution of the turbulence. Secondly, an approach similar to that considered for dynamic textures, is used to simulate aberrations caused by processes that evolve on much longer time scales. The proposed procedure is tested on simulations.

Simulation and Laboratory results of a Linear Quadratic Gaussian tomographic wavefront reconstructor for Raven

Poster - N: 13311

Kate Jackson[1], Carlos Correia[2]

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Raven is a Multi-Object Adaptive Optics (MOAO) technology and science demonstrator under development at the University of Victoria to be tested on the Subaru telescope. The baseline design calls for three natural guide star (NGS) wavefront sensors (WFS) and two science pickoff arms that will patrol a 2 arcminute diameter field of regard (FOR). Sky coverage is an important consideration as Raven is both a technical and science demonstrator. Early stage simulation of Raven's performance established that the key science requirement can be met: that 30% of the energy of an unresolved point spread function (PSF) be ensquared within a 140 mas slit using existing WFS camera and deformable mirror (DM) technology. The 30% ensquared energy (EE) requirement will be met with three NGSs and will exceed 40% if the Subaru Laser Guide Star (LGS) is used on-axis (assuming median image quality). This is projected to be true for NGS as faint as magnitude 14.5. The primary source of error is the tomographic error due to the system's physical configuration. The limiting magnitude of the NGSs is reached when the number of photons is so low that the decrease in signal to noise ratio (SNR) cannot be offset by longer WFS integration times due to the increase in temporal lag error. Previous work has shown that a Linear Quadratic Gaussian (LQG) controller can boost system performance (over using a static wavefront reconstruction algorithm) by improving noise rejection and using a predictive model to reduce temporal lag error. This translates into an increase in the limiting magnitudes of the

NGSs and thus greater sky coverage. This work presents the performance projections of Raven for several tomographic reconstruction algorithms including the LQG. The results are first obtained in simulation and then tested in the lab using the Raven test-bed and telescope simulator.

Fast modelling of MOAO point-spread function image on an ELT

Poster - N: 13343

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We present a method for modelling MOAO-compensated point-spread function images on an ELT. It is inspired from existing Fourier-based methods concerning the terms of the error budget such as fitting or temporal error, while mixing a matrix-based representation for the tomographic error term. This allows us to run the ELT-size simulation on a standard laptop and get results with acceptable approximations in the timescale of a few minutes. The validation of the method has been achieved using the high computing capacity of GPU-accelerated machines, able to achieve the full-scale ELT simulation. The results obstained on both platforms will be shown and compared.

Experimental tests of ARMA prediction AO models for next generation solar telescopes

Poster - N: 13345

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The forthcoming 4-meter class solar telescopes will require a high efficiency adaptive optics (AO) system to address the main science goals, and increase our understanding of the Sun down to the tiniest spatial scales at which magnetic fields are thought to play a fundamental role in determining energy and dynamics of the solar atmosphere. To this aim, difficulties peculiar to the solar case, such as the low contrast and extended nature of solar granulation (the target of AO tracking), have to be considered. We present the results of numerical simulations and laboratory tests of the implementation of a new closed-loop prediction-based control scheme, aimed at increasing the overall performance of solar MCAO systems. Our results demonstrate that this solution can provide a significant increase of the stability of the loop, as well as an intrinsic reduction of the residual uncorrected phase aberrations.

Tip/Tilt/Focus Guide Star Acquisition for TMT NFIRAOS

Poster - N: 13391

Glen Herriot[1], Jean-Pierre Veran, Carlos Correia

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NFIRAOS, the multi-conjugate adaptive optics system for the Thirty Meter Telescope relies on three On-Instrument Wavefront Sensors (OIWFS) using natural guide stars in the infrared to control tip/tilt, focus and plate scale. By operating in the infrared, the OIWFSs take advantage of the image sharpening by NFIRAOS to measure image position with good accuracy. In this paper, we present the acquisition process for these natural guide stars. In operation, two OIWFSs will be remotely configured as a imagers with 1K x 1k pixels, and the other one as a 2x2 SH WFS. During a science exposure, after all loops are locked, a small (4x4 pixels) region of interest (ROI) will be read out around the centre of each imager (or SH detector quadrant), with good speed and noise characteristics. However, the blind pointing accuracy of the telescope means that initially the image may be found anywhere on the detector. Acquisition begins by closing the high-order LGS loop to sharpen the instantaneous PSF. But, reading the entire detector takes a considerable time, and before the image is stabilized it is a broad streak with poor signal to noise. If the OIWFS were to integrate long enough to produce a detectable image, e.g. 1 second, and then offset the telescope or guider to centre the natural guide star, then windshake and turbulence would carry the image out of the central ROI before the tip/tilt loop could be closed. We have devised and simulated an iterative algorithm that progressively reduces the capture window size in steps, while increasing the frame rate and the control loop gain to automatically and robustly centre the guide star on the detector. This algorithm is table-driven and proceeds deterministically without any "if statements." We present results from these simulations.

Error Budgeting of Jitter specifications for AO Real-Time Computers

Poster - N: 13392

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An important item in a wavefront error budget for an adaptive optics system is temporal lag, or servo error. Consequently the frame rate of an AO system, WFS integration and readout time, together with Real-Time Computer latency, is typically specified and simulated carefully. However, programmable computers may exhibit jitter in the execution time to calculate deformable mirror commands from WFS pixels. Benchmarks of candidate Real-Time Computer architectures for TMT NFIRAOS show some jitter. This variable latency is a source of noise, which is a frequency-dependent function of the input turbulence. In the signal-processing industry, 'aperture-jitter' has long been a concern, driving the development of precise sample-and-hold circuits and analog to digital converters. We borrow some of these techniques in this paper to quantify the effect of Real-Time Computer jitter on wavefront error to provide a method to specify acceptable levels, traceable to overall error budgets. We present the results of simulations of the jitter errors of TMT NFIRAOS for turbulence on Mauna Kea.

Tip/tilt mirror control with actuators saturations

Poster - N: 13438

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An astronomical adaptive optics system usually includes a tip/tilt mirror to remove the atmospheric tip/tilt components and also the telescope's tracking error. We consider a standard control strategy where the control system is splitted into two separate and ideally non-interacting control loops (control of a dedicated tip/tilt mirror and control of the DM mirror). In this paper, we study the tip/tilt mirror control in presence of actuators saturations which are always present and can dramatically degrade the performances. Theoretical results (Scorletti 2001) have shown that saturations could be efficiently taking into account by an Linear Matrix Inequality based design approach. This method is used to guarantee performance for the closed loop system by avoiding saturation or by ensuring absolute stability. The achieved performances are evaluated through numerical simulations. G. Scorletti, J.P. Folcher and L. El Ghaoui, ,"Output feedback control systems with input saturations : LMI design approaches", European Journal of Control, vol. 7(6), 2001.

5 Wave-front sensing

Invited

Visible and Infrared Wavefront Sensing detectors review

Invited - N: 15019

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The purpose of this review is to give an overview of the state of the art wavefront sensor detectors developments held in Europe for the last decade. A major breakthrough has been achieved with the development by e2v technologies of the CCD220 between 2004 and 2012. Another major breakthrough is currently achieved with the very successful development of fast low noise infrared arrays called RAPID. The astonishing results of this device will be showed for the first time in an international conference at AO4ELT3.The CCD220, a 240x240 pixels 8 outputs EMCCD (CCD with internal multiplication), offers less than 0.2 e readout noise at a frame rate of 1500 Hz with negligible dark current. The OCAM2 camera is the commercial product that drives this advanced device. This system, commercialized by First Light Imaging, is quickly described in this paper. An upgrade of OCAM2 is currently developed to boost its frame rate to 2 kHz, opening the window of XAO wavefront sensing for the ELT using 4 synchronized cameras and pyramid wavefront sensing. This upgrade and the results obtained are described extensively elsewhere in this conference (Gach et al).Since this major success, new detector developments started in Europe. The NGSD CMOS device is fully dedicated to Natural and Laser Guide Star AO for the E-ELT with ESO involvement. The spot elongation from a LGS Shack Hartman wavefront sensor necessitates an increase of the pixel format. The NGSD will be a 880x840 pixels CMOS detector with a readout noise of 3 e (goal 1e) at 700 Hz frame rate. New technologies will be developed for that purpose: advanced CMOS pixel architecture, CMOS back thinned and back illuminated device for very high QE, full digital outputs with signal digital conversion on chip. This innovative device will be used on the European ELT but also interests potentially all giant telescopes.Additional developments also started in 2009 for wavefront sensing in the infrared based on a new technological breakthrough using ultra low noise Avalanche Photodiode (APD) arrays within the RAPID project. Developed by the SOFRADIR and CEA/LETI manufacturers, the latter offers a 320x240 8 outputs 30 microns IR array, sensitive from 0.4 to 3 microns, with 2 e readout noise at 1500 Hz frame rate. The 2e readout noise of RAPID will be first shown in this conference. The high QE response is almost flat over this wavelength range. Advanced packaging with miniature cryostat using liquid nitrogen free pulse tube.

Oral

First results of a 2000+ frame per second OCAM2

Oral - N: 11531

Jean-luc Gach[1,2], Timothée Greffe[2], Philippe Balard[1,2], Christian Guillaume[2,3], Philippe Feautrier[2,4], Eric Stadler[2,4]

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A major breakthrough has been achieved with the development by e2v technologies of the CCD220. This 240x240 pixels 8 outputs EMCCD (CCD with internal multiplication) has been jointly funded by ESO and Europe under the FP6 programme. The CCD220 detector and the OCAM-2 camera are now the most sensitive system in the world for advanced wavefront sensing, offering less than 0.2 e readout noise at a frame rate of 1503 Hz with negligible dark current. This system is currently commercialized by the First Light Imaging spinoff and many systems are running routinely around the world on various telescopes. We will present a major upgrade of OCAM-2 boosting its frame rate to an unprecedented 2067 frames per second, opening the window of XAO wavefront sensing for the ELT. To achieve this unmatched performance, the CCD is driven well above its nominal specification using proprietary electronics. Detailed performance of this new OCAM-2K wavefront sensor will be exposed.

Pyramid wavefront sensor performance with laser guide stars

Oral - N: 13138

Fernando Quiros-Pacheco[1], Enrico Pinna[1], Alfio Puglisi[1], Guido Agapito[1], Simone Esposito[1]

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All the ELT projects foresee and deeply rely on Laser Guide Star Adaptive Optics (LGS AO) systems. These systems, already successfully employed on the 8-10m class of telescopes, show several limitations in performance linked to the three-dimensional extension of the artificial guide star, which causes a reduction in wavefront sensor sensitivity and generates errors in the wavefront measurements. All of these effects will be accentuated passing from the 8-10m class of telescope to the ELTs. Currently, only the Shack-Hartmann (SH) wavefront sensor has been employed in the existing LGS AO systems, and all the LGS AO systems under design for the ELTs foresee the same kind of sensor. Recently, the use of the pyramid sensor in LGS AO systems has been proposed too, suggesting multiple advantages over the SH-based solution, but the investigations available in the literature are just preliminary. In this paper, we first review the advantages offered by the pyramid wavefront sensor coupled to an LGS, and then we present the results of numerical simulations aimed at quantifying the impact of a three-dimensionally extended source on this sensor. The work presented is a required step before laboratory and on-sky experimentation. If the experimental work confirms the expected results, the pyramid wavefront sensor will become a very attractive alternative to the SH one, simplifying significantly the design of LGS AO systems for the ELTs, and improving their performances and reliability.

COFFEE: Coronagraphic phase diversity improvements for high-order quasi-static aberrations compensation. Application to the SPHERE system

Oral - N: 13229

Baptiste Paul[1,2], Jean-François Sauvage[2], Laurent Mugnier[2], Kjetil Dohlen[1], Mamadou N'Diaye[3], Thierry Fusco[1,2], Marc Ferrari[1]

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The final performance of current and future instruments dedicated to exoplanet detection and characterization (such as SPHERE on the VLT, GPI on Gemini North or future instruments on the E-ELT) is limited by intensity residuals in the scientific image plane, which are due to uncorrected optical aberrations. After correction of the atmospheric turbulence, the main contribution to these residuals comes from the quasi-static aberrations introduced upstream of the coronagraph. In order to measure and compensate for these aberrations, we have proposed a dedicated focal-plane sensor called COFFEE (for COronagraphic Focal-plane wave-Front Estimation for Exoplanet detection), which consists in an extension of conventional phase diversity to a coronagraphic system: aberrations both upstream and downstream of the coronagraph are estimated using two coronagraphic focal-plane images, recorded from the scientific camera itself. Since COFFEE does not require any dedicated hardware (unlike, e.g., the beam splitter for a Shack-Hartman WFS), the aberration estimation is not biased by any differential aberration. In this communication, we present COFFEE's improvements for estimation and compensation of aberrations upstream of the coronagraph as well as experimental results. The phase estimation is now performed on a pixel-wise map, which, used with a dedicated regularization metric, allows COFFEE to estimate very high order aberrations. Besides, COFFEE has been modified so that it can be used with any coronagraphic focal plane mask (such as an Apodized Lyot Coronaraph or a Four Quadrant Phase Mask). Such improvements allow us to estimate and compensate for quasi-static aberrations with nanometric precision, leading to an optimization of the contrast on the scientific detector. Lastly, we use COFFEE to measure and correct the wavefront on the SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research) instrument during its integration phase: COFFEE's estimation is used to compensate for the quasi-static aberrations upstream of the coronagraph, leading to a contrast improvement on the scientific camera.

A study of Pyramid WFS behaviour under imperfect illumination

Oral - N: 13262

Valentina Viotto[1], Demetrio Magrin[1], Maria Bergomi[1], Marco Dima[1], Jacopo Farinato[1], Luca Marafatto[1,2], Roberto Ragazzoni[1]

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Even if still nowadays it's often referred to as an "innovative concept", the Pyramid wavefront sensor has been technologically demonstrated at the TNG in Canary Island years ago. It was again tested in laboratory and on the sky in the framework of the development of MAD, lead by ESO, and recently succeeded to achieve outstanding performances at the LBT telescope. At the same time, several theoretical development raised novel features of this device, and actual measurements in the framework of Pyramir experimentally confirmed the better behavior of this sensor with respect to the Shack-Hartmann in terms of noise propagation in closed loop, as previously analytically predicted. After a brief review of previous works, which revealed or demonstrated some peculiarities of this type of wavefront sensor with respect to other systems, we present a generalization of the photon efficiency and the non linearity estimations of such sensor. The aim of this study is to devise, through analytical computations and Fourier wave-optics propagation simulations, the behavior of the Pyramid wavefront sensor when not-ideal illumination conditions, such as faint-end sources and partial wavefront correction, are purposely applied. In the same framework, the effects of introducing a pyramid modulation are discussed too.

Putting the non-linear Curvature Wavefront Sensor on the 6.5m MMT telescope

Oral - N: 13283

Mala Mateen[1,2], Olivier Guyon[1,3,4], Michael Hart[1,4], Michael Oliker[5,6]

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We present the non-linear Curvature Wavefront Sensor (nlCWFS) built for the MMT. The nlCWFS is derived from the principle of curvature wavefront sensing but instead of using contrast to determine the shape of the wavefront, diffraction effects are taken into account to reconstruct the wavefront with improved sensitivity. Intensity measurements recorded in four out-of-pupil planes are used to determine the complex field in the pupil plane via a non-linear iterative algorithm. The nlCWFS performs at the diffraction limit by using the full aperture of the telescope where as conventional wavefront sensors such as the Shack Hartmann wavefront sensor (SHWFS) sense at the seeing limit. This difference leads to a gain in sensitivity equivalent to increasing the photon flux by ~ (D/r0)2 for sensing low-order aberration, which is a significant improvement for ELTs. The design of the nlCWFS built for the MMT uses dichroic beam splitters to create four wavelength dependent Fresnel planes. The four planes are simultaneously recorded on a single CCD. The nlCWFS we describe will become part of the existing MMT Natural Guide Star (NGS) adaptive optics (AO) system to supplement the present SHWFS. We are initially interested in comparing the performance of the nlCWFS and the SHWFS with open loop on-sky data. Eventually we will close the loop with the nlCWFS. We also present results from an experiment carried out on the 3.5m Air Force Research Lab (AFRL) Space Electro-Optics Division telescope. The experiment consists of taking open loop data with the SHWFS and the nlCWFS using artificial turbulent sources and comparing the wavefront reconstruction. The nlCWFS is placed in an auxiliary path and the four Fresnel planes are created by putting defocus on the deformable mirror (DM).

On-sky validation of the LInearized Focal-plane Technique on GEMS

Oral - N: 13355

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Laser assisted adaptive optics systems rely on Laser Guide Star (LGS) Wave-Front Sensors (WFS) for high order aberration measurements, and rely on Natural Guide Stars (NGS) WFS to complement the measurements on low orders such as tip-tilt and focus. The sky-coverage of the whole system is therefore related to the limiting magnitude of the NGS WFS. LIFT is a novel WFS based on the analysis of a well corrected full aperture short exposure image, simply with a small astigmatism offset. It allows a 1 magnitude gain over the usually used 2x2 Shack-Hartmann WFS. Its noise propagation is comparable to a 4-pixel pyramid sensor without modulation. Besides, it requires a much more simple hardware, making it a reliable and easy to set up solution. Early this year, LIFT came out of the lab and has been tested on GEMS, the multiconjugate adaptive optics system of Gemini South. We present here the first on-sky IR wave-front sensing data obtained with LIFT. We show that these results constitute a clear on-sky demonstration of the LIFT concept.

Improved tilt sensing in an LGS-based tomographic AO system

Oral - N: 13375

Jean-Pierre Veran[1], Glen Herriot[1]

[1] National Research Council Canada

Laser guide star (LGS)-based tomographic AO systems, such as Multi-Conjugate AO (MCAO), Multi-Object AO (MOAO) and Laser Tomography AO (LTAO), require natural guide stars (NGSs) to sense tip-tilt (TT) and possibly other low order modes, to get rid of the LGS-tilt indetermination problem. For example, NFIRAOS, the first-light facility MCAO system for the Thirty Meter Telescope requires three NGSs, in addition to six LGSs: two to measure TT and one to measure TT and defocus. In order to improve sky coverage, these NGSs are selected in a so-called technical field (2 arcmin in diameter for NFIRAOS), which is much larger than the on-axis science field (17x17 arcsec for NFIRAOS), on which the AO correction is optimized. Most times, the NGSs are far off-axis and thus poorly corrected by the high-order AO loop, resulting in spots with low contrast and high speckle noise. Accurately finding the position of such spots is difficult, even with advanced methods such as matched-filtering or correlation, because these methods rely on the knowledge of an average spot image, which is quite different from the instantaneous spot image, especially in case of poor correction. This results in poor tilt estimation, which, ultimately, impacts sky coverage. We propose to improve the estimation of the position of the NGS spots by using, for each frame, a current

estimate of the instantaneous spot profile instead of an average profile. This estimate can be readily obtained by tracing wavefront errors in the direction of the NGS through the turbulence volume. The latter is already computed by the tomographic process from the LGS measurements as part of the high order AO loop. Computing such a wavefront estimate has actually already been proposed for the purpose of driving a deformable mirror (DM) in each NGS WFS, to optically correct the NGS spot, which does lead to improved centroiding accuracy. Our approach, however, is much simpler, because it does not require the complication of extra DMs, which would need to be driven in open-loop. Instead, it can be purely implemented in software, does not increase the real-time computational burden significantly, and can still provide a significant improvement in tilt measurement accuracy, and therefore in sky-coverage. In this paper, we illustrate the benefit of this new tilt measurement strategy in the specific case of NFIRAOS, under various observing conditions, in comparison with the more traditional approaches that ignore the instantaneous variations of the NGS spot profiles.

Lab demonstration of the Zernike phase mask near-coronagraph quasi static aberrations sensor, ZELDA

Oral - N: 13376

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Exoplanet direct imaging instruments such as the VLT-SPHERE and the Gemini Planet Imager will soon be in operation, providing a quantum leap in comparative exo-planetary science. A similar leap will again happen when the next generation of such instruments is built for the future extremely large telescopes gaining a factor of 4-5 in spatial resolution and up to several hundred in sensitivity. These instruments are built around extreme adaptive optics (XAO) systems providing correction both of atmospheric turbulence and inevitable aberrations and wave front ripples due to the optical surfaces. Their performance is however limited by the non-common path aberrations (NCPA) due to the differential wavefront errors existing between the XAO sensing path and the science path, leading to residual speckles that hide the faint exoplanets in the coronagraphic image. Accurate calibration of the NCPA is mandatory in order to correct these quasi-static speckles and allow observation of exo-planets, 106 to 1010 times fainter than their host star. Several approaches to NCPA calibration are currently being developed, including different incarnations of the Zernike phase contrast method. We here present work on one such sensor, known as ZELDA (Zernike sensor for Extremely accurate measurements of Low-level Differential Aberrations). Building on previous experience with phase mask-based wavefront sensors for segment phasing and with phase mask coronagraphs, ZELDA proves to be highly promising both as an upgrade path for current-generation instruments and for implementation into future-generation systems, both ground-based and space based. We present results obtained on a high-contrast test bed where the ZELDA sensor is implemented for on-line calibration of an AO loop feeding a coronagraph system. The setup is representative of systems such as SPHERE, hence providing clear evidence for the applicability of the concept as an upgrade path for that instrument. We also present an error budget indicating that an improvement in image contrast of a factor of at least an order of magnitude with respect to the currently expected performance is within reach. The implementation of such an upgrade would give a second youth to the instrument, by significantly increasing its discovery space.

Natural Guide Star WFS for the GMT Preliminary Design

Oral - N: 15105

Simone Esposito[1], Enrico Pinna[1], Fernando Quiros-Pacheco[1], Alfio Puglisi[1], Luca Carbonaro[1], Marco Bonaglia[1], Valdemaro Biliotti[1], Jacopo Antichi[1], Runa Briguglio[1], Guido Agapito[1], Carmelo Arcidiacono[1], Armando Riccardi[1], Luca Fini[1], Antonin Bouchez[2]

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The paper presents the results of the preliminary design study of the Natural Guide Star Wavefront Sensor for the single conjugate AO system of the GMT telescope. The NGS Wavefront Sensor, already identified as a pyramid sensor, will be in charge of the entire wavefront error measurement, namely atmospheric turbulence and telescope aberrations, including the segment differential piston error. The contribution describes the correction strategy and related modifications of the opto-mechanical assembly of the WFS to achieve a reliable simultaneous control of continuous aberrations and differential pistons. Following the identified strategy end-to-end simulations of the GMT NGS AO system have been performed taking into account correction of the atmospheric perturbation and control of the differential pistons of the GMT segments. The results achieved are presented and compared with the GMT top level requirements for such a system.

Posters

Enhancing SCExAO's inner working angle with phase mask coronagraphy

Poster - N: 12667

Garima Singh[1], Olivier Guyon[1], Pierre Baudoz[2], Frantz Martinache[1], Christophe Clergeon[1]

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Detection of extrasolar companions benefits from coronagraphs with high throughput and the capability to work at the smallest possible inner working angle (IWA). The Subaru Telescope Coronagraphic Extreme AO (SCExAO) is a flexible, high performance coronagraphic system that can detect high contrast structures as close as 1λ/D. To further enhance the IWA of the system, we are modifying the instrument to support phase mask coronagraphy with a goal IWA $< 1\lambda$/D. We will show how both the high order wavefront (WF) calibration and low order WF control will be performed in this new configuration. To improve SCExAO's high order WF calibration capability at the focal plane, we will employ the Self Coherent Camera approach to control and cross calibrate electric field in the focal plane. Tip tilt and few other low order modes will be measured by using coronagraphic stellar residue reflected from the Lyot mask at the pupil plane for fast and accurate closed loop pointing control by low order wavefront sensor (LOWFS). We will present simulation results predicting the performance of the new configuration, as well as preliminary tests in the laboratory.

The AOLI Non-Linear Curvature Wavefront Sensor: High sensitivity reconstruction for low-order AO

Poster - N: 12852

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Many adaptive optics (AO) systems in use today require bright reference objects to determine the effects of atmospheric distortions on incoming wavefronts. This requirement is because Shack Hartmann wavefront sensors (SHWFS) distribute incoming light from reference objects into a large number of sub-apertures. Bright natural reference objects occur infrequently across the sky leading to the use of laser guide stars which add complexity to wavefront measurement systems. The non-linear curvature wavefront sensor as described by Guyon et al. has been shown to offer a significant increase in sensitivity when compared to a SHWFS. This facilitates much greater sky coverage using natural guide stars alone. This paper describes the current status of the non-linear curvature wavefront sensor being developed as part of an adaptive optics system for the Adaptive Optics Lucky Imager (AOLI) project. The sensor comprises two photon-counting EMCCD detectors from E2V Technologies, recording intensity at four near-pupil planes. These images are used with a reconstruction algorithm to determine the phase correction to be applied by an ALPAO 241-element deformable mirror. The overall system is intended to provide low-order correction for a Lucky Imaging based multi CCD imaging camera. We present the current optical design of the instrument including methods to minimise inherent optical effects, principally chromaticity. Wavefront reconstruction methods are discussed and strategies for their optimisation to run at the required real-time speeds are introduced. Finally, we discuss laboratory work with a demonstrator setup of the system.

Real-time wavefront reconstruction from intensity measurements

Poster - N: 13243

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We propose an ecient approximation to the nonlinear phase diversity method for wavefront reconstruction method from intensity measurements in order to avoid the shortcomings of the nonlinear phase diversity method that prevent its real-time application, such as its computationally complex and the presence of local minima. The new method is called linear sequential phase diversity (LSPD). The method assumes that residual phase aberration is small and makes use of a rst order Taylor expansion of the point spread function (PSF). The Taylor expansion is performed in two dierent phase diversities, that can be arbitrary (large) pupil shapes in order to optimize the phase retrieval. For static aberrations LSPD makes use of two images that are collected at each iteration step of the algorithm. In each step the residual phase aberrations are estimated by solving a linear least squares problem, followed by the use of a deformable mirror to correct for the aberrations. The computational complexity of LSPD is O(m*m) - where m*m is the number of pixels. For the static case the convergence of the LSPD iterations have been studied and experimentally veried. In an extensive comparison the method is compared with the recently proposed method of [1]. This study demonstrates the improved performance both computationally and in accuracy with respect to existing competitors that also linearize the PSF. A further contribution of the paper is that we extend the static LSPD method to the case of dynamic wavefront reconstruction based on intensity measurements. Here the dynamics are assumed

to be modelled standardly by a linear innovation model such that its spectrum e.g. approximates that given by Kolmogorov. The advantage of the application of the dynamic variant of the LSPD method is that in closed-loop the assumption that the residual phase aberration is small is justiable, since the goal of the controller is to reduce (minimize) the residual phase aberration. This unique contribution for the rst time puts Adaptive Optics based on intensity measurements in an optimal H2 controller setting. A computationally ecient solution is presented for this H2 controller for the case the mirror dynamics can be considered as a static system. The advantage of this new dynamic aberration correction is also demonstrated in the simulation study. References [1] C. Keller, V. Korkiakoski, N. Doelman, R. Fraanje, R. Andrei, and M. Verhaegen. Extremely fast focal-plane wavefront sensing for extreme adaptive optics. arXiv preprint arXiv:1207.3273, 2012

Development of a pyramidal wavefront sensor test-bench at INO

Poster - N: 13260

Simon Turbide[1], Min Wang[1], Jonny Gauvin[1], Maxime Savard[1], Genevieve Anctil[1], François Chateauneuf[1], Olivier Martin[1]

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The key technical element of the adaptive optics in astronomy is the wavefront sensing (WFS). One of the advantages of the pyramid wavefront sensor (P-WFS) over the widely used Shack-Hartmann wavefront sensor seems to be the increased sensitivity in closed-loop applications. A high-sensitivity and large dynamic-range WFS, such as P-WFS technology, still needs to be further investigated for proper justification in future Extremely Large Telescopes application. At INO, we have recently carried out the optical design, testing and performance evaluation of a P-WFS bench setup. The optical design of the bench setup mainly consists of the super-LED fiber source, source collimator, spatial light modulator (SLM), relay lenses, tip-tilt mirror, Fourier-transforming lens, and a four-faceted glass pyramid with a large vertex angle as well as pupil re-imaged optics. The phase-only SLM has been introduced in the bench setup to generate atmospheric turbulence with a maximum phase shift of more than 2π at each pixel (256 grey levels). Like a modified Foucault knife-edge test, the refractive pyramid element is used to produce four images of the entrance pupil on a CCD camera. The Fourier-transforming lens, which is used before the pyramid prism, is designed for telecentric output to allow dynamic modulation (rotation of the beam around the pyramid-prism center) from a tip-tilt mirror. Furthermore, a P-WFS diffraction-based model has been developed. This model includes most of the system limitations such as the SLM discrete voltage steps and the CCD pixel pitch. The pyramid effects (edges and tip) are considered as well. The modal wavefront reconstruction algorithm relies on the construction of an interaction matrix (one for each modulation's amplitude). Each column of the interaction matrix represents the combination of the four pupil images for a given wavefront aberration. The nice agreement between the data and the model suggest that the limitation of the system is not the P-WFS itself, but rather its environment such as source intensity fluctuation and vibration of the optical bench. Finally, the phase-reconstruction errors of the P-WFS have been compared to those of a Shack-Hartmann, showing the regions of interest of the former system. The bench setup will be focusing on the astronomy application as well as commercial applications, such as bio-medical application etc.

Multiple FoV MCAO on its way to the sky

Poster - N: 13266

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LINC-NIRVANA, an infrared camera working in a Fizeau interferometric layout, takes advantage of the Layer Oriented MCAO MFoV technique to correct a 2' FoV using only Natural Guide Stars (NGSs), exploiting the central 20 arcsec with a resolving power of a 23 meter telescope. For each arm of the LBT telescope 2 WaveFront Sensors (WFSs) optically conjugated, respectively at ground and high (7 km) layers, are used to search for NGSs . To avoid unnecessary waste of photons the two sensors look at different FoVs. The ground-layer one, essentially limited by practical conditions, searches for up to 12 NGSs in an annular 2-6 arcmin FoV, while the high-layer one, limited by the pupils superposition, looks for up to 8 NGSs in the central 2 arcmin FoV. The concept has left paper's realm to become glass and metal a few years ago. With the completion of the 2 high-layer WFSs by INAF-Bologna and, recently with the successful tests performed on the first ground-layer WFSs by INAF-Padova, further followed by the GWS Pathfinder experiment to test the ground layer correction at LBT, in collaboration with MPIA-Heidelberg, the concept is finally getting closer to its on-sky commissioning, foreseen in the next very few years. In this paper the basic concepts of MFoV MCAO will be revised, the current status of the system described and the near future toward final completion of the instrument depicted. Moreover a possible path for this concept toward an ELT will be traced.

Wave-front reconstruction for the non-linear curvature wave-front sensor

Poster - N: 13290

Carlos Correia[1], Jean-Pierre Veran[1], Olivier Guyon, Christophe Clergeon

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Non-linear curvature wave-front sensing (nlCWFS) delivers outstanding sensitivity and high dynamic range by lifting the linearity constraint of standard curvature wave-front sensing. This is achieved by taking full advantage of diffraction, which encodes wave-front aberrations into patterns of diffraction-limited interference speckles. Originally nlCWFS has been proposed for extreme AO, but it could also be used when the number of modes to measure is lower.The trade is set by a non-linear wave-front reconstruction which involves computationally intensive non-linear algorithms. One such example is the Gerchberg-Saxton iterative algorithm proposed originally. In this paper we propose an approximation that allows us to use the framework developed for phase-diversity to compute the maximum a-posteriori wave-front estimate. We characterize this reconstructor in terms of accuracy and sensitivity to noise and compare its performance to that of the Gerchberg-Saxton algorithm. Finally, we assess the computational requirements of our reconstructor, and discuss its possible real-time implementation.

Experimental study of a low-order wavefront sensor for a high-contrast coronagraphic imager at 1.2 lambda/D

Poster - N: 13323

Julien Lozi[1], Ruslan Belikov[2], Glenn Schneider[1], Olivier Guyon[1], Eugene Pluzhnik[2], Thomas Greene[2], Fred Witteborn[2], Dana Lynch[2], Paul Davis[2], Sandrine Thomas[2], Domenick Tenerelli[3]

[1] University of Arizona
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[3] Lockheed Martin

High-contrast imaging will be a challenge for future ELTs, because their vibrations create low-order aberrations - mostly tip/tilt - that reduce coronagraphic performances at 1.2 lambda/D and above. A Low-Order WaveFront Sensor (LOWFS) is essential to measure and control those aberrations. An experiment simulating a starlight suppression system is currently developed at NASA Ames Research Center, and includes a LOWFS controlling tip/tilt modes in real time at 500 Hz. The LOWFS allowed us to reduce the tip/tilt disturbances to 1e-3 lambda/D rms, enhancing the previous contrast by a decade, to 8e-7 between 1.2 and 2 lambda/D. A Linear Quadratic Gaussian (LQG) controller is currently implemented to improve even more that result by reducing residual vibrations. This testbed is developed for the mission EXCEDE (EXoplanetary Circumstellar Environments and Disk Explorer), selected by NASA for technology development, and designed to study the formation, evolution and architectures of exoplanetary systems and characterize circumstellar environments into stellar habitable zones. It is composed of a 0.7 m telescope equipped with a Phase-Induced Amplitude Apodization Coronagraph (PIAA-C) and a 2000-element MEMS deformable mirror, capable of raw contrasts of 1e-6 at 1.2 lambda/D and 1e-7 above 2 lambda/D. Although the testbed simulates space conditions, its LOWFS has the same design than on the SCExAO instrument at Subaru telescope, with whom it shares the same kind of problematic. Experimental results show that a good knowledge of the low-order disturbances is a key asset for high contrast imaging, whether for real-time control or for post processing, both in space and on ground telescopes.

Integration and laboratory characterization of the ARGOS laser guide star wavefront sensors

Poster - N: 13388

Lorenzo Busoni[1], Marco Bonaglia[1], Luca Carbonaro[1], Tommaso Mazzoni[1], Jacopo Antichi[1], Simone Esposito[1], Gilles Orban De Xivry[2], Sebastian Rabien[2]

[1] INAF - Osservatorio di Arcetri
[2] MPE Garching

The integration status of the ARGOS wavefront sensors is presented. ARGOS is the laser guide star AO program for the LBT. It will implement a Ground Layer AO correction for the instruments LUCI, an infrared imaging and spectrograph camera, using 3 pulsed low-altitudes Rayleigh beacons for each LBT's eye. It profits of the LBT's adaptive secondary mirrors and of FLAO's pyramid unit for NGS sensing. Each LGS is independently stabilized for on-sky jitter and range-gated using custom Pockels cells and then sensed by a 15x15 SH sensor. The 3 pupil images are reimaged on a single lenslet array and a single detector. In the WFS are also installed 3 patrol cameras for the acquisition of the laser beacons, a system for the stabilization of the pupil images on the lenslet array and an internal source for calibration purposes. The two units are now completing the integration phase in Arcetri premises. We describe the characterization of the units and the closed-loop test realized using a deformable MEMS mirror.

The Subaru Coronagraphic Extreme AO High Speed and High Sensitivity Wavefront Sensors

Poster - N: 13398

Christophe Clergeon, Olivier Guyon[1], Frantz Martinache[2], Jean-Pierre Veran, Eric Gendron[3], Gérard Rousset[3], Carlos Correia, Vincent Garrel

[1] University of Arizona
[2] Subaru Telescope
[3] Laboratoire d'études spatiales et d'instrumentation en astrophysique

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system uses advanced coronagraphic technique for high contrast imaging of exoplanets and disks as close as 1 lambda/D from the host star. In addition to unusual optics, achieving high contrast at this small angular separation requires a wavefront sensing and control architecture which is optimized for exquisite control and calibration of low order aberrations. To complement the current near-IR wavefront control system driving a single MEMS type deformable mirror mounted on a tip-tilt mount, two high order and high sensitivity visible wavefront sensors have been integrated to SCEXAO: - a non modulated Pyramid wavefront sensor (CHEOPS) which is a sensitivity improvement over modulated Pyramid systems now used in high performant astronomical AO, - a non linear wavefront sensor designed in 2012 by Subaru Telescope with the collaboration of the NRC-CNRC which is expected to improve significantly the achieved sensitivity of low order aberations measurements. I will present the CHEOPS last results measured downstream the Subaru AO188 system highlighting limits of our instrument and then introduce the primary laboratory images of the first built prototype of the non linear curvature wavefront sensor.

Direct detection of exoplanets in polychromatic light with a Self-coherent camera

Poster - N: 13416

Johan Mazoyer[1], Pierre Baudoz, Raphael Galicher, Gérard Rousset

[1] LESIA

Direct detection of exoplanets is a very promising field in astronomy today. Planets unseen by other methods can be discovered and spectroscopically characterized. However, such detections require to overcome the high contrast (larger than 10 thousands up to several billions) and the high angular resolution (smaller than a fraction of arcsec) between the star and its companion. Coronagraphs are being used to reduce the stellar light but their efficiency is limited by wavefront aberrations that produce speckles in the final coronagraphic science plane. Classical adaptive optics usually measure aberrations in a specific estimation channel. To avoid differential aberrations in separate channels, several methods have been developed to estimate the wavefront deformations directly from the science image. Among them, the Self-Coherent Camera (SCC), which uses the principle of the star light coherence to measure the wavefront after a coronagraph. Associated with a deformable mirror, correction in closed-loop with this method has already reached high contrasts in monochromatic light. However, the widening of the wavelength bandwidth, mandatory for spectroscopic analysis of planets, limits the performance in both the estimation by the SCC and the correction by the deformable mirror. After recalling the SCC principle, we will present a theoretical analysis of this problematic and laboratory performance in polychromatic light.

Development of a Pyramid Wave-front Sensor (PWFS) at LAM

Poster - N: 13429

Kacem El Hadi[1], Thierry Fusco[1,2]

[1] Aix Marseille Université, CNRS, LAM
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Within the framework of the E-ELT studies, several laboratories are involved on some instruments: HARMONY with its ATLAS adaptive optics [AO] system, EAGLE or EPICS. Most of the AO systems will probably integrate one or several pyramidal wavefront sensors, PWFS (R. Ragazzoni [1]). The coupling in an AO loop and the control in laboratory (then on sky) of this type of sensor is fundamental for the continuation of the projects related to OA systems on the E-ELT. LAM (Laboratory of Astrophysics of Marseille) is involved in particular in the VLT-SPHERE, ATLAS, EPICS projects. For the last few years, our laboratory has been carrying out different R&D activities in AO instrumentation for ELTs. An experimental AO bench is designed and being developed to allow the validation of new wave-front sensing and control concepts [2]. One the objectives of this bench, is the experimental validation of a pyramid WFS. Theoretical investigations on its behavior have been already made. The world's fastest and most sensitive camera system (OCAM2) has been recently developed at LAM (J.L Gach [3], First Light Imaging). Conjugating this advantage with the pyramid concept, we plan to demonstrate a home made Pyramid sensor for Adaptive Optics whose the speed and the precision are the key points. As a joint collaboration with ONERA and Shaktiware, our work aims at the optimization (measurement process, calibration and operation) in laboratory then on the sky of a pyramid sensor dedicated to the first generation instruments for ELTs. The sensor will be implemented on the ONERA ODISSEE AO bench combining thus a pyramid and a Shack-Hartmann wavefront sensors. What

would give the possibility to compare strictly these two WFS types and make this bench unique in France and even in Europe. Experimental work on laboratory demonstration is undergoing. The status of our development will presented at the conference.

Sensing more modes with less sub-apertures : the LIFTed Shack-Hartmann Wavefront sensor

Poster - N: 13486

Serge Meimon[1], Thierry Fusco[1,2], Vincent Michau[1], Cedric Plantet[1]

[1] Département d'Optique Théorique et Appliquée
[2] Aix Marseille Université, CNRS, LAM

We propose here a novel way to analyse Shack-Hartmann wavefront sensor images in order to retrieve more modes than the two centroid coordinates per subpupil. To do so, we use the LIFT phase retrieval method [1] to each subaperture. We demonstrate that we increase the number of sensed modes with the same computational burden per mode. For instance, we show the ability to control a 21x21 actuator deformable mirror using a 10x10 lenslet array.

6 Wave-front correctors

Oral

The E-ELT M4 Adaptive Unit

Oral - N: 13431

Elise Vernet[1]

[1] European Southern Observatory

A 40 meters class telescope does require adaptive optics to provide few milli arcseconds resolution images. The M4 unit provides adaptive correction and has also to cancel part of telescope wind shaking and static aberrations. The 2.4 meters adaptive mirror will provide as well Nasmyth focus selection. We will present the main design drivers and the main specifications quaternary mirror will have to meet. We will discuss what the challenges are in term of stability and performance of the associated key technologies. We will finally describe the adopted design, the current status of the project and the required schedule and work plan to adequately manufacture the E-ELT quartenary mirror.

MEMS Deformable Mirrors for Advanced AO Instrumentation

Oral - N: 13459

Paul Bierden[1]

[1] Boston Micromachines

Keeping in mind the needs of future Adaptive Optics instruments on the Extremely Large Telescopes, Boston Micromachines has been working on the design and fabrication of a number of high actuator count micro-electroechanical (MEMS) deformable mirrors for ground and space-based astronomical instruments. The mirrors have different mirror surface options: both continuous membrane surfaces and hexagonally segmented tip-tilt-piston. Actuator counts of 952, 1020, 2040, 3063, and 4096 have been built and tested. The surface figure, electro mechanical performance, and actuator yield of these devices are reported here. Statistical distributions of these measurements directly illustrate the surface variance of Boston Micromachines deformable mirrors. The design of these polysilicon, surface-micromachined MEMS deformable mirrors builds on heritage technology and has been used extensively to correct for ocular aberrations in retinal imaging systems and for compensation of atmospheric turbulence in free-space laser communication. Presented in this paper are device characteristics and insertion plans of the devices.

Optical calibration and test of the VLT Deformable Secondary Mirror

Oral - N: 13507

Runa Briguglio[1], Marco Xompero[1], Armando Riccardi[1], Mario Andrighettoni[2], Dietrich Pescoller[2], Roberto Biasi[2], Daniele Gallieni[3], Elise Vernet[4], Johann Kolb[4], Robin Arsenault[4], Pierre-Yves Madec[4]

[1] INAF - Osservatorio di Arcetri
[2] MICROGATE
[3] ADS-International
[4] ESO

The Deformable Secondary Mirror (DSM) for the VLT (ESO) represents the state-of-art of the large-format deformable mirror technology with its 1170 voice-coil actuators and its internal metrology based on actuator co-located capacitive sensors to control the shape of the 1.12m-diameter 2mm-thick convex shell. The present paper reports the results of the optical characterization of the mirror unit with the ASSIST facility located at ESO-Garching and executed in a collaborative effort by ESO, INAF-Osservatorio Astrofisico di Arcetri and the DSM manufacturing companies (Microgate s.r.l. and A.D.S. International s.r.l.). The main purposes of the tests are the optical characterization of the shell flattening residuals, the corresponding calibration of flattening commands, the optical calibration of the capacitive sensors and the optical calibration of the mirror influence functions. The results are used for the optical acceptance of the DSM and to allow the next test phase coupling the DSM with the wave-front sensor modules of the new Adaptive Optics Facility (AOF) of ESO.

The new VLT-DSM M2 unit: construction and electro-mechanical testing

Oral - N: 17883

Daniele Gallieni[1], Roberto Biasi[2]

[1] ADS-International
[2] MICROGATE

We present the design, construction and validation of the new M2 unit of the VLT Deformable Secondary Mirror. In the framework of the Adaptive Optics Facility program, ADS and Microgate designed a new secondary unit which replaces the current Dornier one. The M2 is composed by the mechanical structure, a new hexapod positioner and the Deformable Secondary Mirror unit.The DSM is based on the well proven contactless, voice coil motor technology that has been already successfully implemented in the MMT, LBT and Magellan adaptive secondaries, and is considered a promising technical choice for the E-ELT M4 and the GMT ASM. The VLT adaptive unit has been fully integrated and, before starting the optical calibration, has completed the electromechanical characterization, focused on the dynamic performance. With respect to the previous units we introduced several improvements, both in hardware and control architecture that allowed achieving a significant enhancement of the system dynamics and reduction of power consumption.

Posters

On the cg-method for atmospheric reconstruction

Poster - N: 13241

Andreas Obereder[1], Sergiy Pereverzyev Jun., Ronny Ramlau[2], Matthias Rosensteiner[3]

[1] MathConsult GMBH
[2] Industrial Mathematics Institute, JKU
[3] MathConsult GmbH

Within the scope of the project "Mathematical Algorithms and Software for ELT Adaptive Optics", various algorithms for atmospheric tomography have been studied and developed.One possible approach is to restore the incoming wavefronts from the WFS measurements and subsequently to reconstruct (artificial) atmospheric layers from those data, which numerically can be performed very efficiently. This reconstruction/approximation of the atmosphere can then be used to compute mirror commands for MCAO/LTAO/MOAO systems.In this poster, we focus on a conjugate gradient (cg) method for the atmospheric tomography step.The theoretical foundations of the cg-method as well as results of the algorithm (in terms of LE-Strehl ratios, obtained with the ESO end-to-end simulation tool OCTOPUS) are presented.

Progress towards a woofer-tweeter adaptive optics test bench based on a magnetic-fluid DM

Poster - N: 13277

Denis Brousseau[1], Jean-Pierre Veran[2], Simon Thibault[1], Ermanno Borra[1], Simon Fortin-Boivin[1]

[1] Laval University
[2] NRC Herzberg Institute of Astrophysics

In previous research work, we have demonstrated that magnetic-liquid DMs (MLDMs) offer a practical and credible solution for sub-components optical testing. MLDMs can deliver very large actuator and inter-actuator strokes while maintaining a continuous surface. Here we present our recent progress towards the development of a woofer-tweeter adaptive optics test bench based on a MLDM and an ALPAO DM. During this process, we have been able to gather a much better understanding of MLDMs characteristics and behavior that will enabled us to identify and develop specific targeted applications that use the full potential of this type of DM.

Improving the broadband contrast at small inner working angles using image sharpening techniques

Poster - N: 13359

Sandrine Thomas[1], Ruslan Belikov[1], Laurent Pueyo[2], Bruce Macintosh[3], Patrick Ingraham, Julien Lozi[4]

[1] NASA Ames Research Center
[2] Johns Hopkins University
[3] Lawrence Livermore National Laboratory
[4] University of Arizona

The detection of extrasolar planets, using both space- and ground-based telescopes, is one of the most exciting fields in astronomy today. From the ground, the upcoming Extremely Large Telescopes will offer a significant increase in our capability to directly image exoplanets and could potentially lead to the direct detection of planets in the habitable zone. To obtain contrasts better than 10^-7-10^-9 requires precise wavefront control algorithms. Although wavefront control techniques, such as Electric Field Conjugation and stroke minimization, have been already developed and will soon be operational on 8-m class telescopes, they primarily function in monochromatic light and at moderate separations (r>3 lambda/D). While wavefront control simulations combining polychromatic light and smaller inner working angles (1.2 lambda/D for example) have shown promising results, experimental verification is still ongoing. In

this paper, we discuss the challenges and present our latest contrast results using wavefront control techniques in polychromatic light optimized for small separations. This work is performed using the NASA Ames Center for Exoplanet Studies (ACES) testbed and the Gemini Planet Imager (GPI) – currently in the final phases of integration and test.

Manufacturing E-ELT M4 glassy thin shell: feasibility and preliminary results

Poster - N: 14356

Florence Poutriquet[1], Eric Ruch[1]

[1] Reosc, Safran group

Glassy thin shells are key components for the development of adaptive optics and are part of future & innovative projects such as the E-ELT. However, manufacturing thin shells is a real challenge. Indeed, a classical mirror has a aspect ratio of ~1/10 while glassy thin shells used for adaptive optics have a ratio inferior to 1/600. This important change has impacts in the way the thin shell is manufactured. In particular, the shell is much more fragile and each step of the manufacturing process has to be analysed and secured. Reosc has recently manufactured different types of thin shells in the frame of European projects: E-ELT M4 prototypes and VLT Deformable Secondary Mirror (VLT DSM). E-ELT M4 prototypes were developed and manufactured to compare the feasibility of a 2.7m-diameter monolithic mirror - the largest thin shell manufactured up to present day - and of a segmented mirror. Both solutions were delivered and promising results were obtained in terms of thickness uniformity as well as process validation as it demonstrated that it was possible to polish and handle such kind of mirror. Results obtained and further considerations on future E-ELT M4 will be presented. First VLT DSM thin shell was delivered to ADS & Microgate last year. This convex aspheric shell presented significant challenges during its development and manufacturing. Those innovative developments will be presented. Finally, an update of the second VLT DSM thin shell status will be provided.

GMT Adaptive Secondary Mirrors design overview

Poster - N: 17885

Daniele Gallieni[1], Roberto Biasi[2]

[1] ADS-International
[2] MICROGATE

We present the preliminary design of the Adaptive Secondary Mirrors of the GMT. These units have been conceived on the legacy of our previous contactless deformable mirrors, namely the most recent one the VLT-DSM. Significant effort has been put to fulfill the tight space constraints posed by the GMT optical design, imposing the use of special actuators for the off-axis units outer rings. Mirror passive performances as gravity and thermal stability have been improved significantly by the adoption of distributed support of the reference body. Real time electronics crates have been placed to allow full accessibility to replace their power, communication and control boards on the telescope. The positioner design has been optimized too around the telescope top-end structure to serve both the ASM and the Fast Steering Mirrors.

7 Laser guide star systems

Invited

Properties of the mesospheric sodium region that impact AO

Invited - N: 14324

Paul Hickson[1]

[1] University of British Columbia

Many AO systems generate laser guide stars by means of resonant fluorescence of atomic sodium. These atoms are found in abundance in the mesosphere and lower thermosphere between 80 and 120 km altitude. The large vertical extent of this region, and changes in the density and distribution of sodium, create problems for AO. I will review general properties of the sodium region, physical processes and phenomena, and recent measurements of interest for AO.

Oral

GLAO in the visible, the SAM experience

Oral - N: 12940

Andrei Tokovinin[1]

[1] Cerro Tololo Interamerican Observatory

The SOAR adaptive module (SAM) is going through science verificationand will be offered in 2013B. Current and future science applicationsof this system are presented, with some illustrative results. Thecommissioning results (resolution, PSF profile, sky coverage) aresummarized. Practical aspects of SAM (laser operation, dependence onweather and internal seeing, failure modes) and critical evaluation ofthe design are of interest to other AO instruments. Relevance of thisexperience to ELTs is discussed.

Altair at Gemini North: Full Sky Coverage Laser AO Correction at Visible Wavelengths

Oral - N: 13288

Chadwick Trujillo[1], Jesse Ball[1], Maxime Boccas[2], Chas Cavedoni[1], Julian Christou[1,3], Dolores Coulson[1], Angelic Ebbers[1], Kimberly Emig[1], Inger Jorgensen[1], Stacy Kang[1], Anthony Matulonis[1], Richard McDermid[1], Bryan Miller[2], Benoit Neichel[2], Richard Oram[2], François Rigaut[2,4], Kathy Roth[1], Thomas Schneider[1], Andy Stephens[1], Gelys Trancho[2,5], Brian Walls[1], John White[1], Gemini Software Team[2]

[1] Gemini North Observatory
[2] Gemini South Observatory
[3] Large Binocular Telescope Observatory
[4] The Australian National University
[5] Giant Magellan Telescope Corporation

We present two recent upgrades to the Gemini North Adaptive Optics(AO) system, Altair. These two upgrades provide 100% sky coverage forlow performance AO suitable for improving the natural seeing byfactors of 2 to 3 from blue visible wavelengths (350 nm) through thenear infrared (2.5 micron wavelengths). The first upgrade, dubbed LGS + P1 "Super Seeing" mode allowscorrection of high order aberrations with an on-axis Laser Guide Star(LGS) while tip/tilt correction is performed with a more distantperipheral wavefront sensor (P1). Most currently operating LGS AOsystems are limited in their sky coverage, primarily due to tip/tiltstar availability. Although P1 provides sub-optimal tip/tiltcorrection due to its distance from the science source, its patrolradius allows operation in LGS + P1 mode anywhere in the sky fromdeclinations of +70 degrees to -30 degrees. This mode was offered forscience use at Gemini North in 2013A. We will present typicalperformance and use from its first semester in science operation,where we expect to improve image quality by a factor 2 to 3 overseeing limited images. The second upgrade is the commissioning of the AO system to correct atvisible wavelengths, which is expected to be completed in late 2013.In this mode, Altair will feed the Gemini Multi-Object Spectrograph(GMOS), which is an optical imager as well as a long-slit, multi-slitand integral field unit spectrograph. We intend to replace thecurrent Altair science dichroic with a sodium notch filter, passingonly the 589nm wavelength light from the LGS to the AO system. Therest of the spectrum from 400 nm to the GMOS red cutoff at 1.1 micronsis intended as science capable light. Tip/tilt correction will beperformed close to the science target with the GMOS on-instrumentwavefront sensor or with P1 as in the P1+LGS mode discussed

above. Weexpect an image quality improvement of roughly a factor 2 in this modeover seeing limited observations. Since exposure time to reach a given signal-to-noise ratio scalesroughly as the square of the image quality, these two upgradesrepresent a substantial efficiency improvement which is available tonearly all targets normally observed at Gemini North.

Larmor-resonant Sodium Excitation for Laser Guide Stars

Oral - N: 13306

Ronald Holzloehner[1], Simon Rochester[2], Dmitry Budker[3], Domenico Bonaccini Calia[1]

[1] European Southern Observatory
[2] Rochester Scientific, LLC
[3] Berkeley University of California

Extremely large telescopes will rely on powerful sodium laser guide stars (LGS) to enable adaptive optics with high sky coverage. Since each watt of laser power is expensive, and because scattering of the uplink laser beam is detrimental, it is beneficial to optimize the specific LGS return flux per laser power. Narrow-band continuous-wave and long-pulse lasers with about 20W (average) beam power have been shown by studies carried out so far to achieve the highest specific efficiencies of all laser formats of up to about sce = 250-400 photons/s/W/(atoms/m^2). These simulations have yet to be confirmed experimentally. Larmor precession of the mesospheric sodium atoms tends to redistribute atomic populations among different magnetic sublevels which thwarts optical pumping and thus diminishes the LGS photon return efficiency. If the atoms are excited by a train of short powerful laser pulses whose repetition time equals the Larmor period (3-6 μs), the periodic population redistribution is in phase with the laser excitation and thus no longer has a detrimental influence. This method was already known from precision magnetometry, but proposed in 2012 by Hillman et al. for LGS. Simulations show an efficiency near sce = 370-400 ph/s/W/(atoms/m^2). The proposed pulse format may thus yield a more uniform LGS return flux vs pointing direction. However, the Larmor frequency (and thus the geomagnetic field strength around 90 km altitude) must be known to about 1% accuracy, and a pulsed laser with the described pulse format may be difficult to build. The presentation discusses some tradeoffs and investigates possibilities of periodically chirping the laser, instead of pulsing it.

Horizontal structure of mesospheric sodium

Oral - N: 13393

Thomas Pfrommer[1], Paul Hickson[2], Ronald Holzloehner[1]

[1] European Southern Observatory
[2] University of British Columbia

Spatial variations in the density of mesospheric sodium have a direct impact on the performance of adaptive optics systems that employ sodium laser guide stars (LGS). Fluctuations in the sodium centroid altitude result in focus errors in the wavefronts derived from LGS, leading to errors in the tomographic reconstruction of atmospheric turbulence. These errors are proportional to the square of the telescope aperture diameter, and are particularly important for AO systems on extremely large telescopes. Temporal variations of the centroid altitude have been well studied, but little is known about variations on horizontal scales. Such variations would produce differential focus errors between different LGS in an asterism, which might affect the performance of wide-field AO systems. This paper takes two approaches to assessing horizontal centroid altitude variations. One is to apply the assumption of frozen flow (Taylor hypothesis) and mesospheric wind data in order to estimate the horizontal structure function from the observed temporal spectrum. The second approach is to perform direct measurements using a lidar system and rapid horizontal chopping of the laser beam in two perpendicular directions. These have been attempted using the lidar system of the 6-m Large Zenith Telescope, located near Vancouver, Canada. While the small, unvignetted field of view of the current lidar receiver limits the accuracy that can be achieved, we do find general agreement between the two approaches. At least in the direction of the predominant mesospheric wind, the RMS centroid altitude difference increases roughly as the square root of the separation, with a typical amplitude of ~20 m at a separation of 25 m. This corresponds to ~140 nm of differential focus wavefront error for a 40-m telescope with a 1-arcmin diameter asterism. Whether this differential focus term is isotropically distributed in the sodium region cannot be firmly established from the present data and a new receiver design and experiment has been proposed to be carried out in summer 2013. The quantitative impact of such spatial variations on AO is a subject of current research.

Performance Evaluation of Refocussed and Uplink Corrected Laser Guide Stars

Oral - N: 13893

Sebastian Rabien[1], Lorenzo Busoni[2], Wolfgang Gaessler[3], Simone Esposito[2]

[1] MPE Garching
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[3] Max-Planck-Institut fuer Astronomie

Laser guide star adaptive optics performance is strongly affected by the LGS spot size. An increased spot size and deformation can be caused by uplink wavefront deformation and the thickness of the sodium layer. With the perspective elongation of the fluorescing stripe being imaged on the wavefront sensor, the signal to noise ratio of Hartmann type sensors is lowered, pyramid type sensors would even not work properly. With the upcoming extremely large telescopes this problem is getting a serious issue. In this paper we will discuss a twofold possible solution to this problem: The use of pulsed lasers in conjunction with dynamical refocussing and the uplink adaptive correction of the launched lasers. Dynamical following the laser pulse as it propagates through the sodium layer not only removes the elongation of the laser guide star on the detector, but as well allows for pyramid sensors and removes the Rayleigh scattered light from the detection. This mean removes theperspective elongation and sharpens the LGS spot on the wavefront detector. An additional adaptive optics correction of the launched laser even further decreases the laser spot size- finally leading to increased signals and lower required laser power.

Upgrade of the ESO Laser Guide Star Facility

Oral - N: 16284

Steffan Lewis[1], Domenico Bonaccini Calia[1], Bernard Buzzoni[1], Philippe Duhoux[1], Gert Fischer[1], Ivan Guidolin[1], Ronald Holzloehner[1], Paul Jolley[1], Thomas Pfrommer[1], Dan Popovic[1], Alvaro Alvarez[1], Juan Beltran[1], Julien Girard[1], Frederic Gonte[1]

[1] ESO

The laser guide star facility (LGSF) is part of the fourth Unit Telescope, Yepun, at Paranal observatory. It provides a single centre-launched sodium beacon for the two adaptive optics instruments SINFONI and NACO located at Cassegrain and Nasmyth B respectively. The original facility, which was installed in 2006, comprised a high-power sodium-resonant dye laser source, PARSEC, producing an output beam that was delivered via a 27 metre long single-mode photonic crystal optical fibre to a launch system located behind the telescope secondary mirror. This dye laser was recently replaced with a laser system based on solid-state Raman fibre laser technology known as PARLA. Apart from the laser source, the design of the rest of the LGSF remained essentially unchanged during the upgrade. Requirements for the new laser system include start-up times consistent with the flexible observing strategy of the Paranal telescopes, and an output beam format compatible with the existing fibre-delivered launch system. Reported here are the main results of the design, integration and commissioning of the new laser system. Service mode observing using the LGSF restarted on February 20th 2013.

Posters

GMT Laser Guide Star Facility Preliminary Design

Poster - N: 13119

Celine D'Orgeville[1]

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The Giant Magellan Telescope (GMT) Adaptive Optics (AO) System includes a Laser Guide Star Facility capable of projecting six sodium Laser Guide Stars (LGS) for use in the Laser Tomography AO (LTAO) and Laser Ground Layer AO (LGLAO) modes of operation. The laser beams are projected from the edge of the GMT primary mirror to form a one- (LTAO) or seven- (LGLAO) arcminute diameter circular asterism. The LGSF is made of six identical LGS Units, each containing a Laser System, a Beam Conditioning and Diagnostic System (BCDS), a Laser Launch Telescope (LLT) and their associated Laser Interlock System (LIS). This paper provides an overview of the GMT LGSF requirements, error budgets and preliminary design at the system, subsystem and componet level. The LGSF operational model and its interactions with LTAO and LGLAO are also discussed.

Emulating the effects of laser guide star spot elongation and uplink turbulence: First results from DRAGON, the Durham adaptive optics test bench

Poster - N: 13255

Andrew Reeves[1], Tim Morris[1], Richard Myers[1], Nazim Bharmal[1], Alastair Basden[1]

[1] Durham University

The effects of Laser Guide Star spot elongation and uplink turbulence on Adaptive Optics performance must be considered when designing an AO system for use on an Extremely Large Telescope. The former is the effect of atmospheric turbulence on a LGS as it travels up to excite the mesospheric sodium layer, resulting in unknown tip/tilt modes and laser plume shape and the latter the effect of the sodium layer's finite thickness, degrading Shack Hartmann wave front sensor performance through elongated spots. DRAGON is an AO test bench under construction in Durham, which can explore these effects in real time through the use of a novel LGS emulator, where a laser is projected through a realistic turbulence simulator into a cell filled with a water solution of fluorescent dye. The resulting plume provides

a 3-D light source analogous to a sodium LGS. The turbulence simulator consists of 4 rotating phase screens, which can be independently translated in height. We present here first results from DRAGON, comparing wave-front sensing accuracy when the LGS is emulated by (a) the 3-D fluorescent cell (uplink turbulence and elongation), (b) a thin florescent film (uplink turbulence, no elongation), (c) the 3-D cell back illuminated (no uplink turbulence, elongation) and (d) a back illuminated thin fluorescent film (no uplink turbulence, no elongation).

Modified Shack Hartmann concept for efficient LGS measurement on ELTs

Poster - N: 13301

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Laser Guide Star adaptive optics is a mandatory technology to make the ELTs work. However, a major issue for the next generation of Shack Hartmann wave front sensors is the so-called spot elongation, corresponding to a variable footprint of the LGS image on the SH detector. To overcome this issue, and avoid the use of large detector matrices that will increase the acquisition time, we propose an innovative SH concept compressing the spot in the elongation direction. By use of a combination of two micro-lenses arrays, we develop an optical solution to concentrate the spot and allow a drastic reduction of the detector size. One array is made of cylindrical lenses, with a power varying with the radial position. We will present the first simulations of performances and the studies for the manufacturing of this optimised SH-WFS.

Analysis of fratricide effect observed with GeMS and its relevance for large aperture astronomical telescopes

Poster - N: 13303

Angel Otarola[1], Benoit Neichel[2], Lianqi Wang[1], Corinne Boyer[1], Brent Ellerbroek[1], François Rigaut[2]

[1] Thirty Meter Telescope
[2] Gemini Observatory

Large aperture ground-based telescopes require Adaptive Optics (AO) to correct for the distortions induced by atmospheric turbulence and achieve diffraction limited imaging quality. These AO systems rely on Natural and Laser Guide Stars (NGS and LGS) to provide the information required to measure the wavefront from the astronomical sources under observation. In particular one such LGS method consists in creating an artificial star by means of fluorescence of the sodium atoms at the altitude of the Earth's mesosphere. This is achieved by propagating one or more lasers, at the wavelength of the Na D2a resonance, from the telescope up to the mesosphere. Lasers can be launched from either behind the secondary mirror or from the perimeter of the main aperture. The so-called central- and side-launch systems, respectively. The central-launch system, while helpful to reduce the LGS spot elongation, introduces the so-called "fratricide" effect. This consists of an increase in the photon-noise in the AO Wave Front Sensors (WFS) sub-apertures, with photons that are the result of laser photons back-scattering from atmospheric molecules (Rayleigh scattering) and atmospheric aerosols (dust and/or cirrus clouds ice particles). This affects the performance of the algorithms intended to compute the LGS centroids and subsequently compute and correct the turbulence-induced wavefront distortions. In the frame of the Thirty Meter Telescope (TMT) project and using actual LGS WFS data obtained with the Gemini Multi-Conjugate Adaptive Optics System (Gemini MCAO a.k.a. GeMS), we show results from an analysis of the temporal variability of the observed fratricide effect, as well as comparison of the absolute magnitude of fratricide photon-flux level with simulations using models that account for molecular (Rayleigh) scattering and photons backscattered from cirrus clouds.

A 2-deformable-mirror concept and algorithm to improve the laser efficiency of Gemini South MCAO (Gems')

Poster - N: 13344

Clémentine Béchet[1], Andrés Guesalaga[2], Benoit Neichel[3], Dani Guzman[2]

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Gem's is the first laser-based multi-conjugate adaptive optics offeredto the astronomical community. Its asterism of 5 laser guide stars hasrecently proved to provide very uniform turbulence correction over the85"x85" observation field, opening the new era of wide-field highangular resolution studies from the ground. Good AO performance requireshowever good wavefront sensing measurements from the laser guide stars,which directly depends on the quality of the laser spot image. Theoptimization of the lasers launched out of the telescope requires tofollow frequent and constraining calibrations and alignments procedures(quasi-static aberrations), in order to guarantee satisfying amplitudeand phase of the beam. These complex and time-consuming procedures willstrongly penalize the availability of Gem's.A laser

beam shaping concept has been recently suggested to overcomesuch issues. It consists in applying, in the beam transfer optics, afield-conjugation thanks to 2 deformable mirrors. We review thisconcept. In particular, we discuss the criterion to be optimized and thedesired amplitude and phase shapes at the output of the Gemini beamtransfer optics. We deduce the control to be applied to the mirrors fromthe optimization of the signal-to-noise ratio of the wavefront sensingin Gem's. An iterative algorithm is used to estimate the phases, with aweighted least-squares unwrapper to avoid branch points. This algorithmefficiency is demonstrated with adequate beam shaping simulations.Discussion is made about how to implement such concept at Gemini.

Impact of Sodium Layer variations on the performance of the E-ELT MCAO module

Poster - N: 13357

Laura Schreiber[1], Emiliano Diolaiti[2], Italo Foppiani[2], Matteo Lombini[2]

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Adaptive optics systems based on sodium Laser Guide Stars (LGS) may exploit Natural Guide Stars (NGS) to solve intrinsic limitations of artificial beacons, such as tip-tilt indetermination and, in the case of Multi-Conjugate Adaptive Optics (MCAO), tip-tilt anisoplanatism. NGSs are also required to mitigate the impact of the sodium layer structure and variability: on 8-meter telescopes the main effect is fast focus variation; on a 40-meter class telescope, as a consequence of the sodium layer perspective elongation and of the finite field of view of the LGS WaveFront Sensor (WFS), additional spurious aberrations are generated. The sodium layer may also have transverse structures leading to significant differential effects among LGSs. All these aspects show up in MAORY, a concept for a MCAO module for the European Extremely Large Telescope designed to provide uniform correction over an extended field of view. Starting from the analysis and modeling of the input perturbations related to the Sodium Layer properties we show the impact of the low/medium orders iduced on global performance of the E-ELT MCAO module.

Status of ARGOS - The Laser Guide Star System for the LBT

Poster - N: 13512

Walfried Raab, Sebastian Rabien[1], Wolfgang Gaessler[2], Simone Esposito[3], Michael Lloyd-Hart, Lothar Barl, Udo Beckmann, Marco Bonaglia[3], Jose Borelli, Joar Brynnel, Peter Buschkamp, Lorenzo Busoni[3], Luca Carbonaro[3], Jacopo Antichi[3], Claus Connet, Richard Davies, Deysenroth Matthias, Olivier Durney, Richard Green, Hans Gemperlein, Victor Gasho, Marcus Haug, Pete Hubbard, Sebastian Ihle, Martin Kulas, Christina Loose, Michael Lehmitz, Jamison Noenickx, Edmund Nussbaum, Gilles Orban De Xivry, Andreas Quirrenbach, Diethard Peter, Matt Rademacher, Jesper Storm, Christian Schwab, Vidhya Vaitheeswaran, Julian Ziegleder

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ARGOS is an innovative multiple laser guide star adaptive optics system for the Large Binocular Telescope (LBT), designed to perform effective GLAO correction over a very wide field of view. The system is using high powered pulsed green (532 nm) lasers to generate a set of three guide stars above each of the LBT mirrors. The laser beams are launched through a 40 cm telescope and focused at an altitude of 12 km, creating laser beacons by means of Rayleigh scattering. The returning scattered light, primarily sensitive to the turbulences close to the ground, is detected by a gated wavefront sensor system. The derived ground layer correction signals are directly driving the adaptive secondary mirror of the LBT. ARGOS is especially designed for operation with the multiple object spectrograph Luci, which will benefit from both, the improved spatial resolution, as well as the strongly enhanced flux. In addition to the GLAO Rayleigh beacon system, ARGOS was also designed for a possible future upgrade with a hybrid sodium laser - Rayleigh beacon combination, enabling diffraction limited operation. The ARGOS laser system has undergone extensive tests during Summer 2012 and is scheduled for installation at the LBT in Spring 2013. The remaining sub-systems will be installed during the course of 2013. We report on the overall status of the ARGOS system and the results of the sub-system characterizations carried out so far.

Review of Gemini South Laser Guide Star Facility performance and upgrades

Poster - N: 16120

Vincent Fesquet[1], Constanza Araujo[1], Gustavo Arriagada[1], Sarah Diggs[1], Jeff Donahue[2], Celine D'Orgeville[3], Claudio Marchant[1], Vanessa Montes[1], Cristian Moreno[1], Benoit Neichel[1], Richard Oram[1], William Rambold[1], Andrew Serio[1], Cristian Urrutia[1], Tomislav Vucina[1]

[1] Gemini Sur Observatory
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The Gemini South (GS) Observatory acquired a 50W sodium Guide Star Laser System back in March 2010, as one of the key component of the Gemini Multi-Conjugate Adaptive Optics System (GeMS) project. After a successful post-delivery acceptance in laboratory, the system was installed on the elevation platform of the telescope. Following an intensive period of optimization, the Gemini South Laser Guide Star Facility (LGSF) delivered its first light on the sky in January 2011. Over the two years following the event, and while the LGSF was being commissioned, the GS LGSF team was able to gather a lot of data concerning its laser system, and therefore to work on ways to improve both its overall performance and reliability. This work is critical knowing that the LGSF system will transition from development to normal operations mode in March 2013. This paper will report on the LGSF performance during GeMS runs over two years of use. It will then provide an exhaustive list of the numerous findings made over this period, and will explain what has been done to enhance the system. Finally, we will comment on how the LGSF team is organized to provide every month the adaptive optics instrument CANOPUS with a good photon return.

Laser Guide Stars for Hypertelescopes

Poster - N: 16359

Paul Nuñez[1], Antoine Labeyrie[1]

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Optical interferometry has allowed us to achieve milli-arc-second resolution in an increasing number of science cases using aperture synthesis with a limited number of apertures. A hypertelescope with a spherical (Carlina) architecture has been proposed in order to simultaneously use several (˜100) mirrors in a (˜100m) interferometric array. Provided that phasing is possible, such an instrument may in principle provide us with snap-shot images of smaller and fainter sources than planned monolithic telescopes. A modified laser guide star technique, suitable for large diluted apertures, has been proposed in order to achieve adaptive phasing. Although still in a simulation stage, recent laboratory and numerical efforts have provided evidence for the feasibility of such a technique.

Production of RFA-Based 589-nm Guide Star Lasers for ESO VLT

Poster - N: 19214

Axel Friedenauer[1], Bernhard Ernstberger[1], Wilhelm Kaenders[1], Vladimir Karpov[2], Daoping Wei[2], Wallace Clements[2]

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[2] MPB Communications Inc.

Industrial partners Toptica and MPBC are nearing completion of the production of the Raman Fiber Amplifier (RFA) based Guide Star lasers for the ESO VLT. These Guide Star Lasers emit 22W of narrow-linewidth (< 5MHz) continuous wave (CW) radiation at a wavelength of 589nm and include an integrated sodium repumping scheme. A master oscillator signal from a linearly-polarized Toptica CW diode laser emitting at 1178nm with actively stabilized emission frequency is amplified in an MPBC polarization-maintaining (PM) RFA pumped by a high-power 1120-nm PM fiber laser. With efficient stimulated Brillouin scattering suppression, an unprecedented 40W of narrow-band RFA output has been obtained. The fiber amplifier design is based on ESO's patented narrow-band RFA technology. The output of the RFA is mode-matched into a resonant frequency doubling cavity with a free-spectral-range matching the sodium D2a to D2b separation, allowing simultaneous generation of an additional frequency component (D2b line) to re-pump the sodium atom electronic population, thereby increasing the return flux. With demonstrated doubling efficiencies $> 80\%$, output powers at 589nm easily exceed the 20W design goal. The fiber-based lasers provide excellent beam quality and are modular, turn-key, maintenance-free, reliable devices. Their compactness allows installation directly into the launch telescope structure. The delivery of the four ESO Laser Units is foreseen this year. We report on the design, production and testing status of the four Laser Units.

8 System control and algorithms

Invited

Trends on real time control for adaptive optics

Invited - N: 16778

Enrico Fedrigo[1]

[1] ESO

the Real Time Control for Adaptive Optics workshop series has been conceived to bring together international AO RTC specialists in order to share and exchange experience regarding the design and implementation of these systems. Such shared experience can be used to improve the design of new and proposed AO systems, increasing their performance and usability. The second in a series of Real Time Control for AO workshop was held at ESO Garching, Germany, on the 4th and 5th of December. During the two full days of the 2012 workshop, the participants were presented with 28 talks divided into 7 sessions, one panel discussion and two free-form open discussions. In this talk we briefly report about the major topics covered during the workshop and further initiatives ESO is bringing forward with the help of the community on the same topic.

Oral

Reliable optimal control for ELT AO systems

Oral - N: 12634

Niek Doelman[1,2]

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Linear Quadratic Gaussian (LQG) control has the potential to perform significantly better than the commonly used controllers in AO systems. This has been demonstrated in various simulation studies and laboratory experiments. Recently, it has also been demonstrated in on-sky telescope test runs. For application of a new control method to the AO systems of ELT's, the reliability of the control performance is crucial. Especially, in the high-complexity environment of an ELT, the AO controller should be flawless and meet the Strehl ratio requirement for each atmospheric condition, windshake condition or external vibration. The reliability or performance robustness of LQG-type control for AO systems is questionable. In particular, the attractive performance of LQG is based on having an accurate model of the wavefront distortions. For turbulence-induced distortions for instance, this model depends on the actual properties of the turbulence outer scale, coherence length and wind. To keep the attractive performance, an LQG controller would have to be re-designed as soon as the turbulence properties change. This paper discusses a control design method for AO controllers that are optimized for a robust performance over the full range of atmospheric conditions. It is shown that this robust design leads to very different behavior from that of an LQG controller, which is optimized for a single atmospheric condition only. In simulations of an ELT-relevant AO system under von Karman type turbulence it is demonstrated that a robust AO controller reaches a very good performance over a wide range of atmospheric conditions and also it is significantly better than the integrator controller performance. The LQG-type AO controller only performs very well for a small range of turbulence conditions. For larger deviations of the turbulence parameters, the LQG performance quickly deteriorates. The complexity and computational demands of the robust AO controller are limited and much less than what an adaptive implementation of LQG would require.

Design and Testing of GPU based RTC for TMT NFIRAOS

Oral - N: 13172

Lianqi Wang[1]

[1] Thirty Meter Telescope Project

Graphical processing units (GPUs) are now gaining popularity in general computing applications due to their high computing power and high memory bandwidth (~10x of CPUs). For the same reason, GPUs are also suitable processors for the real time controllers (RTCs) of next generation adaptive optics (AO) systems. In this talk, we present a CPU+GPU based RTC design for the Thirty Meter Telescope (TMT) Narrow Field Infrared AO System (NFIRAOS), as part of an ongoing trade study of control algorithms and processor hardware options. We demonstrate that the system will meet the stringent latency requirement of first computing gradients for ~15500 laser guide star wavefront sensor sub-apertures, and then commands for ~7000 deformable mirror actuator at 800 Hz, using 12 Nvidia GTX 580

GPUs (2 GPUs per WFS). A classical matrix vector multiply reconstruction algorithm is used for its simplicity and parallelizability. Obtaining the conventional control matrix by inverting the forward influence matrix is impractical due to the large system size and sub-optimal performance due to lacking proper regularization. Instead, the control matrix implements a minimum variance wavefront reconstruction algorithm and is computed column-by-column using an iterative solver. We demonstrate that we can initialize the control matrix in about 1 minute and update it in 10 seconds as operating conditions vary to maintain optimal performance. Additionally, the weights used to compute the subaperture gradients are updated at a similar rate to track changes in the profile of the mesospheric sodium layer. These soft real time and background processes will largely be handled by CPUs. Finally,we will show a first version of the complete block diagram of data flow and mapping to hardware.

P-CuReD - a fast wavefront reconstruction algorithm for XAO with pyramid WFS

Oral - N: 13184

Iuliia Shatokhina[1], Andreas Obereder[2]

[1] Industrial Mathematics Institute, Johannes Kepler University Linz
[2] MathConsult GMBH

For large AO systems equipped with a pyramid wavefront sensor (WFS) the existing control algorithms (MVM, FTR) are computationally very heavy. Thus it was impossible to achieve a reconstruction in real time (e.g., on the E-ELT XAO system EPICS running at a frequency of 3 kHz). To overcome this problem, we developed a new algorithm for wavefront reconstruction from pyramid WFS measurements, the P-CuReD. Closed loop simulations (using the ESO OCTOPUS simulation tool) show that our algorithm provides a quality of AO correction which is comparable to the MVM results. At the same time, our method is much more efficient from the computational point of view. The P-CuReD algorithm has a linear computational complexity O(n) (compared to O(n2) for the MVM), and requires only 0.04% of the number of flops needed for the MVM (200x200 WFS). We show that the method is parallelizable and pipelinable, and highlight some implementational aspects.

Real-time control system verification for ELT AO systems

Oral - N: 13189

Alastair Basden[1], Richard Myers, Tim Morris, Nigel Dipper, Nazim Bharmal, Urban Bitenc, Andrew Reeves, Eric Gendron, Zoltan Hubert, Fabrice Vidal, Olivier Matin, Arnaud Sevin, Gérard Rousset, Damien Gratadour, Fanny Chemla

[1] Durham University

ELT AO systems have demanding computational requirements for real-timecontrol. These systems are required to be fully tested and robustbefore commissioning so that valuable on-sky time is not wasted. Inthis talk I will report recent work at Durham on our ELT AO real-timecontrol system, algorithms that we use to improve robustness, anddevelopment of an end-to-end testing environment that will allow fulltesting of real-time control systems, including both Monte-Carlosimulation and hardware approaches. The talk will include experiencegained with CANARY, how the robustness of this system has beenimproved, and our experience operating with four laser guide stars. Workcarried out in this area on the DRAGON test-bench will also bedescribed.

NFIRAOS Real-Time Controller Trade Study

Oral - N: 13294

Jean-Pierre Veran[1], Glen Herriot[1], Zoran Ljusic[1], Carlos Correia[1], Eric McVeigh[2], Robert Prior[2], Darryl Gamroth[2], Gilles Luc[3], Wang Lianqi[3], Corinne Boyer[3], Brent Ellerbroek[3]

[1] National Research Council Canada
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In 2008-2009, the Thirty Meter Telescope (TMT) commissioned two conceptual design studies for the real-time controller (RTC) of NFIRAOS, TMT's first light facility Multi-Conjugate AO system, which, at the time, was in its preliminary design phase. AO systems for Extremely Large Telescopes such as NFIRAOS pose unprecedented real-time computational challenges due to the sheer number of measurement points and the need for full tomographic reconstruction. As reported at the 2009 edition of the AO4ELT Conference, both studies proposed a dedicated FPGA-based architecture running an iterative tomographic solver. For instance, the NRC team proposed to run the Block-Gauss-Seidel algorithm on a custom board made of several interconnected high-end FPGAs, which was being developed for radio-astronomy Since 2009, the technological landscape has changed dramatically: GPUs are now offering incredible compute power at very low cost, and other similar commercial off-the-shelf (COTS) massively parallel co-processors are rapidly emerging; the custom FPGA-Board for radio astronomy (now called the Kermode board) has been manufactured and is ready for AO benchmarking. At the same time, algorithms have been improved and requirements have been refined. In light of these developments, we have decided to take another look at the different

options for the NFIRAOS RTC through a trade study. This paper reports on the findings of this study. The hardware options that we have considered in our conceptual designs are: high end GPUs or the newly released Intel Xeon Phi co-processor in a commercial PC-based architecture; GPUs and/or COTS FPGAs in a more rugged architecture such as OpenVPX; and the Kermode board. Algorithm options include the brute-force matrix-vector multiply, as well as a number of iterative solvers. Our trade study relies in part on analytical estimates, but mostly on actual end-to-end benchmarking, and addresses criteria such as cost, performance, reliability and flexibility.

Fast iterative reconstructors for MCAO, MOAO and LTAO

Oral - N: 13299

Ronny Ramlau[1], Andreas Obereder[2], Matthias Rosensteiner[2], Daniela Saxenhuber[1]

[1] Industrial Mathematics Institute, JKU
[2] MathConsult GmbH

Extremely large telescopes as the E-ELT rely on adaptive optics systems in order to correct for atmospheric turbulences. Due to the changing atmosphere, the computation of the shapes for the correcting deformable mirrors from incoming wavefronts of laser/natural guide stars has to be done within 1-2 ms, which requires fast numerical algorithms. The Austrian Adaptive Optics team has developed a 3 step approach for the computation of the mirror shapes. First, the wavefronts are computed from the sensor measurements. Next, the turbulent layers are reconstructed from the wavefronts, and in a final step the shape of the deformable mirrors is determined. For the wavefront reconstruction, the CuReD algorithm is used. The atmospheric layers and the mirror shapes are computed iteratively. We propose to use different iterative methods, as Kaczmarz, gradient, and conjugate gradient method. The modular approach of our reconstructors allows an easy adaption to different AO systems. Quality and speed results are presented for MCAO, LTAO and MOAO.

Building a reliable, scalable and affordable RTC for ELTs AO instruments

Oral - N: 13354

Damien Gratadour[1], Arnaud Sevin[1], Denis Perret[1], Julien Brule[1]

[1] Laboratoire d'études spatiales et d'instrumentation en astrophysique

Addressing the unprecedented amount of computing power needed by the ELTs AO instruments real-time controllers (RTC) is one of the key technological developments required for the design of the next generation AO systems. Throughput oriented architectures such as GPUs, providing orders of magnitude greater computational performance than high-end CPUs, have recently appeared as attractive and economically viable candidates since the fast emergence of devices capable of general purpose computing. However, using for real-time applications a I/0 device which cannot be scheduled nor controlled internally by the operating system (OS) but is sent commands through a closed source driver comes with a number of challenges. Beyond technological bottlenecks such as memory bandwidth currently addressed by manufacturers, resource management related obstacles such as preemption policy or interrupt handling are of major concern for real-time applications requiring strong determinism. Building on the experience of almost real-time end-to-end simulations using GPUs, and relying on the development of the COMPASS platform, a unified and optimized framework for AO simulations and real-time control, our team has engaged into the development of a scalable, heterogeneous GPU-based prototype for an AO RTC. In this paper, we will review the main challenges arising when utilizing GPUs in real-time systems for AO and rank them in terms of impact significance and available solutions. We will present our strategy, in terms of hardware, OS and software, to mitigate these issues including the general architecture of our prototype, the real-time core and additional dedicated components for data acquisition and distribution. Finally, we will discuss the expected performance in terms of latency and jitter on the basis of realistic benchmarks and focusing on the dimensioning of the MICADO AO module RTC.

A finite element - wavelet hybrid algorithm for atmospheric tomography

Oral - N: 13433

Mykhaylo Yudytskiy[1], Tapio Helin[2], Ronny Ramlau[3]

[1] Johann Radon Institute for Computational and Applied Mathematics
[2] University of Helsinki
[3] Industrial Mathematics Institute, JKU

Telescopes of the next generation will utilize complex adaptive optics (AO) systems that employ multiple wavefront sensors in combination with several deformable mirrors. Many of these system, 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 profiles 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 propose a novel iterative approach, which combines wavelet-based techniques and conjugate gradient schemes to efficiently and accurately tackle the problem of atmospheric reconstruction. The aim of our approach is to keep the

qualitative performance of currently used methods, such as the MVM, but significantly decrease the computational load. We will present results of our algorithm with respect to quality in the context of MCAO on OCTOPUS, the ESO end-to-end simulation tool. Moreover, in the E-ELT setting, the current implementation of our method is estimated to take only 1.1% of an MVM's cost in terms of FLOPs. The method is highly flexible, has a good potential for efficient parallelization, and is pipelinable to some degree.

Posters

Fast wavefront reconstruction with the CuReD algorithm

Poster - N: 13208

Matthias Rosensteiner[1]

[1] MathConsult GmbH

The reduction of the computational load for the RTC in adaptive optics systems for future extremely large telescopes is an critical issue. The CuReD algorithm is an extremely fast wavefront reconstructor of Shack-Hartmann wavefront sensor data and therefore especially suitable for this class of telescopes. Additionally to its superior speed the quality of the algorithm is comparable to the standard methods. The algorithm is fully developed and was already tested on sky. We present the idea of the CuReD algorithm and its application on SCAO systems. Further, we show the possibility to succesfully use the algorithm in an GLAO system.

A gradient based method for wavefront reconstruction

Poster - N: 13209

Daniela Saxenhuber[1], Ronny Ramlau[1]

[1] Industrial Mathematics Institute, JKU

Large ground-based telescopes rely on adaptive optics systems in order to achieve a good image quality. Due to steadily growing telesope sizes there is a strong increase in the computational load for atmospheric reconstruction with current methods, first and foremost the MVM. 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). In this poster, we propose a gradient based method for the atmospheric tomography. To reconstruct the incoming wavefronts from Shack-Hartmann wavefront sensor data, the CuReD algorithm was used. The gradient method can, however, be easily combined with different methods and is, furthermore, highly parallelizable. The main goal of this iterative approach is the comparability with the MVM method in quality and a considerable reduction of computational cost. Numerical results will be presented within the MCAO setting for the E-ELT, obtained on the ESO ent-to-end simulator, OCTOPUS.

Local Ensemble Transform Kalman Filter: a non stationary control law for complex AO on ELTs

Poster - N: 13253

Morgan Gray[1], Cyril Petit[2], Thierry Fusco[2], Sergey Rodionov[3], Marc Bocquet, Laurent Bertino

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[3] Laboratoire d'Astrophysique de Marseille (CNRS - Université Aix Marseille)

We propose a new algorithm for an AO control law which allows to reduce the computation burden in the case of an Extremely Large Telescope and to deal with a non stationary behavior of the atmospheric turbulence. This approach uses Ensemble Transform Kalman Filter (ETKF) and localizations by domains decomposition: the assimilation is split into local domains on the pupil of the telescope and each of the update data assimilation for each domain is performed independently. This kind of assimilation enables parallel computation of much less data during the update stage. This is a Kalman Filter adaptation for large scale systems with a non stationary turbulence when the explicit storage and manipulation of extremely large covariance matrices are impossible. This distributed parallel environment implementation is highlighted and studied in the context of an ELT application. First simulation results are proposed to assess our theoretical analysis and to demonstrate the potentiality of this new approach for an AO control law on ELTs.

Adaptive Optics Real-time Control in the ELT Era

Poster - N: 13267

Nigel Dipper[1]

[1] Durham University

The next generation of large telescopes will depend critically on Adaptive Optics. The instrumentation now proposed for ELTs makes substantial demands on computing power for real-time control. These demands will be met by a combination of novel algorithms and the use of new developments in the world of high power computing. This poster will summarise the developments made in meeting this challenge at the CfAI in Durham and our research and development plan over the next few years. We will demonstrate what can be done on an ELT scale with existing hardware (FPGA, GPU and CPU) and to what aspects of the real-time control system these technologies are best applied. In addition, we will report on initial attempts at Durham to abstract the hardware from the software, using high-level languages such as OpenCL. This will be critical to making software for the E-ELT 'future proof' allowing the easy introduction of new computing technology that will emerge over the long development period of ELT instrumentation.

Tests of novel wavefront reconstructors on sky with CANARY

Poster - N: 13268

Urban Bitenc[1], Matthias Rosensteiner[2], Nazim Bharmal[1], Alastair Basden[1], Tim Morris[1], Andreas Obereder[2], Eric Gendron[3], Fabrice Vidal[3], Gérard Rousset[3], Damien Gratadour[3], Olivier Martin[3], Zoltan Hubert[3], Richard Myers[1]

[1] Durham University
[2] MathConsult GMBH
[3] Laboratoire d'études spatiales et d'instrumentation en astrophysique

The E-ELT will require novel optimal wavefront reconstruction algorithms that can handle the larger scale of ELT instrumentation. Two such algorithms, developed by the Austrian Adaptive Optics Team and within the CANARY collaboration, have been successfully tested with CANARY both on the bench and on sky at the 4m WHT telescope during 2012. The results of these tests will be presented and the performance compared with more traditional reconstructors.

A hierarchical wavefront reconstruction algorithm for gradient sensors

Poster - N: 13280

Nazim Bharmal, Urban Bitenc[1], Alastair Basden[1], Richard Myers[1]

[1] Durham University

ELT-scale extreme adaptive optics systems will require new approaches tocompute the wavefront suitably quickly, when the computational burden ofapplying a MVM is no longer practical. An approach is demonstrated here whichis hierarchical in transforming wavefront slopes from a WFS into a wavefront,and then to actuator values. First, simple integration in 1D is used to create1D-wavefront estimates with unknown starting points at the edges of independentspatial domains. Second, these starting points are estimated globally. By thesestarting points are a sub-set of the overall grid where wavefront values are tobe estimated, sparse representations are produced and numerical complexity canbe chosen by the spacing of the starting point grid relative to the overallgrid. Using a combination of algebraic expressions, sparse representation, anda conjugate gradient solver, the number of non-parallelized operations forreconstruction on a 100x100 sub-aperture sized problem is ~600,000 or O(N^3/2),which is approximately the same as for each thread of a MVM solutionparallelized over 100 threads. To reduce the effects of noise propagationwithin each domain, a noise reduction algorithm can be applied which ensuresthe continuity of the wavefront. To apply this additional step has a cost of~1,200,000 operations. We conclude by briefly discussing how the final step ofconverting from wavefront to actuator values can be achieved.

Assessing new technological developments on Graphical Processors for applications on real-time control for Adaptive Optics

Poster - N: 13330

Richard Myers[1], Sofia Dimoudi, Alastair Basden, Nigel Dipper

[1] Durham University

We study the use of GPUs for the wavefront reconstruction problemon ELT scale AO modes. We look at changes through GPU generations.In particular, we look at the impact that the two most recent NVIDIAtechnologies for GPU computing, namely RDMA for GPUDirect andDynamic Parallelism, have on computational performance of classic andadvanced algorithms for real-time control.

Reducing the latency of the Fractal Iterative Method to half an iteration

Poster - N: 13346

Clémentine Béchet[1], Michel Tallon[1]

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The fractal iterative method for atmospheric tomography (FRiM-3D) has been introduced to solve the wavefront reconstruction at the dimensions of an ELT with a low-computational cost. Previous studies reported the requirement of only 3 iterations of the algorithm in order to provide the best adaptive optics (AO) performance. Nevertheless, any iterative method in adaptive optics suffer from the intrinsic latency induced by the fact that one iteration can start only once the previous one is completed. Iterations hardly match the low-latency requirement of the AO real-time computer. We present here a new approach to avoid iterations in the computation of the commands with FRiM-3D, thus allowing low-latency AO response even at the scale of the European ELT (E-ELT). The method highlights the importance of "warm-start" strategy in adaptive optics. To our knowledge, this particular way to use the "warm-start" has not been reported before. Futhermore, removing the requirement of iterating to compute the commands, the computational cost of the reconstruction with FRiM-3D can be simplified and at least reduced to half the computational cost of a classical iteration. Thanks to simulations of both single-conjugate and multi-conjugate AO for the E-ELT,with FRiM-3D on Octopus ESO simulator, we demonstrate the benefit of this approach. We finally enhance the robustness of this new implementation with respect to increasing measurement noise, wind speed and even modeling errors.

Loop control structure for the LINC-NIRVANA high-layer wave-front sensor

Poster - N: 13372

Juergen Berwein[1], Florian Briegel[1]

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LINC-NIRVANA is a Fizeau interferometer for the Large Binocular Telescope doing imaging in the near infrared. Multi-conjugated adaptive objects (MCAO) is used to increase sky coverage and to get diffraction limited images over a 2 arcminute field of view. Our instrument consists of altogether four wavefront subsystems, two for each side. The groundlayer wavefront sensor (WFS) loop which controlls the adaptive secondary deformable mirror is based on a FPGA slope calculation unit. Whereas the highlayer wavefront sensor (HWS) loop controlling the on-bench deformable mirror is run an a off-the-shelf multi-core Linux system. Using wavefront sensor data collected from a prior lab experiment, we have shown via simulation that the Linux based system is sufficient to operate at 1 kHz, with jitter well below the needs of the final system. We tested several combinations by varying the processor type, scheduling algorithm, and number of cores used. Based on the same system we testes the performance of the end-to-end data flow through all parts of the system which consits of the camera, loop control and deformable mirror. We will present our loop control structure and the results of those performance tests.

Fast, autonomous, holographic adaptive optics

Poster - N: 19098

Geoff Andersen[1], Fassil Ghebremichael[1], Ravi Gaddipati[1], Phani Gaddipati[1], Ken MacDonald[1], Paul Gelsinger-Austin[1]

[1] HUA Inc.

We present an adaptive optics system incorporating a holographic wavefront sensor with the autonomous closed-loop control of a MEMS deformable mirror. HALOS incorporates a multiplexed holographic recording of the response functions of each actuator in a deformable mirror. On reconstruction with an arbitrary input beam, multiple focal spots are produced. By measuring the relative intensities of these spots a full measurement of the absolute phase can be constructed. Using fast photodiodes, direct feedback correction can be applied to the actuators.In this talk we will present the results from an all-optical, ultra-compact system that runs in closed-loop without the need for a computer. The 32-actuator HALOS runs at a 100kHz bandwidth, but the speed is independent of the number of actuators and should run equally fast with 32 million. Additionally, the system is largely insensitive to obscuration unlike the more conventional Shack-Hartmann WFS. We will present information on how HALOS can be used for image correction and beam propagation as well as several other novel applications.

9 Atmospheric turbulence and AO disturbances

Oral

MOSE: a feasibility study for the prediction of the optical turbulence and meteorological parameters at Cerro Paranal and Cerro Armazones

Oral - N: 13219

Elena Masciadri[1], Franck Lascaux[1], Marc Sarazin[2]

[1] INAF - Osservatorio Astrofisico di Arcetri
[2] European Southern Observatory

The optical turbulence (OT) forecast is definitely mandatory for ground-based astronomy supported by AO to schedule scientific programs, instrumentation and instrumentation mode (ex: narrow or wide field) to retrieve effective outputs from the AO potentialities and optimize the telescope management and scientific feedbacks.A status report of the on-going MOSE project aiming at assess the feasibility of the prediction of the (1) OT and (2) all the classical atmospheric parameters from which the OT depends on at the two major ESO sites for ground-based astronomy in the visible and infrared regimes is presented. The study employed a wide variety of measurements obtained with different instruments running simultaneously to constrain and validate the model. Results obtained so far are very promising showing that the hydrodynamic technique is already mature for an operational implementation in present and forthcoming observatories. In this contribution we will present a summary of the most important achieved results and forthcoming plans to overcome the observed limitations. The analysis of procedures required to quantify the models score of success for the OT revealed us that an improved strategy for automatic systematic monitoring of turbulence is necessary in modern Observatories.

Stereo SCIDAR: Profiling atmospheric optical turbulence with improved altitude resolution

Oral - N: 13302

James Osborn[1], Richard Wilson[1], Harry Shepherd[1], Timothy Butterley[1], Vik Dhillon[2], Remy Avila[3]

[1] Durham University
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We report on the recent results of stereo SCIDAR from the Nordic Optical Telescope in La Palma. Stereo SCIDAR is a new extension to the Generalised–SCIDAR method. We use two fast imaging cameras to record the pupil images of a double star pair on separate channels. We can then reconjugate the cameras to planes above the telescope. In Generalised–SCIDAR the cameras are conjugate below the ground allowing profiling of the full volume of atmospheric turbulence above the telescope. By conjugating to multiple altitudes above the telescope in step increments we increase the altitude resolution of SCIDAR and are able to build up a full profile at this resolution or even concentrate profiling to a pre-selected altitude range. This is because the impulse response function of SCIDAR is altitude dependent and so by conjugating close to a layer we are able to reduce the width of the response function and so increase the resolution. As we conjugate close to a turbulent layer the signal from that layer also reduces, there will be a point where we become blind to any turbulence. A balance between these effects defines the resolution. This increased resolution could allow real-time profiles with ˜100˜m altitude resolution, which may be required for real-time optimisation LTAO on the ELT.

Cn2 profile reconstruction with Shack-Hartmann slope and scintillation data: first on-sky results

Oral - N: 13326

Juliette Voyez[1], Clélia Robert[1], Jean-Marc Conan[1], Vincent Michau[1], Laurent Mugnier[1], Bruno Fleury[1], Etienne Samain[2]

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All Wide Field Adaptive Optics systems for the ELTs need a precise tomographic reconstruction of the turbulent volume. The Cn2 profile, representing the turbulence strength, becomes a critical parameter for the tomographic reconstruction performance. CO-SLIDAR (Coupled Slope and scIntillation Detection And Ranging) is a method using both correlations of slopes and correlations of scintillation recorded with a Shack-Hartmann on binary stars. The extent of the method to a single source is also possible. CO-SLIDAR leads to a precise retrieval of the Cn2 profile

for both low and high altitude layers. Here, we present the first on-sky results of the method. A Shack-Hartmann with 30x30 subapertures is set up on a 1.5-meter telescope. Images are recorded on single and binary stars. Preliminary data reductions are performed to check the hypothesis of Kolmogorov turbulence and estimate the Fried parameter. We also control the hypothesis of Rytov regime. We finally restore the Cn2 profiles. The results are compared with those of methods which are only using correlations of slopes or correlations of scintillation. The position of the CO-SLIDAR method with respect to other existing Cn2 profilers is discussed.

Analysis of the frozen flow assumption using GeMS telemetry data

Oral - N: 13364

Angela Cortés[1], Lisa Poyneer[2], Benoit Neichel[3], S. Mark Ammons[4], Alex Rudy[5], Andrés Guesalaga[1]

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[2] Lawrence Livermore National Laboratory
[3] Gemini Observatory
[4] Steward Observatory
[5] National Central University

We use telemetry datafrom the Gemini south multi-conjugate adaptive optics system (GeMS) to studythe validity of the frozen flow hypothesis using two types of algorithms: i)the Predictive Fourier Control (PFC) framework; and ii) spatiotemporalcross-correlations of the wave-front sensor (WFS) measurements. The pros andcons of each technique are identified as well as their ability to determine thenumber of layers present and the associated velocities. Their potential use todetermine the altitude, i.e. turbulence profiler, is also addressed. Examplesderived from simulations and on-sky data are presented.

Defining reference turbulence profiles for E-ELT AO performance simulations

Oral - N: 13383

Marc Sarazin[1]

[1] European Southern Observatory

ELT sites have been chosen after many years of site evaluation with various atmospheric turbulence profilers. ELT instrument planners are expecting reference profiles as input to the AO instrument performance estimators. It appears however that, for some AO modes like LTAO, the requirements exceed the available products in terms of altitude resolution. We explore the possibility of mixing long term statistics at low altitude resolution with high resolution data collected during short term campaigns to produce representative profiles

Posters

MOSE: meso-scale prediction of near-ground meteorological parameters at ESO sites (Cerro Paranal and Cerro Armazones)

Poster - N: 13217

Franck Lascaux[1], Elena Masciadri[1]

[1] INAF - Osservatorio di Arcetri

In the framework of the MOSE project, we present in this contribution a detailed analysis of the results obtained by comparison between Meso-NH numerical model simulations and measurements from in situ instruments. The important amount of meteorological data comes from in situ measurements from masts (distributed from the ground up to 30 m) and automatic weather stations (AWS). Parameters analyzed are wind speed, wind direction and temperature, at both sites. Different numerical set-up have been tested, with the highest model horizontal resolution equal to 100 m. A sample of 20 nights in 2007 have been simulated. Model outputs have been compared to the in situ measurements from masts and AWS. The Meso-NH model succeeded very well in reproducing the meteorological parameters near the surface. We obtained excellent results for both wind and temperature parameters. These very encouraging results proved that the model could be used in operational mode at ESO E-ELT site to forecast wind speed, wind direction and temperature with a good level of accuracy, for application to the telescope management. Among the most important applications we cite the near-ground temperature forecast fundamental for the thermalization of the dome and the wind forecast extremely useful to evaluate telescope and secondary mirror vibrations.

An accelerometer based dual loop approach to minimize the impact of fast telescope vibrations seen by the E-ELT/MICADO wavefront sensors

Poster - N: 13254

Alexander Keck[1,2], Jörg-Uwe Pott[2], Oliver Sawodny[1]

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State-of-the-art AO systems for ELTs often have to deal with two contradictory requirements: On the one hand, a large camera integration time on the wavefront sensor is required for decent imaging contrast. On the other hand, the large wavefront sensor integration time limits the disturbance frequencies that can be compensated for, following Nyquist's sampling theorem. Analyzing typical disturbance spectra at ELTs reveals that the major contributor to these large-frequency disturbances, which affect mostly the tip-tilt Zernike modes, is the vibration of the telescope's mechanical structure. The largest disturbances induced by atmospheric turbulences have comparably low frequencies. This conclusion raises a possibility to overcome the mentioned problems: A dual-loop approach allows to establish two control loops compensating the atmospheric induced and the vibration induced disturbances separately. The classical AO feedback loop compensates for the low-frequent atmospheric turbulences using a deformable mirror, allowing long WFS integration times. Accelerometers are mounted on the telescope's structure in order to measure its vibrations. The second control loop, a disturbance feedforward loop, uses these measurements to reconstruct the tip-tilt errors and compensate them using an actuated tip-tilt mirror. Each control loop can thus be designed to match one of the contradictory requirements. We present our efforts to evaluate this approach using a full adaptive optics testbed in the laboratory. A piezo-driven tip-tilt mirror unit is used to induce high-frequency disturbances. Accelerometers are coupled to this device to allow laboratory testing of the feedforward loop. Our ultimate goal is to demonstrate in realistic laboratory tests, how telescope vibrations faster than atmospheric tip-tilt disturbances can be measured by accelerometers, and controlled in real-time feedforward to allow for longer and more sensitive wavefront sensor integrations.

First results on dome turbulence characterisation using the LOTUCE prototype

Poster - N: 13309

Amokrane Berdja[1], James Osborn[2], Marc Sarazin[3], Wassila Dali Ali[4]

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[2] University of Durham
[3] European Southern Observatory
[4] Observatoire de la Côte d'Azur

Free-atmosphere and surface-layer optical-turbulence have been extensively probed over the years. However, the optical-turbulence characteristics within a telescope enclosure are not yet very well known. LOTUCE (LOcal TUrbulenCe Experiment) is an optical experiment aimed at the measurement and characterization of the optical turbulence that occurs locally in the dome under various conditions and how it may interact with the surface-layer optical turbulence for instance. We present the experimental setup of LOTUCE and the results of the first measurements that were carried-out at the 1.52m telescope dome at La Silla Observatory. We then discuss the instrument capabilities, its actual limitations, and the undergoing effort to upgrade the present prototype.

Lotuce: A new monitor for turbulence characterization inside telescope's dome

Poster - N: 13350

Aziz Ziad[1], Wassila Dali Ali[1], Julien Borgnino[1], Marc Sarazin[2], Bernard Buzzoni[2]

[1] Université de Nice
[2] European Southern Observatory

A new concept of an instrument, Lotuce, dedicated to measure the turbulence inside the dome has been developed jointly with ESO. It consists of using parallel laser beams separated by non redundant baselines between 0.1 and 2-3m and measuring Angle-of-Arrival (AA) fluctuations from spots displacements on a CCD. We use weighted least-square method to fit the measured AA longitudinal and transverse covariances with theoretical forms deduced from the usual models of turbulence. Then, the whole parameters characterizing this turbulence are provided from a complete spatio-temporal analysis of AA fluctuations. The first results of this new instrument are presented and discussed.

A roadmap for a new era turbulence studies program applied to the ground-based astronomy supported by AO

Poster - N: 13542

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Sites selection for ELTSs concluded and a new era opens for turbulence studies in application to the ground-based astronomy supported by AO. If in the last decade the main interest of astronomy has been focused on the characterization of sites, now priorities change. In the last years more and more AO systems have seen their first light. A few more complex AO techniques are still in a phase of verification/validation. The efficiency of the operating and forthcoming AO systems can strongly be affected by turbulence and observation strategies rely on our ability in knowing in advance the turbulence spatial distribution in a region around the telescope. Progresses in development of more sophisticated AO techniques (such as the LTAO, MCAO and MOAO) definitely depend on a more detailed knowledge of the main turbulence features such as the turbulence stratification at high vertical resolution. An European working group has been recently set-up aiming at defining the roadmap of a program of site testing campaigns for OT measurements having multiple goals mainly addressed to support requirements for 3D OT modeling with hydrodynamical approach and AO at wide field in application to the ground-based astronomy. The main first objective of this program will be the absolute instrument cross-calibration (in particular the vertical profilers for the whole troposphere and low stratosphere ~20km) and validation of techniques for turbulence stratification on the same vertical range at high vertical resolution (with the optimal goal of 100-200m). In this contribution we will present the motivations of our work, the goals, the instrumentation we are taking into accounts, the different strategies and constraints we are considering for the conception of site testing campaigns.

Performance of two turbulence profilers for a MCAO system under strong dome seeing conditions

Poster - N: 16162

Andrés Guesalaga[1], Benoit Neichel[2], Angela Cortés[1], Dani Guzman[1]

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[2] Gemini Observatory

We compare the performance of two turbulence profilers for the Gemini South Multi-Conjugate AO system (GeMS); one based on a SLODAR approach which assumes a Kolmogorov or Von Karman model and the second based on direct temporal cross correlations among wavefront sensor measurements, also known as wind profiler.Data from on-sky observations collected during the month of October to December 2012 show that an important component of the turbulence is caused by what it appears to be turbulence generated inside or in the dome boundaries. It is shown that this turbulence, which departs significantly from a Kolmogorov model, introduces significant errors in the profile estimation for the SLODAR case.On the other hand, the wind profiler behaves satisfactorily, but questions arise whether classical Cn2 and r0 indices (based on Kolmogorov assumptions) are adequate to characterize the turbulence under these conditions.

Surface Layer turbulence profiling with the SL-SLODAR and LuSci at ESO Paranal Observatory

Poster - N: 18787

Gianluca Lombardi[1], Marc Sarazin[1], Julio Navarrete[1], Consuelo Gonzales[2], Farid Char[3]

[1] European Southern Observatory
[2] Las Campanas Observatory
[3] Universidad de Antofagasta

In the context of the Surface Layer (SL) investigation at ESO Paranal Observatory, a SL Slope Detection And Ranging (SL-SLODAR) instrument prototype has been used at Paranal during 2012, while Lunar Scintillometer (LuSci) measurements campaigns are being carried out since 2008. Simultaneous Surface Layer profiling data from the two instruments are analyzed in order to compare the two instruments to enforce their reliability and finely characterize the Paranal Surface Layer profile. Instruments, data acquisition and analysis, and results are discussed.

10 Data post-processing & optimization

Oral

Super resolution imaging with an ELT: Kernel-phase interferometry

Oral - N: 12659

Frantz Martinache[1]

[1] Subaru Telescope

Kernel-phase is a recently developed paradigm to tackle the classical problem of image deconvolution, based on an interferometric point of view of image formation. Kernel-phase inherits and borrows from the notion of closure-phase, especially as it is used in the context of non-redundant Fizeau interferometry, but extends its application to pupils of arbitrary shape, for diffraction limited images. The additional calibration brought by kernel-phase boosts the resolution of conventional images and enables the detection of otherwise hidden faint features at the resolution limit and beyond, a regime often refered to as super-resolution, which for a 30-meter telescope in the near IR, this translates into a resolving power smaller than 10 mas. Kernel-phase analysis of archival space and ground based AO data leads to new discoveries and/or improved relative astrometry and photometry. The paper presents the current status of the technique and some of its recent developments and applications that lead to recommendations for super-resolution imaging with ELTs.

From CANARY to ELT: lessons learned in open-loop tomography

Oral - N: 13273

Olivier Martin[1], Eric Gendron[1], Gérard Rousset[1], Fabrice Vidal[1], Tim Morris[2], Richard Myers[2]

[1] Laboratoire d'études spatiales et d'instrumentation en astrophysique
[2] Durham University

CANARY is the on-sky demonstrator of the Multi-Object AO concept for EAGLE, the near-IR AO-compensated multi-object spectrograph proposed for the E-ELT. The CANARY experiment has been developed to prove the reliability of the open-loop tomographic control and quantify its performance. CANARY has successfully passed this demonstration using three NGSs in 2010 and with an additional Rayleigh LGS in 2012. We first present an analysis of the variation of the atmospheric turbulence profile for more than a hundred recorded tomographic datasets taken over several nights of observation. Turbulence profiles were derived during the Learn & Apply (L&A) tomographic calibration algorithm developed for CANARY. We will give more details on the performance of the L&A method, particularly with respect to the fraction of turbulence strength found in the ground layer, quantify the impact of our model approximations, and describe the dependency of the computation time with the model parameters. From all these considerations and our on-sky data, we will statistically quantify the performance of MOAO in comparison with SCAO and GLAO results. We then extrapolate MOAO system performance to E-ELT scales based on these on-sky results.

Practical issues with phase diversity for NCPA compensation resolved on the CANARY demonstrator

Oral - N: 13325

Damien Gratadour[1], Eric Gendron[1], Gérard Rousset[1]

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On an adaptive optics bench, in the lab, phase diversity (PD) for non common path aberration retrieval and compensation is mainly limited by the accuracy of the AO bench calibration in the image plane: pupil model (shape, size and illumination), IR camera pixel size, deformable mirror influence functions geometrical model. Some of these issues can be treated numerically from classical PD data but with limited accuracy and implying large use of the bench and large amount of computational resources. We propose a new fast and practical approach based on the combination of a simplified optical setup on the bench and an empirical numerical model to perform these calibrations with high accuracy. This approach has been tested successfully using a NICMOS-based IR camera: CAMICAz installed on the CANARY MOAO demonstrator and allowed us to increase significantly image quality in the near-IR. Additionally, some authors have proposed to use long exposure phase diversity to sense online the quasi-static aberrations under partial AO correction on sky. Applying our practical approach in this context and using an original image formation model, we were able to reach on sky the same level of static aberration compensation, independently and assuming no pre-compensation from lab measurements, leading to a significant increase of on-sky performance. We will detail this new approach and present results obtained wih CAMICAz on CANARY in July 2012.

PSF reconstruction for W. M. Keck and Gemini-North AO systems : practical experience with static aberration estimation using phase diversity on sky images, and last PSF-R results on Altair

Oral - N: 13436

Laurent Jolissaint[1], Sam Ragland[2], Peter Wizinowich[2], Chris Neyman[2], Laurent Mugnier[3], Maxime Boccas[4], Chadwick Trujillo[4]

[1] Haute Ecole d'Ingenierie du Canton de Vaud
[2] W.M. Keck Observatory
[3] Office National d'Etude et de Recherche Aérospatiale
[4] Gemini Observatory

We have initiated in 2009 a PSF reconstruction program for both GEMINI-North (ALTAIR) and W.M.Keck observatories AO systems, in NGS and LGS modes. Our practical experience shows that the quality of the reconstruction really depends on the ability to estimate the static aberrations, which are, for most systems, of the same order than the residual turbulent aberrations uncorrected by the AO. On both systems, we are using a phase diversity (PD) approach to retrieve the static aberration directly from sky AO corrected images, but seeing variation sets a limit on the reconstructed phase accuracy. We present in this paper the last results of our sky-based PD approach, and discuss in detail the practical issues we are facing, for both systems. The knowledge of the static aberration has been used to improve the quality of the PSF reconstruction on ALTAIR, and our most recent results are shown and discussed here.

Posters

Analysis tools for the calibration and commissioning of the AOF

Poster - N: 12808

Aurea Garcia-Rissmann[1], Johann Kolb[1], Miska Le Louarn[1], Pierre-Yves Madec[1], Nicolas Muller[1]

[1] European Southern Observatory

The Adaptive Optics Facility (AOF) is an AO-oriented upgrade envisaged to be implemented at the UT4 in Paranal in 2013-2014, and which could serve as a test case for the E-ELT. Counting on the largest Deformable Secondary Mirror ever built (1170 actuators) and on four off-axes Na laser launch telescopes, the AOF will operate in distinct modes (GLAO, LTAO, SCAO), in accordance to the instruments attached to the 2 telescope Nasmyth ports (GALACSI+MUSE, GRAAL+HAWK-I) and to the Cassegrain port (ERIS). Tools are under development to allow a fast testing of important parameters for these systems when at commissioning and for posterior assessment of telemetry data. These concern the determination of turbulence parameters and Cn2 profiling, measurement of Strehl and ensquared energies, misregistration calculation, bandwidth & overall performance, etc. Our tools are presented as Graphical User Interfaces developed in the Matlab environment, and will be able to grab through a dedicated server data saved in SPARTA standards. We present here the tools developed up to present date and discuss details of what can be obtained from the AOF, based on simulations.

Point spread function reconstruction on the MCAO Canopus bench

Poster - N: 13201

Luc Gilles[1], Benoit Neichel, Jean-Pierre Veran, Brent Ellerbroek

[1] Thirty Meter Telescope Observatory Corporation

This paper discusses point spread function reconstruction (PSFR) experiments performed on the adaptive optics (AO) bench of the Gemini Multi Conjugate Adaptive Optics (MCAO) System (GeMS) aiming at validating the components of the recently proposed simulation-based laser guide star (LGS) MCAO PSFR algorithm [Gilles et. al. Appl. Opt. 51, 7443 (2012)]. Since GeMS is a LGS MCAO system, it is an ideal test bed to study PSFR for LGS MCAO on extremely large telescopes (ELTs). Open loop, single-conjugate experiments were performed with turbulence injected on the ground conjugated deformable mirror (DM) and on the tip/tilt mirror (TTM). High-order and tip/tilt (TT) telemetry was recorded, as well as on-detector guide window short exposure images serving as diagnostic and tip/tilt WFS data. Future experiments are planned with the 2 DMs of the Canopus bench to fully validate the algorithm for closed loop laser guide star (LGS) multi conjugate adaptive optics (MCAO) and will be reported elsewhere.

Performances of the GMOS-GeMS system

Poster - N: 13279

Pascale Hibon[1]

[1] Gemini South Observatory

During the commissioning of the Gemini MCAO System (GeMS), we had the opportunity to obtain data with the Gemini Multi-Object Spectrograph (GMOS) in March and May 2012. Several globular clusters were observed that allow us to study the performance of this unexpected combination. GMOS is a visible camera, hence pushing MCAO toward the visible. We report here on the early results with the GMOS instruments, derive performance in term of FWHM and improvement against natural seeing, and derive a first photometric and astrometric analysis.

A new method for adaptive optics point spread function reconstruction

Poster - N: 13328

Jonathan Exposito[1], Damien Gratadour[1], Gérard Rousset[1], Yann Clenet[1], Laurent Mugnier[2]

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In this paper, we present a new method based on a maximum likelihood (ML) approach to estimate the PSF obtained on a AO system from telemetry data. Using circular buffers of wavefront sensor measurements and actuators commands, this method can be used to estimate simultaneously, the covariance of the residual phase, the propagation of the noise on the deformable mirror, the Fried parameter r0 during the observations and eventually the corresponding PSF. To get an accurate reconstruction, a number of priors related to the system behavior and the turbulence statistics are needed. While, for Shack-Hartmann based systems, the accuracy of the classical least square (LS) approach for PSF reconstruction developed by Véran et al. was limited by the ability to estimate properly the contribution, in the residual phase, of the aliasing error and its coupling to the actual DM commands, especially for low bandwidth setups, we alternatively propose a new recursive approach to estimate these so called "cross terms" that can be tuned to accommodate for any kind of bandwidth. We will present a theoretical analysis of the ML reconstruction method itself, our novel approach to estimate the "cross terms" directly from the AO data and using basic assumptions on the turbulence statistics and finally, the ML reconstruction performance on simulated data as compared to the classical LS approach.

Point Spread Function extraction in crowded fields using blind deconvolution

Poster - N: 13358

Laura Schreiber[1], Andrea La Camera

[1] INAF-OAPD

The extraction of the Point Spread Function (PSF) from astronomical data is an important issue for data reduction packages for stellar photometry that use PSF fitting. High resolution Adaptive Optics images are characterized by a highly structured PSF that cannot be represented by any simple analytical model. Even a numerical PSF extracted from the frame can be affected by the field crowding effects. In this paper we use blind deconvolution in order to find an approximation of both the unknown object and the unknown PSF.In particular we adopt an iterative inexact alternating minimization method where each iteration (that we called outer iteration) consists in alternating an update of the object and of the PSF by means of fixed numbers of (inner) iterations of the Scaled Gradient Projection (SGP) method. The use of SGP allows the introduction of different constraints on the object and on the PSF. In particular, we introduce a constraint on the PSFÂ which is an upper bound derived from the Strehl ratio (SR), to be provided together with the input data. In this contribution we show the photometric error dependence on the crowding, having simulated images generated with synthetic PSFs available from the Phase-A study of the E-ELT MCAO system (MAORY) and different crowding conditions.

Vibration control at MACAO and NACO

Poster - N: 13366

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Vibrations and external disturbances of various origins (e.g. structural, wind, axis control) have shown to degrade the image quality at the instrument focus of the telescopes. Furthermore, ELTs and their associated AO systems will reach new levels of high angular resolution, thus reducing vibrations represents becomes highly desirable to ensure that the scientific instruments will take full advantage of this unprecedented resolution. We present a method that aims to mitigate the effect of vibrations at Paranal's NACO and MACAO instruments. A frequency-based controller, based on the H2 synthesis technique, is used to maximize the closed-loop performance of the system. The pseudo open-loop slopes are reconstructed from on-sky data and then used to find the controller that minimizes the variance of the tip-tilt residuals in an off-line simulation of the closed-loop system. Implementation of the method in the MACAO systems is envisioned for real-time on-sky testing of the method.

Efficient PSF reconstruction process for partially-corrected GLAO images: application to the MUSE-wide field modes

Poster - N: 13472

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The resolution of ground-based telescopes is dramatically limited by the atmospheric turbulence. Adaptative optics (AO) is a real-time opto-mechanical approach, which allows to correct for the turbulence effect and to reach the ultimate diffraction limit astronomical telescopes and their associated instrumentation. Nevertheless, the AO correction is never perfect especially when it has to deal with large Field of View (FoV). Hence, a posteriori image processing really improves the final estimation of astrophysical data. Such techniques require an accurate knowledge of the system response at any position in the FoV The goal of this study is to propose a dedicated algorithm for the efficient PSF reconstruction algorithm in the case of the MUSE WF mode assisted by AO (GLAO mode of Galacsi). In this section we will summarize the main hypothesis underlying the algorithm developments. The purpose of this work is to propose a dedicated algorithm for the efficient PSF reconstruction algorithm in the particular case of the MUSE /GALACSI instrument (a 3D multi-object spectrograph combined with a Laser-assisted wide field AO system which will be installed at the VLT in 2013-2014). Using telemetry data coming from both AO Laser and natural guide stars, a Point Spread Function (PSF) is derived at any location of the FoV and for every wavelength of the MUSE spectrograph. The various hypothesis and approximations are detailed and justified and the method of PSF reconstruction with the optical path difference structure function computation is proposed paying a specific attention to the residual anisoplanetic structure function describing the PSF evolution in the FoV. The proposed solution is validated using first numerical simulations then experimental results (obtained on the ONERA wide field bench and on GEMS data). Its performance is assessed through a detail error budget analysis. Finally some implementation strategies for the VLT-MUSE instrument are presented

Deconvolution-based super resolution for post-AO data

Poster - N: 13505

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[1] Observatoire de la Cote d'Azur

This poster will present, in one hand, some results on NACO/VLT images of close binary stars obtained by means of a Richardson-Lucy-based algorithm of super resolution, attaining down to less than a half-resolution element, with confirmation from VLTI observations. In the other hand, the implementation within the Software Package AIRY of a new gradient method, called Scaled Gradient Projection (SGP), will permit both the acceleration of existent methods (such as Richardson-Lucy and OSEM) and the further implementation of a novel algorithm of Strehl-constrained iterative blind deconvolution, based on SGP. The gain achieved with respect to previous versions of the algorithms (included in AIRY), as well as some preliminary results obtained with the novel blind deconvolution method, will be shown.

11 Other

Posters

Characterization of the main components of the GTCAO system: 373 actuators DM and Ocam2 camera

Poster - N: 13248

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Adaptive optics systems rely on wavefront correctors and wavefront sensors as main components. At GTC, we are integrating the adaptive optics system, which is a classic, single conjugate. However, it will employ a 373 a actuators (21x21) DM from CILAS and the camera employed at the wavefront sensor will be OCam2 a state of the art camera based on L3CCD technology. OCam2 is one of the most perfomant camera for Adaptive Optics offering at the same time very low readout noise (subelectron noise) at very high frame rate (>1Kfps). Both components have been extensively tested at our premises, and the results are presented here. A better knowledge of these components allows having a more efficient adaptive optics system. The DM is characterized by means of interferometric measurements to assess its main parameters, as inter-actuator stroke, full mechanical actuator stroke, homogeneity of the influence function, hysteresis... On the other hand, we have at our premises two Ocam2 cameras with CCD220 detector (one science, one engineering) since November 2011. Our characterization included the main parameters of the cameras, and concluded that they meet the requirements needed for GTCAO wavefront sensor. The scientific grade camera has been characterized not only to check its compliance to GTCAO requirements but also to obtain typical camera performances and understand its behavior in depth. We also benefit from this characterization phase to develop and implement an optimization process. Some unknown features which are of general interest have been reported even if they don't affect OCAM2 camera compliance with GTCAO system.

AdapTube: Adaptive Optics animations for tutorial purposes

Poster - N: 13265

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As it happens in most scientific fields, many Adaptive Optics concepts and instrumental layouts are not easily understandable. Both in outreach and in the framework of addressing to experts, computer graphics (CG) and, in particular, animation can aid the speaker and the auditor to simplify concepts description, translating them into a more direct message. This paper presents a few examples of how some instruments, as Shack-Hartmann and Pyramid wavefront sensors, or concepts, like MCAO and MOAO, have been depicted and sometimes compared in a more intuitive way, emphasizing differences, pros and cons. Some experiments of referencing animation with respect to the real world are also outlined, pushing the edges of the way a complicated concept can be illustrated embedding complex drawings into the explanation of a human. The used CG software, which are completely open source and will be presented and briefly described, turn out to be a valid communication tool to highlight what, on a piece of paper, could seem obscure.

The Laboratory Results of a 595-unit Adaptive Optical System

Poster - N: 13298

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A 595-unit adaptive optical system is designed for the 4-meter diameter high resolution astronomical telescope. The deformable mirror adopts PZT actuators with 300mm diameter reflecting surface. A debugging system is established in laboratory and closed loop results are obtained. The scheme of the system, the design of the wavefront sensor, the wavefront processing system and the control software are described in this paper. Special influence matrix measuring methods are for the first time used on this debugging system and show better results than the classic actuator by actuator method. The system is successfully closed loop to correct the simulated static aberration. Using FWHM as the merit, the corrected PSF equals less than 1.1 times of that of the diffraction limit. A 913-unit adaptive optical system has been developed and will be closed loop in laboratory based on the experiments of this 595-unit system.

Lab results from the GREGOR MCAO testbench

Poster - N: 13386

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We present the performance of the GREGOR MCAO system. This MCAO system, which actually is a tripple-conjugate adaptive optics, was set up in a laboratory testbench. GREGOR is the new German 1.5-meter solar telescope, and it is currently equipped with a 256-actuators classical adaptive optics system. On-sky tests of the MCAO system are planned for this observing season. A cooktop plate was used to generate turbulence in the testbench. We present the measurements of residual agile image distortion, wavefront errors in the 19 guide directions, and the bandwidth of the closed loop control.

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