Adaptive Optics for Extremely Large Telescopes 4

Lake Arrowhead, California
October 26-30, 2015

This booklet was prepared using LaTeX

Table of Contents

Introduction and Welcome

Welcome to the 4th edition of the Adaptive Optics for Extremely Large Telescopes (AO4ELT4). The Center for Adaptive Optics is hosting the meeting this year in conjunction with it's annual Fall Retreat and the Workshop on Laser Technology and Systems for Astronomical Adaptive Optics. The four AO4ELTs so far have alternated location between Europe and North America, the first being in Paris in 2009, then Victoria in 2011, followed by Florence in 2013. We hope that you enjoy this venue at Lake Arrowhead in the San Bernardino/San Gabriel mountain ranges of Southern California. These mountains have a rich tradition in astronomy, starting with the Mt. Wilson observatory, home to the 100-inch Hooker telescope where Edwin Hubble first recorded the expansion of the universe, and the Big Bear Solar Observatory on Big Bear Lake near Mt. San Gorgonio, where today's largest solar telescope is pioneering the use of multi-conjugate adaptive optics. We hope that you will partake of the tour of BBSO taking place mid-week of our meeting.

Let me acknowledge the kind contributions of these institutions in support of our meeting: the Thirty Meter Telescope Project, The National Institute for Astrophysics of Italy through Arcetri Observatory and Padova Observatory, and the University of California Observatories. Furthermore we'd like to thank our commercial sponsors ALPAO, Boston Micromachines Corporation, CILAS, e2v, First Light Imaging and Iris AO Corporation. Their displays can be seen in the poster exhibit area.

Today we are on the verge of some very large telescope endeavors. The three major "extremely" large, $>$ 20m, telescope projects are just now in their starting phases, the EELT, TMT, and GMT. All these will depend crucially for their science programs on adaptive optics. And the adaptive optics types are widely varied, as is the modern technology needed to implement them, including adaptive secondary mirrors, large arrays of laser beacons, and photon-counting wavefront sensors, to name a few. The goal of this meeting is to foster the exchange of new information and ideas that will mutually benefit all of the AO programs, and will spur new concepts for future systems.

This booklet provides an overview of the technical program, and the full set of abstracts, with the oral presentation abstracts in the order of presentation and the poster presentation abstracts grouped according to poster session. There are three poster sessions, rotating into the display area in groups of roughly 30 each session. Above each oral abstract title you will find day, session number, and time of presentation. Above each poster abstract title you will find the poster session number, the evening assigned to that poster session, and the topic area.

The day-by-day social and auxiliary event schedule is posted online at http://cfao.ucolick.org/ao4elt4/schedule.html.

Finally, let me mention a little about the UCLA Center. The main lodge was originally Lake Arrowhead's North Shore Tavern, a resort for Hollywood's rich and famous during the 1920's and 1930's at which time it was accessible only by a boat trip across the lake. The tavern, and in fact the entire lake, was later owned by the Los Angeles Turf Club through the 1940's and 1950's. In 1957 the lake was sold to the aggregate of surrounding homeowners while the Tavern was donated to the University of California. UCLA now runs the center yearround for educational meetings and summer camp for UC employees. You can read more about it on the UCLA Conference Center web site, http://uclaconferencecenter.com.

So, sit back and enjoy the surroundings, walks around the lake, resort amenities, and the company of your colleagues from the adaptive optics community.

Sincerely,
Don Gavel
on behalf of the AO4ELT4 Local Organizing Committee

Overview Schedule

Monday	
08:30 - 09:00	Poster setup, session #1
09:00 - 10:20	Session 1 Astronomy with AO
10:20 - 10:40	Break
10:40 - 12:00	Session 2 Science with ELTs relating to AO requirements
12:00	Lunch
13:30 - 15:10	Session 3 Current designs for ELT AO systems
15:10 - 15:30	Break
15:30 - 17:10	Session 4 AO instruments and pathfinders
20:00	Evening poster session (session #1)
Tuesday	
09:00 - 10:20	Session 5 Laser guide star systems
10:20 - 10:40	Break
10:40 - 12:00	Session 6 AO instruments and pathfinders
12:00	Lunch
12:00 - 13:00	Poster setup, session #2
13:30 - 15:10	Session 7 System control & algorithms
15:10 - 15:30	Break
15:30 - 17:10	Session 8 Wavefront sensing
20:00	Evening poster session (session #2)
Wednesday	
09:00 - 10:00	Session 9 Wavefront sensing detectors
10:00 - 10:40	Session 10 Wavefront sensing
10:40 - 11:00	Break
11:00 - 12:00	Session 11 AO community and professional development
12:00	Lunch
12:00 - 15:00	BBSO Tour / Free Time

Wednesday		
15:00 - 16:00	Session 12	Current designs for ELT AO systems
16:00 - 17:00	Session 13	Science with ELTs relating to AO requirements
17:00 - 17:20	Session 14	Atmospheric turbulence and other AO disturbances
18:30	Dinner	
20:00 - 21:00	Session 15	AO instruments and pathfinders
Thursday		
08:30 - 09:00	Poster setup, session #3	
09:00 - 10:20	Session 16	Numerical simulations and modeling
10:20 - 10:40	Break	
10:40 - 12:00	Session 17	System control & algorithms
12:00	Lunch	
13:30 - 14:50	Session 18	Laser guide star systems
14:50 - 15:10	Break	
15:30 - 17:30	Session 19	Wavefront correctors
20:00	Evening poster session (session #3)	
Friday		
09:00 - 10:20	Session 20	AO instruments and pathfinders
10:20 - 10:40	Break	
10:40 - 12:00	Session 21	Data post-processing
12:00	Lunch	
13:30 - 15:10	Session 22	Wavefront sensing
15:10 - 15:30	Wrap-up discussion	
15:30	Meeting end	

Detailed Schedule

Monday		
Session 1: **Astronomy with AO**		
09:00	Gratadour	Extragalactic science with extreme AO: flushing out the torus of an active galactic nucleus with an exoplanet hunter
09:20	Turri	Precise and deep photometry from the ground: on-sky science performance of MCAO
09:40	Andersen	MCAO capabilities in crowded fields: A case study of Westerlund 1
10:00	Males	Imaging exoplanets at visible wavelengths from the ground
Session 2: **Science with ELTS relating to AO requirements**		
10:40	Lu	Free-Floating Black Holes with Astrometric Microlensing
11:00	Ammons	Microarcsecond Sparse-Field Astrometry with the ELTs: Capabilities, Exoplanet Science, and Test Cases.
11:20	Fitzgerald	An Instrument for Imaging and Spectroscopy of Planetary Systems with TMT
11:40	Marois	The 30m Era: High-Contrast Imaging Science with TMT at first light
Session 3: **Current designs for ELT AO systems**		
13:30	Stuik	The METIS AO systems
13:50	Morris	AO for MOSAIC, the E-ELT Multiple Object Spectrograph
14:10	Bouchez	The Giant Magellan Telescope Wavefront Control System
14:30	Boyer	Adaptive Optics Program at TMT
14:50	Diolaiti	The MAORY first-light adaptive optics module for E-ELT
Session 4: **AO instruments and pathfinders**		
15:30	Trujillo	The Future of Gemini Adaptive Optics
15:50	Mawet	Keck Planet Imager and Characterizer concept
16:10	Orban de Xivry	First on-sky results of the GLAO system ARGOS. The astronomical perspective.
16:30	Pinna	XAO at LBT: current performances in the visible and upcoming upgrade.
16:50	Garrel	GeMS, the path toward AO facility

Tuesday		
Session 5: **Laser guide star systems**		
09:00	Gavel	Summary of the Laser Guidestar Workshop
09:20	Rabien	First Light of the ARGOS Facility
09:40	Bonaccini Calia	LGS R&D for the ELT: perspective and results
10:00	Ragland	Recent Improvements to the Keck II Laser Guide Star Adaptive
Session 6: **AO instruments and pathfinders**		
10:40	Schmidt	MCAO at the Big Bear Solar Observatory
11:00	Guyon	SCExAO: the first high contrast exoplanet imager on an ELT?
11:20	Gendron	CANARY closes the open-loop demonstration of MOAO
11:40	Lardiere	On-sky results of Raven, a Multi-Object Adaptive Optics science demonstrator at Subaru Telescope
Session 7: **System control & algorithms**		
13:30	Correia	Spatio-angular Linear Quadratic Gaussian algorithm for prediction and control in Tomographic Systems
13:50	Ono	Development of multi time-step tomographic reconstruction with RAVEN.
14:10	Obereder	Spiders - a problem for the DM control?
14:30	Rudy	Erasing the wind: Predictive Control for Adaptive Optics on sky and in the lab
14:50	Barr	Reducing AO latency using many-core processors
Session 8: **Wavefront sensing**		
15:30	Andersen	The TMT IRIS On-Instrument Wavefront Sensor System
15:50	Veran	Pyramid versus Shack-Hartmann: Trade Study Results for the NFIRAOS NGS WFS
16:10	Goodwin	Miniaturized Shack-Hartmann Wavefront-Sensors for ELTs
16:30	Rampy	Near-infrared tip/tilt sensing at Keck: System architecture and on-sky performance
16:50	Fauvarque	Flatten the Pyramid, you still have a Wavefront Sensor
17:10	Langlois	Extreme Adaptive optics Wavefront Control Towards High-Contrast and Extrasolar Planet Imaging with ELTs

Wednesday		
Session 9: **Wavefront sensing detectors**		
09:00	Baker	Selex infrared sensors for astronomy – present and future
09:20	Finger	Development of near infrared eAPD wavefront sensors for the ELT with sub-electron read noise
09:40	Feautrier	State of the art IR cameras for wavefront sensing using e-APD MCT arrays
Session 10: **Wavefront sensing**		
10:00	Esposito	Non common path aberration correction with nonlinear WFSs
10:20	Blain	Use of Laser Guide Star with Pyramid Sensor
Session 11: **AO community and professional development**		
11:00	Masciadri	Gender equity in science and astronomy: state of the art
11:20	d'Orgeville	We are all made of (un-twinkling) stars: establishing gender equity in the Adaptive Optics community
Session 12: **Current designs for ELT AO systems**		
15:00	McLeod	An off-axis segment piston sensor for the Giant Magellan Telescope
15:20	Neichel	The AO modes for HARMONI: from classical to Laser-assisted tomographic AO systems
15:40	Herriot	NFIRAOS
Session 13: **Science with ELTS relating to AO requirements**		
16:00	Gullieuszik	Exploring the stellar population of nearby and high redshift galaxies with ELTs
16:20	Portaluri	Statistical and morphological analysis of mock galactic fields in the Global-MCAO perspective
16:40	Close	Visible Wavelength AO Systems and Science For ELTs
Session 14: **Atmospheric turbulence and other AO disturbances**		
17:00	Masciadri	Operational optical turbulence forecasts for the E-ELT Service Mode

Wednesday		
Session 15: **AO instruments and pathfinders**		
20:00	Schwab	AO-coupled single mode fibres: enabling photonic spectrographs for ELTs
20:20	Meeker	Design and Development Status of MKID Integral Field Spectrographs for High Contrast Imaging
20:40	Farinato	SHARK-NIR Channel: an high contrast imager with coronographic capabilities for the Large Binocular Telescope

Thursday		
Session 16: **Numerical simulations and modeling**		
09:00	Wang	Optimizing LGS AO Performance in the Context of Evolving Turbulence and Sodium Profiles
09:20	Le Louarn	Simulations of Adaptive Optics systems for the European Extremely Large Telescope and its instruments
09:40	Beaulieu	A Fresnel propagation analysis for SPEED
Session 17: **System control & algorithms**		
10:40	Doelman	Forecasting optical turbulence behaviour by fractional time series analysis
11:00	Gratadour	GreenFlash: Energy efficient high performance computing for real-time science
11:20	Saxenhuber	Updates on the performance of fast iterative reconstruction algorithms for ELT AO systems
11:40	Juvenal	Performance assessment for the linear control of adaptive optics systems: noise propagation and temporal errors.
Session 18: **Laser guide star systems**		
13:30	Gavel	Laser guide star adaptive optics at Lick Observatory
13:50	Pfrommer	The horizontal structure function of the sodium centroid in the upper mesosphere
14:10	Holzlohner	The ESO Laser Test Bench
14:30	Fusco	New concepts of modified Shack-Hartman for an elongation-free wavefront sensing of Na-Laser guide stars
Session 19: **Wavefront correctors**		
15:30	Guan	Recent progress on astronomical PZT DM of the IOE,CAS
15:50	Vernet	Deformable mirrors development at ESO
16:10	Bierden	MEMS Deformable Mirrors for ELT Instrumentation
16:30	Sevin	Emulating an extreme density AO loop with a Spatial Light Modulator and GPUs
16:50	Cavaco	Deformable Mirror Designs for Extreme AO
17:10	Pagès	Recent developments on piezo-stack deformable mirrors for ELTs

Friday		
Session 20: **AO instruments and pathfinders**		
09:00	Herbst	The LINC-NIRVANA MCAO System: On Its Way to Sky
09:20	Pedichini	The Visible channel of SHARK and the 4runner experiment
09:40	Fusco	On-sky operation, improvement and final performance of SAXO, the SPHERE extreme AO system – lesson learned for the future ELT instrumentation
10:00	Sauvage	Spatial and temporal unexpected wave-front perturbations on SPHERE instrument: a sightview of E-ELT limitations.
Session 21: **Data post-processing**		
10:40	Bernard	Dissecting Star-forming regions with the GeMS MCAO instrument: lessons learned for optimal post-processing of WFAO data
11:00	Jolissaint	Natural Guide Star Point Spread Function Reconstruction for the Keck Telescope Adaptive Optics System: Final Results.
11:20	Fritz	Astrometry with MCAO at Gemini and ELTs
Session 22: **Wavefront sensing**		
13:30	Gach	OCAM2S: an integral shutter ultrafast and low noise wavefront sensor camera for laser guide stars adaptive optics systems
13:50	van Dam	Measuring Segment Piston with a Dispersed Fringe Sensor on the Giant Magellan Telescope
14:10	Lamb	Calibrating the Non-Common Path Aberrations on the MOAO system RAVEN and first science results using RAVEN
14:30	Viotto	GMCAO for E-ELT: a feasibility study
14:50	Ragazzoni	Dark Wavefront Sensing

Mon 1 09:00

Extragalactic science with extreme AO: flushing out the torus of an active galactic nucleus with an exoplanet hunter

Gratadour, Damien; Rouan, Daniel; Grosset, Lucas; Boccaletti, Anthony; Clénet, Yann
LESIA - Observatoire de Paris

To investigate the central regions of active galactic nuclei (AGN) at short wavelengths, high angular resolution and high contrast observations are mandatory. One of the main observational challenge is the direct detection of the circumnuclear optically thick material hiding the central core emission when viewed edge-on. The lack of direct evidence is limiting our understanding of AGN and several scenarios have been proposed to cope for the diverse observed aspects of activity in a unified approach. The core of NGC 1068 was observed with the SPHERE instrument on the Very Large Telescope, under the science verification program, using the infrared camera IRDIS in its polarimetric mode. SPHERE has been designed for hunting exoplanets through direct imaging and is equipped with the extreme adaptive optics system SAXO. The achieved resolution at H and K' reveals new details over more than 600 pc around the central engine. The orientation of the polarization vectors clearly evidences the presence of a structured hourglass-shaped bicone and a compact elongated (20 x 60 pc) nuclear structure perpendicular to the bicone axis. The linearly polarized emission in the bicone is dominated by a centro-symmetric pattern, but the central compact region shows a clear deviation from the latter with linear polarization aligned along a direction perpendicular to the bicone axis. These new observations clearly evidence for the first time a rather flat and extended torus at the core of the archetypal Seyfert galaxy. We will present the data obtained with and without the coronagraph as well as the dedicated data reduction pipeline, the first results obtained with these data and the constraints on future observations.

Mon 1 09:20

Precise and deep photometry from the ground: on-sky science performance of MCAO

Turri, Paolo; McConnachie, Alan; Stetson, Peter; Fiorentino, Giuliana; Andersen, David
University of Victoria

Multi-conjugate adaptive optics is a central technology for the Extremely Large Telescopes (NFIRAOS on TMT and MAORY on E-ELT). GeMS on the 8-m Gemini South telescope is the first facility-class MCAO and the first to use laser guide stars. We have observed the Galactic globular cluster NGC 1851 (and 5 other targets) and here we present the results of the profile-fitting

photometry in J (1.25 μm) and Ks (2.15 μm) bands. The photometric precision is comparable to that of the Hubble Space Telescope, confirmed by our ability to detect the double subgiant branch, previously observed only from space. The high Strehl ratio of the images pushes the depth of the stellar detections well below the main sequence knee of the colour-magnitude diagram, making this the deepest near-infrared CMD yet obtained from ground. The large number of stars allows to evaluate the performance of the instrument in terms of position-dependent PSF. We demonstrate how the analysis of the spatial and temporal PSF variations allows us to develop effective photometric techniques for MCAO to be used for the next generation of large telescopes.

Mon 1 09:40

MCAO capabilities in crowded fields: A case study of Westerlund 1

Andersen, Morten; Neichel, Benoit; Bernard, Anais
Gemini Observatories, AURA

We present recent multi-band observations of the most massive young star cluster known in the Galaxy, Westerlund 1, using Gemini GSAOI/GeMS MCAO observations. The photometric properties and quality is compared directly with HST WFC3 observations. A particular focus is placed on the effects of crowding and the recovery of the faintest stars in dense high contrast environments. The effects of distortions in the GeMS/GSAOI observations are quantified and the potential to correct them is discussed. Finally we present a few results on the low-mass content and age spread in Westerlund determined from the GeMS/GSOAI observations

Mon 1 10:00

Imaging exoplanets at visible wavelengths from the ground

Males, Jared; Close, Laird; Morzinski, Katie
Steward Observatory

High-contrast imaging of extrasolar planets in the visible is challenging, but offers many advantages. The ELTs have the potential to image habitable rocky planets in the visible, if they are suitably optimized, and several groups have begun short wavelength high contrast imaging investigations. Located at the excellent site of the GMT, the Magellan AO system (MagAO) is an ideal testbed for visible high contrast imaging development. Here we will review exoplanet imaging with the MagAO's VisAO camera, including optical images of beta Pictoris b and observations of the habitable zone of alpha Centauri A. We will discuss planned upgrades to MagAO, including improvements in WFS sampling and an increase in speed to 2000 Hz (the MagAO-2K upgrade). Finally, we will briefly describe our conceptual design for MagAO-X,

an extreme-AO "afterburner" system which will be optimized for visible light coronagraphy.

Mon 2 10:40

Free-Floating Black Holes with Astrometric Microlensing

Lu, Jessica; Sinukoff, Evan; Ofek, Eran
Institute for Astronomy, U. of Hawaii

While dozens of stellar mass black holes have been discovered in binary systems, isolated black holes have eluded detection. In principle, their presence can be inferred from astrometric and photometric signatures produced when they lens light from a background star. We will present results from a pilot program to find free-floating stellar mass black holes using Keck adaptive optics and high-precision astrometry. We will discuss key limitations to our current astrometric precision and advancements underway. Finally, we will discuss how the substantial astrometric improvements of the Thirty Meter Telescope could lead to the detection of a large sample of free-floating black holes and neutron stars.

Mon 2 11:00

Microarcsecond Sparse-Field Astrometry with the ELTs: Capabilities, Exoplanet Science, and Test Cases.

Ammons, S. Mark; Lu, Jessica; Neichel, Benoit; Bendek, Eduardo; Macintosh, Bruce; Garrel, Vincent; Marin, Eduardo; Sivo, Gaetano; Guyon, Olivier; Savransky, Dmitry; Graham, James; Salama, Maissa; Dennison, Kaitlin
LLNL

ELTs equipped with MCAO systems will be powerful astrometric tools for the next 20 years. With sparse-field precisions exceeding 30 uas for V > 18, the ELTs will surpass even GAIA's per-epoch precision for faint stars (V > 12). I present three largely overlooked sparse-field astrometry science cases and discuss synergies with GAIA and WFIRST. Firstly, with ELTs+MCAO, it will be possible to measure masses of exoplanets discovered with today's generation of direct-imaging AO systems and independently calibrate planet formation models. Furthermore, ELTs will astrometrically probe M stars and brown dwarfs for companions down to superearth masses, testing population synthesis models on all mass scales. Third, high-contrast AO systems on ELTs will be able to confirm planet candidates orbiting a subset of young stars identified as "trending" by GAIA, displaying accelerations that indicate the presence of companions.

As a test case of high-precision astrometry with MCAO systems, I present new astrometric limits from GeMS on the presence of an exoplanet orbiting

either component of Luhman 16AB, the nearest brown dwarf binary known. As opposed to traditional adaptive optics systems, GeMS' wide field of view provides numerous reference stars for calibrating rotation and plate scale, producing a more precise measurement of the binary separation (sigma = 0.2 mas single-axis per epoch) that improves the literature measurements by more than a factor of 20. We find that a mutual Keplerian orbit with no perturbing planets fits the binary separation to within the measurement errors, ruling out companions down to 14 earth masses for certain orbits.

Drawing from experience calibrating GeMS astrometry, I present a series of calibration routines and instrumental modifications to ELT MCAO systems for improving astrometric stability. I also present an engineered design of an insertable diffractive mask for GeMS to anchor changing optical distortion which will, for the first time, enable an independent measure of exoplanet mass for GPI and SPHERE discoveries.

Mon 2 11:20

An Instrument for Imaging and Spectroscopy of Planetary Systems with TMT

Fitzgerald, Michael; Macintosh, Bruce; Mazin, Ben
UCLA

The Planet Formation Imager was conceived as a TMT instrument enabling detection and characterization of exoplanetary systems. This instrument concept study was completed in 2006. We describe ongoing efforts to revisit the scientific motivation for such an instrument, including an update to the expected scientific landscape. We describe how these drivers have led us to explore a range of new instrument architectures, based on high-order adaptive optics coronagraphy, that enable detection and characterization of exoplanets in reflected light and moderate resolution spectroscopy of giant planets in thermal emission.

Mon 2 11:40

The 30m Era: High-Contrast Imaging Science with TMT at first light

Marois, Christian
National Research Council of Canada Herzberg

All three 30m class telescopes have one thing in common: no dedicated first light exoplanet imaging/characterization instrument. The potential for 30m class telescopes is enormous, given the smaller inner working angle and D^2 advantage, opening a vast array of new science capabilities. I will discuss the various steps we have been taking to "bend" the first generation TMT adaptive optics/IFS NFIRAOS/IRIS instrument design to allow improve exoplanet science at first light. I will also present ideas to complement these performances with visitor-class instruments.

Mon 3 13:30

The METIS AO systems

Stuik, Remko; Feldt, Markus; Hippler, Stefan; Obereder, Andreas; Shatokhina, Iuliia; Saxenhuber, Daniela; Brandl, Bernhard; Kenworthy, Matt; Jager, Rieks; Venema, Lars; The Metis Team
Leiden Observatory, Leiden University/NOVA

METIS, the Mid-infrared E-ELT Imager and Spectrometer, is one of the three first light science instruments on the European Extremely Large Telescope (E-ELT). METIS will be providing high-sensitivity imaging and high-resolution spectroscopy in the mid-infrared (3-19 micrometer) to the E-ELT. METIS will provide AO correction using two, largely independent, Adaptive Optics systems an internal SCAO system provides diffraction limited point spread functions (PSFs), driven by the science case for exoplanets and proto-planetary disks, and, at a later stage, an external LTAO system, providing sky coverage at high Strehl Ratio for those targets that do not feature bright targets within the METIS field of view. The focus of this paper will be on the design and expected performance of the internal SCAO system. In order to keep the number of warm surfaces towards the science detectors minimal, METIS SCAO and its pick-off mirror are located inside the METIS cryostat. The design of the SCAO system is driven both by technical feasibility—under cryogenic conditions— as well as performance. A trade-off has been made between both visible versus infrared wave front sensing as well as Pyramid versus Shack-Hartmann, under various observing conditions and target geometries, taking into account performance, target availability, reliability and technology readiness level. A last section is dedicated to the future LTAO system and the potential use of the internal SCAO system as either Low-Order WFS or metrology system.

Mon 3 13:50

AO for MOSAIC, the E-ELT Multiple Object Spectrograph

Morris, Tim; Basden, Alastair; Buey, Tristan; Chemla, Fanny; Conan, Jean-Marc; Correia, Carlos; Dohlen, Kjetil; Fusco, Thierry; Gendron, Eric; Gratadour, Damien; Jagourel, Pascal; Myers, Richard; Neichel, Benoit; Petit, Cyril; Rees, Phil; Rousset, Gerard
Durham University

MOSAIC is the proposed multiple object spectrograph for the E-ELT that will eventually combine two AO observing modes within a single instrument. MOSAIC will contain up to 20 open-loop multiple object AO channels feeding NIR IFUs in addition to up to 200 seeing-limited (or GLAO corrected) VIS – NIR fibre pickoffs. Wavefront tomography will be implemented using a combination of LGS and a few high-order NGS distributed across the field with the wavefront correction applied in a split open/closed loop configuration. MOSAIC will be the only E-ELT instrument planned that can utilise

the full 10 arcminute diameter field of view, enabling highly efficient observing modes for this workhorse instrument. Use of the full E-ELT field inevitably requires a closer integration between the telescope control system and the instrument AO systems, however this can bring several potential benefits to overall system performance. Here we present the initial design concept and baseline performance of the MOSAIC instrument and AO system(s) taking advantage of the CANARY on-sky results and inheriting from the previous Phase A study of EAGLE. Finally, we will highlight areas of system performance and calibration that will require further analysis and trade-off during the course of the upcoming Phase A study.

Mon 3 14:10

The Giant Magellan Telescope Wavefront Control System

Bouchez, Antonin
GMTO

The Giant Magellan Telescope wavefront control system will provide high-order wavefront correction to every instrument on the 25.4 m diameter GMT, with seeing-limited, ground-layer AO, natural guidestar AO, and laser tomography AO observing modes. An active segment phasing system maintains the seven GMT segments phased in the diffraction-limited modes. We describe the wavefront control system preliminary design, its expected performance, and current prototyping activities.

Mon 3 14:30

Adaptive Optics Program at TMT

Boyer, Corinne
Thirty Meter Telescope

The TMT first light Adaptive Optics (AO) facility consists of the Narrow Field Infra-Red AO System (NFIRAOS) and the associated Laser Guide Star Facility (LGSF). NFIRAOS is a 60 x 60 laser guide star (LGS) multi-conjugate AO (MCAO) system, which provides uniform, diffraction-limited performance in the J, H, and K bands over 17-30 arc sec diameter fields with 50 per cent sky coverage at the galactic pole, as required to support the TMT science cases. NFIRAOS includes two deformable mirrors, six laser guide star wavefront sensors, and three low-order, infrared, natural guide star wavefront sensors within each client instrument. The first light LGSF system includes six sodium lasers required to generate the NFIRAOS laser guide stars. In this paper, we will provide an update on the progress in designing, modeling and validating the TMT first light AO systems and their components over the last two years.

Mon 3 14:50

The MAORY first-light adaptive optics module for E-ELT

Diolaiti, Emiliano; Agapito, Guido; Antichi, Jacopo; Arcidiacono, Carmelo; Baruffolo, Andrea; Bellazzini, Michele; Bregoli, Giovanni; Butler, Reginald Christopher; Cascone, Enrico; Ciliegi, Paolo; Cortecchia, Fausto; Cosentino, Giuseppe; De Caprio, Vincenzo; De Rosa, Adriano; Di Rico, Gianluca; Esposito, Simone; Fantinel, Daniela; Feautrier, Philippe; Foppiani, Italo; Giordano, Christophe; Giro, Enrico; Lombini, Matteo; Morgante, Gianluca; Patti, Mauro; Ragazzoni, Roberto; Riccardi, Armando; Ricciardi, Sara; Riva, Marco; Salasnich, Bernardo; Schreiber, Laura; Spanò, Paolo; Zerbi, Filippo Maria; Casali, Mark; Kerber, Florian; Marchetti, Enrico; Ramsay, Suzanne

INAF - Osservatorio Astronomico di Bologna

MAORY is a post-focal adaptive optics module for the European Extremely Large Telescope that forms part of the first light instrument suite for the telescope. MAORY supports the MICADO near-infrared camera by offering two adaptive optics modes: Multi-Conjugate Adaptive Optics (MCAO) and Single-Conjugate Adaptive Optics (SCAO). Development of the SCAO mode is a joint endeavour between the MAORY and MICADO instrument teams. The MCAO mode is required to achieve uniform adaptive optics compensation over the full MICADO field of view the SCAO mode is required for peak performance, rather than uniformity over the field, when a suitable Natural Guide Star is available. In the MCAO mode, wavefront sensing is performed by a system based on up to six Laser Guide Stars for high-order wavefront sensing and three Natural Guide Stars for low-order wavefront sensing wavefront compensation is achieved by one or two deformable mirrors in MAORY, which work together with the telescope adaptive and tip-tilt mirrors M4 and M5 respectively. In the SCAO mode, wavefront distortions are measured by a single Natural Guide Star wavefront sensor and compensated by the telescope M4 and M5 mirrors, while the deformable mirrors inside MAORY are kept flat. MAORY also offers provision for a second port for a future instrument, as yet undefined. The MAORY instrument project is advancing towards Phase B. Consolidation of the baseline instrument design is underway, following the refinement of the top-level requirements and of the interfaces with the telescope and with the client instruments. Optimisation of the adaptive optics system in MAORY is in progress, taking into account the wavefront disturbances to be compensated (atmospheric turbulence, wind action on the telescope, sodium layer effects, etc.) and the key hardware components requirements. A system level overview of the on-going technical activities is presented in this contribution.

Mon 4 15:30

The Future of Gemini Adaptive Optics

Trujillo, Chadwick
Gemini Observatory

The recent commissioning of the Gemini Multi-Conjugate Adaptive Optics System (GeMS) and the Gemini Planet Imager (GPI) at Gemini South has revitalized Gemini's Adaptive Optics science capabilities. We will outline Gemini's near, mid and long-range plans for Adaptive Optics instrumentation at both sites. A key component of this will be the upgrade of existing Adaptive Optics instruments and laser guide star facilities to remain competitive as the thirty meter telescopes come on line. The next opportunity for a competitive call for a new Adaptive Optics system design will be in a few years, so preparations are beginning now. We will present the scope, cost, development timeline, and science requirements of such a system and describe how potentially interested instrument teams may wish to participate.

Mon 4 15:50

Keck Planet Imager and Characterizer concept

Mawet, Dimitri
Caltech

The advent of fast low-noise infrared cameras (IR-APD), the rapid maturing of efficient wavefront sensing techniques (Pyramid/Zernike), small inner working angle coronagraphs (vortex, HLC, PIAA) and associated low-order wavefront sensors, as well as recent breakthroughs in Doppler imaging techniques applied to brown dwarfs and exoplanets, open new avenues complementary to first and second-generation extreme adaptive optics (ExAO) systems. For instance, the search and characterization of planetary systems around M-dwarfs, the prime science case for future extremely large telescope planet finder instruments, such as PFI and PCS on TMT and the EELT, respectively, can be initiated now on a 10-meter class telescope. The Keck Planet Imager and Characterizer (KPIC) is a cost-effective module for Keck-AO, building on the lessons learned from Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), VLT SPHERE, Gemini Planet Imager (GPI), Palomar P3K/P1640 and Stellar Double Coronagraph (SDC) to explore new scientifically exciting niches paving the way to the TMT-Planet Finder Instrument (PFI) core science, while maturing system-level and critical components for future ground- and space-based instrumentation (TMT, WFIRST-AFTA, EXO-C/S).

Mon 4 16:10

First on-sky results of the GLAO system ARGOS. The astronomical perspective.

Orban de Xivry, Gilles; Bonaglia, Marco; Borelli, Jose; Busoni, Lorenzo; Deysenroth, Matthias; Esposito, Simone; Gaessler, Wolfgang; Kulas, Martin; Mazzoni, Tommaso; Peter, Diethard; Rabien, Sebastian; Rahmer, Gustavo; Ziegleder, Julian
Max-Planck-Institut für extraterrestrische Physik (MPE)

ARGOS is the multiple laser guide star and wavefront sensing facility for the Large Binocular Telescope. It aims to deliver an improvement by a factor of 2 in FWHM over the 4'x4' FoV of both LUCI instruments and this under most seeing conditions. LUCI1 and LUCI2 are two near-infrared wide field imagers and multi-object spectrographs whose capabilities and efficiencies will be boosted by the increased resolution and encircled energy.

The first on-sky GLAO closure with ARGOS has been achieved in Fall 2014 producing the first observations for performance analysis since then. We discuss here the very first science data in term of PSF characteristics, uniformity, and the gains provided by ARGOS in term of scientific capabilities.

Mon 4 16:30

XAO at LBT: current performances in the visible and upcoming upgrade.

Pinna, Enrico; Pedichini, Fernando; Farinato, Jacopo; Esposito, Simone; Centrone, Mauro; Puglisi, Alfio; Carbonaro, Luca; Agapito, Guido; Riccardi, Armando; Xompero, Marco; Hinz, Philip; Montoya, Manny; Bailey, Vanessa
INAF OSSERV. ASTROFISICO ARCETRI

The Extreme Adaptive Optics is one of the new frontiers for astronomical AO and LBT is hosting one of the few XAO systems available on 8m class telescopes. With the 4Runner, a fast visible camera, we measured the AO performances at visible wavelengths. We were able to correct up to 500 modes at 1kHz of framerate, reaching Strehl ratios of about 50% and at 630nm of wavelength. We will show the results obtained in daytime with the calibration source and on-sky using natural guidestars. These performances have been obtained at the LBTI-DX focus, one of the 4 LBT focal stations equipped with a SCAO system. All these 4 systems will be upgraded in the framework of the SOUL project. The wavefront sensor detectors will be substituted with low readout noise ones, the adaptive secondary firmware and the AO control both improved. We will briefly describe here SOUL and its performances as estimated via numerical simulations.

Mon 4 16:50

GeMS, the path toward AO facility

Garrel, Vincent; Sivo, Gaetano; Marin, Eduardo; Trujillo, Chadwick; Carrasco Damele, Rodrigo; Neichel, Benoit; Van Dam, Marcos; Ammons, Mark; Rigaut, Francois; Diaz, Ruben; Schirmer, Mischa; Gimeno, German; Hibon, Pascale; Leboulleux, Lucie; Montes, Vanessa; Lazo, Manuel; Rambold, William; Gigoux, Pedro; Galvez, Ramon; Moreno, Cristian; Araujo-Hauck, Constanza; Vucina Parga, Tomislav; Donahue, Jeff; Gausachs, Gaston; Lopez, Ariel
Gemini Telescope

GeMS, the Gemini South MCAO System, has now been in regular operation since mid-2013 with the imager instrument GSAOI. We review the performance obtained during this past year as well as some of its current limitations. While in operation, GeMS is still evolving to push them back and is currently in the path of receiving two major upgrades which will allow new exciting science cases: a new natural guide star wavefront sensor called NGS2 and a replacement of the current 50W laser. We are also actively moving along the path of further deeper integration with the future AO-fed instruments, we present our first preliminary results of astrometric and spectrometric calibrations with diverse Gemini instruments using an internal calibration source. We finally report our efforts to make GeMS a more robust instrument with the integration of a vibration rejection feature and a more user-friendly AO system as well with advanced gain optimization automatization.

Tue 5 09:00

Summary of the Laser Guidestar Workshop

Gavel, Donald
UC Obseratories

This is a summary of the CfAO Laser Guidestar Workshop

Tue 5 09:20

First Light of the ARGOS Facility

Rabien, Sebastian
MPE

ARGOS is the Laser Guide Star and Wavefront sensing facility for the Large Binocular Telescope. With first laser light on sky in 2013, followed by first corrected images in late 2014, the system is currently undergoing commissioning at the telescope. Within the last commissioning runs we have shown the first Laser Guide Star based GLAO correction on 8m class telescopes. We will give an overview of the system, present the status and design, and show first results on sky. Aiming for a wide field ground layer correction, ARGOS is designed as a multi-Rayleigh beacon adaptive optics system. A total of six powerful pulsed lasers are creating the laser guide stars in constellations above each of the LBTs primary mirrors. With a range gated detection in the wavefront sensors, and the adaptive correction by the deformable secondaries, ARGOS enhances the image quality over a large range of seeing conditions. With the two wide field imaging and spectroscopic instruments LUCI1 and LUCI2 as receivers and the Multi Object Spectroscopy, ARGOS will be a unique tool to boost LBTs scientific capabilities.

Tue 5 09:40

LGS R&D for the ELT: perspective and results

Bonaccini Calia, Domenico; Guidolin, Ivan; Pfrommer, Thomas; Centrone, Mauro; Reyes Garcia Talavera, Marcos; Pedichini, Fernando; Holzlöhner, Ronald; Lombardi, Gianluca; Bello, Dolores; Lewis, Steffan; Ambrosino, Filippo; Hackenberg, Wolfgang; Montilla, Iciar; Hickson, Paul
ESO

We present the perspective, plan and preliminary results of our R&D on LGS, aimed at maturing LGS technologies for future LGS-AO systems and the ELTs.

The ESO 'Wendelstein' transportable laser guide star unit has been installed in July 2014 at the UBC Large Zenith Telescope to study the feasibility to recover the mesospheric sodium profile and its centroid by pseudo-random modulation of 10% of the emitted CW power. The results of the field tests will be reported.

Since February 2015 we started measurements of the return flux for different laser emission formats, at the IAC's Observatorio de el Teide, to find the optimal format which gives the maximum LGS return flux. We will report preliminary results of these field tests.

In the final outlook we will review the R&D plan forthe next years and its rationale.

Tue 5 10:00

Recent Improvements to the Keck II Laser Guide Star Adaptive

Ragland, Sam; Chin, Jason; Wizinowich, Peter; Cetre, Sylvain; Lilley, Scott; Wetherell, Ed; Medeiros, Drew; Rampy, Rachel
W.M. Keck Observatory

The laser guide star (LGS) adaptive optics (AO) system on Keck II telescope was recently upgraded with a Center Launch Laser System (CLS). The purpose of the CLS is to improve the performance of the existing Keck II LGS AO system by reducing the perspective elongation of the LGS as seen by the AO wavefront sensor and hence the measurement error, one of the largest terms in the current error budget. This performance improvement is achieved by projecting the laser from behind the Keck telescope's secondary mirror instead of from the side of the Keck telescope. The CLS has transitioned to shared-risk science phase in June 2015. The intent of this paper is to provide a high level overview of the design and implementation and the on-sky performance. Future Keck II LGS AO improvements, including the implementation of a TOPTICA/MPBC laser, will also be presented in the context of AO for extremely large telescopes.

Tue 6 10:40

MCAO at the Big Bear Solar Observatory

Schmidt, Dirk; Gorceix, Nicolas; Zhang, Xianyu; Marino, Jose; Goode, Phil; Rimmele, Thomas; Berkefeld, Thomas
National Solar Observatory

An MCAO system for solar observations has been set up at the 1.6 meter clear aperture New Solar Telescope in Big Bear Lake. Being a pathfinder to address some fundamental design questions in solar MCAO experimentally, the system is purposely flexible. We deploy three deformable mirrors (DM). One of which is conjugate to the telescope pupil, and the others to higher altitudes. The pupil DM can be either placed into a pupil image up- or downstream of the high-altitude DMs. The high-altitude DMs can be separately and quickly conjugated to various altitudes between 2 and 8 km. Three Shack-Hartmann wavefront sensor units are available, one low-order multi-directional model and two high-order on-axis units, of which one is used at a time. The flexibility of the setup allows us to experimentally study the various orderings of DMs and WFSs sequences which are hard to simulate conclusively. During a run in May 2015, we were able to repeatedly and clearly visibly extend the compensated area of the solar image by controlling two DMs compared to classical AO control. Performance analysis in going on, and another run is planned for September 2015. We report on the preliminary results and summarize the design and the configuration options of the MCAO system at Big Bear Solar Observatory.

Tue 6 11:00

SCExAO: the first high contrast exoplanet imager on an ELT?

Guyon, Olivier; Jovanovic, Nemanja; Lozi, Julien; Singh, Garima; Clergeon, Christophe; Doughty, Danielle; Pathak, Prashant; Goebel, Sean; Kudo, Tomoyuki
NAOJ - Subaru Telescope / University of Arizona

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) instrument, currently under development for the Subaru Telescope, optimally combines state-of-the-art technologies to study exoplanets and stellar environments at the diffraction limit, both in visible and infrared light (0.6 to 2.4 um). The instrument already includes an ultra-fast visible pyramid wavefront sensor operating at 3.5 kHz, a 2k-actuator deformable mirror, a set of optimal coronagraphs that can work as close as 1 l/D, a low-order wavefront sensor, a high-speed speckle control, and two visible interferometric modules, VAMPIRES and FIRST. After the integration of the integral field spectrograph CHARIS and a Microwave Kinetic Inductance Detector (MKID) in 2016, SCExAO will be one of the most powerful and effective tools for characterizing exoplanets and disks. None of the ELTs include a high-contrast imager and spectrograph

amongst the first generation of instruments. To address this, we propose to upgrade SCExAO and deliver it as a first light visitor instrument to TMT, a decade before the second generation instruments come online. SCExAO's flexibility assures that it will include the latest technologies when it arrives on TMT, achieving the ultimate goal of characterizing the first terrestrial planets in the habitable zones of M-type stars.

Tue 6 11:20

CANARY closes the open-loop demonstration of MOAO

Gendron, Eric; Morris, Tim; Basden, Alastair; Vidal, Fabrice; Buey, Tristan; Gratadour, Damien; Morel, Carine; Chemla, Fanny; Cohen, Mathieu; Sevin, Arnaud; Younger, Eddy; Hubert, Zoltan; Osborn, James; Henry, David; Dipper, Nigel; Wilson, Richard; Butterley, Tim; Bitenc, Urban; Reeves, Andrew; Bharmal, Nazim; Huet, Jean-Michel; Perret, Denis; Dickson, Colin; Atkinson, David; Longmore, Andy; Todd, Stephen; Talbot, Gordon; Morris, Simon; Rousset, Gérard; Myers, Richard
Observatoire de Paris

CANARY is an on-sky Laser Guide Star (LGS) tomographic AO demonstrator in operation at the 4.2m William Herschel Telescope (WHT) in La Palma. From the early demonstration of open-loop tomography on a single deformable mirror, using natural guide stars in 2010, CANARY has been progressively upgraded each year to reach its final goal in July 2015. It is now a two-stage system that mimics the future E-ELT: a LTAO-driven woofer based on 4 laser guide stars delivers a ground-layer compensated field to a figure-sensor locked tweeter DM, that achieves the final on-axis tomographic compensation. We will present the overall system, the control strategy and an overview of its on-sky performance, as well as the ensemble of tools and techniques that were used to assess, at each phase of the project, the wave-front error breakdown.

Tue 6 11:40

On-sky results of Raven, a Multi-Object Adaptive Optics science demonstrator at Subaru Telescope

Lardiere, Olivier; Dave, Andersen; Bradley, Colin; Oya, Shin; Ono, Yoshito; Gamroth, Darryl; Correia, Carlos; Lamb, Masen
University of Victoria

Raven is a Multi-Object Adaptive Optics science demonstrator which has been used on-sky at the Subaru telescope from May 2014 to July 2015. Raven has been developed at the University of Victoria AO Lab, in partnership with NRC, NAOJ and Tohoku University. Raven includes three open loop WFSs, a central laser guide star WFS, and two science pick-off arms feeding light to the Subaru IRCS spectrograph. Raven supports different AO modes: SCAO,

open-loop GLAO and MOAO. This paper gives an overview of the instrument design, compares the on-sky performance of the different AO modes and presents some of the science results achieved with MOAO.

Tue 7 13:30

Spatio-angular Linear Quadratic Gaussian algorithm for prediction and control in Tomographic Systems

Correia, Carlos; Jackson, Kate; Konnik, Mikhail; Véran, Jean-Pierre; Andersen, David; Lardière, Olivier; Bradley, Colin
LAM

We present the spatio-angular Linear Quadratic Gaussian algorithm for temporal wave-front prediction and minimum-variance control in tomographic adaptive optics systems. We have fully validated the algorithm in the lab and on-sky with the Raven multi-object science and technology demonstrator installed on the Subaru telescope. We report 2 stellar magnitudes improvement in limiting magnitude which provides roughly a factor 5 better sky-coverage. We further address sparse implementations and compliance with ELT-sized systems. The algorithm is particularly suitable to laser-tomography systems both for the high order correction or for optimal modal tilt anisoplanatism compensation in split tomography. We review parameter identification methods and robustness metrics ahead of major design phases for LTAO and MOAO instruments.

Tue 7 13:50

Development of multi time-step tomographic reconstruction with RAVEN.

Ono, Yoshito; Masayuki, Akiyama; Oya, Shin; Lardiere, Olivier
Tohoku University

In this presentation, we propose a new tomographic reconstruction method to reduce a tomographic error, "multi time-step reconstruction". Based on the frozen flow assumption, we can compute the time evolution of WFS measurements at previous time-steps with using wind information. Our idea is to reduce the tomographic error by using the measurements at both of the current and the previous time-steps simultaneously. We also develop a method to estimate wind velocity and direction at each altitude from temporal correlation of phase distortion pattern reconstructed by a classical tomography. We evaluate the performance of the method by a MOAO bench test with the RAVEN, an MOAO technical and science demonstrator. In the bench test, our wind estimation method can estimate wind velocities and directions of multiple layers. by the new reconstruction method, the ensquared energy in a 140mas box increases about 4% compared with a classical tomographic reconstruction.

Tue 7 14:10

Spiders - a problem for the DM control?

Obereder, Andreas; Yudytskiy, Misha; Ramlau, Ronny
RICAM, MathConsult GmbH

All reflecting telescopes need support structures to hold the secondary mirror. To cope with the weight of the secondary mirror in the planned ELTs, large support structures must be used. Inadvertently, these support structures will obstruct several wavefront sensor subapertures fully or at least partly. These effects, also known as spiders, manifest in the WFS measurements as higher measuring inaccuracies or even missing measurements from completely obstructed WFS subapertures. Subsequently effects of spiders appear as a set of disconnected domains with valid measurements on the wavefront sensor. This may, if no proper regularization is used, result in separate piston modes in the DM shape on each disconnected domain. As the piston mode is in the null-space of, e.g., the SH-WFS, those constant shifts may evolve slowly over time and lead to decreasing Strehl ratios. In this talk we focus on stable DM control using the CuReD (Cumulative Reconstructor with Domain Decomposition) and will compare the obtained results with existing algorithms.

Tue 7 14:30

Erasing the wind: Predictive Control for Adaptive Optics on sky and in the lab

Rudy, Alexander; Poyneer, Lisa; Srinath, Srikar; Ammons, Mark; Gavel, Donald
UCSC

We identify wind correlated motion in telemetry from the ShaneAO system on the 3-meter telescope at Lick Observatory, and in the Lab for Adaptive Optics test bench. We test the identification and suppression algorithm with ShaneAO WFS telemetry and characterize the performance improvement, with the ultimate goal of reducing the limiting guide star magnitude on-sky.

Tue 7 14:50

Reducing AO latency using many-core processors

Barr, David; Basden, Alastair; Dipper, Nigel; Schwartz, Noah
UK Astronomy Technology Centre

The high control frequency required of planned E-ELT instruments (from several hundreds of Hz to thousands and typically in the region of 500 Hz for first-light E-ELT instruments such as HARMONI) along with the high number of actuators leads to very demanding computational needs for the real-time AO control (RTC) systems. The number of actuators, proportional the total area of the telescope primary mirror, will range from several thousands to tens

of thousands (typically 5-6 thousand for a first-light E-ELT instrument such as HARMONI). Traditional RTC architectures based on CPU only technologies are typically unable to achieve the required performance in a cost-effective and maintainable manner. Alternative hardware such as many-core hardware accelerators need to be considered to deliver the computational power. These many-core processors offering a highly parallel environment have the potential of coping with the high computational load and of accelerating parts of the AO control system. AO systems for the E-ELT however, also put heavy constrains on jitter and latency. In this paper, we investigate the Intel Xeon Phi and the TILERA TILE-Gx processors to accelerate wavefront reconstruction and wavefront pre-processing. We present a detailed performance analysis putting an emphasis on execution time, jitter (variation in execution time) and outliers (results significantly apart from the mean). Results are explored both for typical first-light E-ELT instruments and, to stay as general as possible and fully appreciate scalability issues, for a much wider range of AO system sizes. The paper also addresses anticipated hardware developments in the near future and examines their suitability for the E-ELT.

Tue 8 15:30

The TMT IRIS On-Instrument Wavefront Sensor System

Andersen, David; Dunn, Jennifer
NRC Herzberg

IRIS is a first-light facility instrument for the TMT that operates as a client of the NFIRAOS MCAO system. IRIS is a collaboration between Caltech, the University of California, NAOJ and NRC Herzberg. IRIS contains three On-Instrument WaveFront Sensors (OIWFS) probes which pick off light from natural guide stars over a two arcminute diameter field of regard. The OIWFS operates in the near infrared and takes advantage of image sharpening of the point spread functions by NFIRAOS. We report on the preliminary design of the OIWFS and show how their design meets its requirements to deliver excellent image quality, astrometry and sky coverage.

Tue 8 15:50

Pyramid versus Shack-Hartmann: Trade Study Results for the NFIRAOS NGS WFS

Veran, Jean-Pierre; Esposito, Simone; Spano, Paolo; Herriot, Glen; Andersen, David
National Research Council of Canada

NFIRAOS, the first light AO system for the Thirty Meter Telescope, will include a natural guide star (NGS) pyramid wave-front sensor (PWFS). This WFS will have two functions: (i) when there is a bright enough NGS within the science field and the lasers are turned off, the PWFS will act as the fast

high order WFS driving the SCAO loop (e.g. for high-contrast imaging) and (ii) when the lasers are in use and the system operates in MCAO mode, the PWFS will act as a slow truth WFS (e.g. to measure drifts in the structure of the sodium layer). The decision to select a PWFS instead of a more conventional Shack-Hartmann WFS (SHWFS) is the outcome of a detailed trade study. In this paper, we summarize the results of this trade study. These include extensive simulation work, which shows that, in the expected operating conditions of NFIRAOS, the PWFS will bring significant performance improvements, including higher Strehl ratio, higher limiting magnitude and lower residual speckle levels for high contrast imaging, even when the system has to correct for significant levels of non-common path aberrations. We also report on opto-mechanical design work, which shows that, with the PWFS, the two functions (i) and (ii) can actually be combined into a single optical path, thus reducing the complexity in terms of number of mechanisms and optical elements. Finally, we discuss the impacts of switching to a PWFS on the other already designed NFIRAOS sub-systems (e.g. the real-time computer), which we have found to be very modest.

Tue 8 16:10

Miniaturized Shack-Hartmann Wavefront-Sensors for ELTs

Goodwin, Michael; Zheng, Jessica; Lawrence, Jon; Richards, Sam; Leon-Saval, Sergio
Australian Astronomical Observatory

The miniaturization of wavefront sensors overcomes some of the potential barriers faced by ELTs in implementing large-scale multi-object adaptive optics over large focal surfaces. The Australian Astronomical Observatory is prototyping a compact and lightweight Shack-Hartmann wavefront-sensor designed to be positioned by their Starbug parallel fibre positioning robots. Starbugs perform the critical positioning of optical fibers for the MANIFEST instrument for the GMT. Each wavefront sensor uses a set of polymer bundles to relay the image produced by a microlens array near to the focal plane to a re-imaging module. This allows multiple wavefront sensors to be multiplexed to a single low-noise camera for cost efficiencies per wavefront sensor. The ability to have a large number of wavefronts sensors are likely increase the scientific impact of future ELTs. We illustrate our miniature wavefront sensor concept with a potential design for GMT.

Tue 8 16:30

Near-infrared tip/tilt sensing at Keck: System architecture and on-sky performance

Rampy, Rachel; Femenia, Bruno; Lyke, Jim; Wizinowich, Peter; Cetre, Sylvain; Ragland, Sam; Stomski, Paul
W. M. Keck Observatory

The sky coverage and performance of laser guide star (LGS) adaptive optics (AO) systems is limited by the natural guide star (NGS) used for low order correction. This limitation can be reduced by measuring image motion of the NGS in the near-infrared where it is partially corrected by the LGS AO system and where stars are generally several magnitudes brighter than at visible wavelengths. We have integrated a near-infrared tip/tilt sensor with the Keck I telescope's LGS AO system and recently began offering it for science use. The implementation involved modifications to the AO bench, real-time control system, higher level controls and operations software. The tip-tilt sensor is a H2RG-based near-infrared camera with 0.05 arc second pixels. Low noise at high sample rates is achieved by only reading a small region of interest, from 2x2 to 16x16 pixels, centered on an NGS anywhere in the 100 arc second diameter field. The sensor operates at either Ks or H-band using light reflected by a choice of dichroic beam-splitters located in front of the OSIRIS integral field spectrograph. This work presents an overview of the completed system along with on-sky performance results. Lessons learned and efforts to extend the capabilities and further optimize the system are also discussed.

Tue 8 16:50

Flatten the Pyramid, you still have a Wavefront Sensor

Fauvarque, Olivier; Neichel, Benoit; Fusco, Thierry; Sauvage, Jean-Francois
Laboratoire d'Astrophysique de Marseille

We propose a new type of Wave Front Sensor (WFS) derived from the Pyramid WFS (PWFS). This new WFS, called the Flattened Pyramid-WFS (FP-WFS), has a reduced Pyramid angle in order to optically overlap the four pupil images into an unique intensity. This map is then used to derive the phase information. In this paper this new WFS is compared to three existing WFSs, namely the PWFS, the Modulated PWFS (MPWFS) and the Zernike WFS (ZWFS) following tests about sensitivity, linearity range and low photon flux behavior. The FPWFS turns out to be more linear than a modulated pyramid for the high-spatial order aberrations but it provides an improved sensitivity compared to the non-modulated pyramid. The noise propagation may even be as low as the ZWFS for some given radial orders. Furthermore, the pixel arrangement on the detector is more efficient due to the optical recombination. These characteristics make the FPWFS particularly well suited for high-contrast applications.

Tue 8 17:10

Extreme Adaptive optics Wavefront Control Towards High-Contrast and Extrasolar Planet Imaging with ELTs

Langlois, Maud; Loupias, Magali; Delacroix, Christian; Tallon, Michel; Thiébaut, Eric; Moretto, Gil
CNRS/CRAL

In order to allow the discovery of other Earths, different teams around the world are conceiving a new generation of instruments and telescopes. These new discoveries will rely on high contrast imaging that requires near perfect wavefront so that speckles of starlight, created by subtle aberrations caused by atmospheric turbulence and by the telescope optics, will not create a glare that would obscure the presence of very faint planets. In our presentation we propose real time wavefront control strategies and a WFS concepts to push the performances. Our main goal is the development of adaptive optics (AO) systems to enable ultra-high-contrast astronomical observations to allow such achievements. From the ground, the core of any high contrast instrument is an extreme adaptive optics (ExAO) system correcting both for atmospheric turbulence and for internal aberrations of the instrument itself. There are currently several high contrast instruments equipped with ExAO under development around the world (Macintosh, 2006 and Beuzit, 2007) on 8 m class telescopes. For E-ELTs. it is extremely difficult, with the current technology, to achieve ExAO on such large telescopes. To address this difficulty, we have dedicated efforts in R&D for demonstrating the feasibility of the required high-order, high-speed wavefront control despite the increase of the number of actuators for the E-ELT. Faster algorithms based on fractal iterative method such as FrIM (Thiébaut and Tallon, 2010) are being studied and tested experimentally to cope with the insufficient computer power that is currently anticipated. In this context, we present results on a new wavefront sensor concept, based on the Mach-Zehnder wavefront sensor (MZWFS), as a single stage sensor in order to achieve better performances and to decrease hardware complexity. Thanks to a better sensitivity at high spatial frequencies, such WFS favors a clean correction of the starlight halo at small angular separations where the most demanding contrast is required. But it's use is hampered by its non-linear response. We propose to use the inverse approach to attempt direct wavefront control with a MZWFS and we describe the steps to validate this architecture by using the ExAO bench available at CRAL/CNRS.

Wed 9 09:00

Selex infrared sensors for astronomy – present and future

Baker, Ian; Maxey, Chris; Barnes, Keith
Selex-ES

This paper describes the Selex MOVPE technology and its strengths for scientific applications. The ability to grow complex HgCdTe heterostructures has proved crucial in meeting the sensitivity and speed of response requirements of modern scientific applications. The paper will outline current programs from the European Space Agency on 1k x1k NIR and 2k x 2k SWIR developments and eAPD developments mainly from collaborative programs with

the University of Hawaii and ESO. The Saphira array will be described as a Selex product developed exclusively for wavefront sensing. Plans for a larger format version of Saphira for the giant telescope era will be outlined. With its potential to achieve single photon detection in long exposures the eAPD is attracting more interest for imaging and a roadmap will be presented.

Wed 9 09:20

Development of near infrared eAPD wavefront sensors for the ELT with sub-electron read noise

Finger, Gert
European Southern Observatory

In 2007 ESO started the development of near infrared detectors for wavefront sensing and fringe tracking with the British company SELEX. In the near infrared the sub-electron readout noise at frame rates of 1KHz can only be achieved with HgCdTe avalanche photodiode arrays. This technology is currently deployed in the fringe tracker and the four wavefront sensors of the VLTI instrument GRAVITY. The characteristics of an advanced version of the SAPHIRA 320x256 pixel eAPD array will be presented. A new development of a 1Kx1K NIR wavefront sensor for ELTs will be proposed.

Wed 9 09:40

State of the art IR cameras for wavefront sensing using e-APD MCT arrays

Feautrier, Philippe; Gach, Jean-Luc; Wizinowich, Peter
First Light Imaging / IPAG

Developed by First Light Imaging and based on the Saphira detector developed by Selex for ESO, the C-RED infrared camera is opening a new era in terms of sensitivity and speed in the SWIR scientific cameras domain and is particularly suited for infrared wavefront sensing in complex AO systems like MCAO. Infrared HgCdTe Avalanche Photo Diodes (APD) have been shown in the literature to exhibit single carrier multiplication of electrons up to gains in the order of 10 000 associated with low excess noise factors F=1.05-1.2, record high gain-bandwidth product GBW>2.1THz and low dark currents. The technology used to manufacture APDs is similar to the one used for standard n on p HgCdTe diodes explaining why a high quantum efficiency (typically QE=70-75 %) is maintained. This technology allows to apply moderate multiplication gain without adding noise, therefore lowering the readout noise without almost no penalty. This is in strong contrast to what is observed in APDs made out of III-V material or Si, which requires high inverse bias and have typical noise factors of F 4-5 for III-V semi-conductors and F 2-3 for Si respectively. These exceptional characteristics of HgCdTe APDs are due to a nearly exclusive impaction ionization of the electrons, why these devices have been called electrons avalanche photodiodes, e-APDs. These results have

inspired a large effort in developing focal plan arrays using HgCdTe APDs for low photon number applications such as active imaging in the range gated mode (2D) and/or with direct time of flight detection (TOF) (3D) and, more recently, passive imaging for infrared wave front correction and fringe tracking in astronomical observations. C-RED is using the SAPHIRA 320x256 2.5 microns cut-off 24 microns pixel pitch HgCdTe e-APD array allowing to obtain sub-electron readout noise, taking advantage of the APD noise-free multiplication gain and non destructive readout ability. Another major AO wavefront sensing detector development concerns the RAPID project. Developed by the SOFRADIR and CEA/LETI manufacturers, the latter offers a 320x255 8 outputs 30 microns e-APD array, sensitive from 0.4 to 3 microns, with less than 2 e readout noise at 1600 fps. A rectangular window can also be programmed to speed up even more the frame rate when the full frame readout is not required. The high QE response, in the range of 70%, is almost flat over this wavelength range. Advanced packaging with miniature cryostat using pulse tube cryocoolers was developed in the frame of this programme in order to allow use on this detector in any type of environment. The characterization results of this device are presented here. Readout noise as low as 1.7 e at 1600 fps has been measured with a 3 microns wavelength cut-off chip and a multiplication gain of 14 obtained with a limited photodiode polarization of 8V. This device also exhibits excellent linearity, lower than 1%. The pulse tube cooling allows smart and easy cooling down to 55 K. Vibrations investigations using centroiding and FFT measurements were performed proving that the miniature pulse tube does not induce measurable vibrations to the optical bench, allowing use of this cooled device without liquid nitrogen in very demanding environmental conditions. In 2013, the partners delivered the first prototypes and, given the performance results of these prototypes, the decision was quickly taken to push for an on-sky demonstration on a demanding instrument. PIONIER was chosen as its interferometric combination of light requires a very fast detector to fight against atmospheric turbulence, and a minimum amount of noise in order to detect faint objects. The RAPID detector is now implemented on the PIONIER instrument on the ESO/VLTI interferometer in Paranal since December 2014. Since this time, RAPID observed more than 150 stars during more than 45 nights on the VLTI with a tremendous gain compared the previous camera based on conventional IR detectors. As illustration of AO wavefront sensing capabilities, we propose to study the interest of such low noise device for the Keck AO system. A near-infrared (NIR) tip-tilt sensor has been implemented and is being commissioned with the Keck I laser guide star (LGS) adaptive optics (AO) system. The initial performance results are very promising and we are planning to propose for a similar sensor for the Keck II LGS AO system for operation with NIRC2. In this paper, we propose to evaluate the options given the recent developments in NIR APD arrays. The options are to largely reproduce the Keck I system or to implement a new system based on a NIR APD array. This evaluation will be considered from the perspective of two systems: the Keck II LGS AO system and the Keck next generation adaptive optics (NGAO) system. The evaluation criteria include capabilities, performance, risk, schedule, cost and potential collaborations.

Wed 10 10:00

Non common path aberration correction with nonlinear WFSs

Esposito, Simone; Pinna, Enrico; Puglisi, Alfio; Agapito, Guido; Veran, Jean Pierre; Herriot, Glen
INAF / Osservatorio di Arcetri, Firenze

Non Common Path Aberrations (NCPAs) are a usual problem encountered when using an Adaptive Optics (AO) system to produce corrected images in an astronomical instrument. The usual way to correct for such NCPAs is to introduce offsets in the Wavefront Sensor (WFS) signals that correspond to the aberrations to correct. In such a way, when the AO loop is closed, the Deformable Mirror (DM) will converge to the shape required to null the NCPAs. The method assumes that the WFS operation is linear and completely described by some pre-calibrated interaction matrix. This is not the case for some frequently used wavefront sensors like the Pyramid sensor or a quad-cell Shack-Hartmann sensor. Here we present a method to work in closed loop with a Pyramid Wavefront Sensor (PWS), or more generally a nonlinear WFS, while introducing a static offset on the DM. The DM shape is kept constant even if the AO residuals change over time because of variations of seeing, wind speed and so on. Results from numerical simulations and on-sky operations with LBT FLAO system are presented. Other implications of the considered method on AO loop optimization will be briefly introduced.

Wed 10 10:20

Use of Laser Guide Star with Pyramid Sensor

Blain, Celia; Esposito, Simone; Puglisi, Alfio; Agapito, Guido; Pinna, Enrico
INAF / Osservatorio di Arcetri, Firenze

Laser Guide Star (LGS) reference sources, artificially generated at an altitude of 90 km at the atmospheric sodium layer, are mandatory to ensure large sky coverage of astronomical Adaptive Optics (AO) systems developed for 8m and Extremely Large Telescope (ELT) class telescopes. As a result of the projection effect of an object located at a finite distance from the telescope, the AO wavefront sensor perceives the LGS as elongated. This elongation is a few arcseconds for the 8m class telescopes and can be more than 10 arcseconds for the ELTs. This can pose several challenges when using a Shack-Hartmann (SH) sensor such as truncation effects, the requirement for large detectors, and/or the requirement for detectors with geometry that corresponds to the source shape. In this work, we report the results of numerical simulations focused on the use of a Pyramid sensor with LGS. In addition, the requirements and performance of both the Pyramid and SH wavefront sensors are compared using example cases.

Wed 11 11:00

Gender equity in science and astronomy: state of the art

Masciadri, Elena; D'Orgeville, Celine; Rigaut, Francois
INAF-Arcetri Astrophysical Observatory

The 'gender equity' issue is a general and important feature of our professional life. It indicates the necessity to assure parity in work opportunities, intellectual recognition, access to professional benefits, presence in decision making bodies and scientific advisory committees to contribute to the success of all professional activities, in our case to the progress of scientific research. It is commonly perceived as 'woman's problem' and, even if in the most recent years the situation is less critical than a few decades ago, it is still an unsolved problem. In this contribution we will try to trace the state of the art in the research field and in particular in the scientific field and in the sub-sample of astronomy providing information and answers to a few among the most common questions related to this topic: are women employed as researchers still a minority? Are women effectively progressing in their career to achieve top levels positions? Does the gender gap penalize only women or also men? Can the under-representation of women in science be explained by weaker skills of women in this discipline? Which are the main causes of discrimination and which are the possible solutions? Is the gender equity issue something we have to take care or can we simply wait for a sufficiently long time assuming that the problem will disappear on its own?

Wed 11 11:20

We are all made of (un-twinkling) stars: establishing gender equity in the Adaptive Optics community

d'Orgeville, Celine; Masciadri, Elena
Australian National University

For the first time in the history of Adaptive Optics conferences, the 2014 SPIE conference included an invited presentation discussing the status and participation of women in the Adaptive Optics community. The presentation and associated paper, titled "Gender equity in astronomy: facts, fiction, and what the adaptive optics community can do to close the gap", explored the many causes behind the low participation level of women in STEM (Science, Technology, Engineering and Medicine) fields in general, and in astronomy and adaptive optics in particular.

This paper aims to focus and further expand on the third section of the 2014 SPIE paper which discussed practical ways to increase female participation in the adaptive optics community. Examples of successful approaches will be presented as well as recommendations for all individuals, departments and institutions who aim to increase female participation in our community: in

the office, in the lab, at conferences, in review panels, and eventually through the glass ceiling at executive and board levels as well.

The stated purpose of this work, in combination with its companion paper "Gender equity in science and astronomy: state of the art", is to generate healthy discussions in our community and provide practical guidelines to improve the status and number of women working in this field so that, together, we can establish gender equity in the Adaptive Optics community.

Wed 12 15:00

An off-axis segment piston sensor for the Giant Magellan Telescope

McLeod, Brian; Kopon, Derek; van Dam, Marcos; Bouchez, Antonin
Smithsonian Astrophysial Observatory

With seven 8.4m segments separated by 0.4m, phasing is one of the biggest technical challenges of the Giant Magellan Telescope project. In particular, maintaining the required 50nm segment piston when observing faint sources on-axis with laser tomography AO is particularly difficult. We describe here the design of a sensor that operates using natural guide stars 6'-10' off-axis by dispersing J-band light from 1.4m subapertures centered on the 12 segment tangent points. Simulations performed using YAO show that using three such sensors will meet the requirement with >90% sky coverage at the galactic pole.

Wed 12 15:20

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

Neichel, Benoit; Fusco, Thierry; Sauvage, Jean-Francois; Correia, Carlos; Dohlen, Kjetil; Thatte, Niranjan; Clarke, Fraser; Gray, Morgan; Schwartz, Noah; Schnetler, Hermine; Bryson, Ian; Tecza, Matthias; Vernet, Joel
LAM (Laboratoire d'Astrophysique de Marseille)

HARMONI is a visible and near-infrared integral feld spectrograph, providing the E-ELT's core spectroscopic capability. It will exploit the E-ELT's scientific niche in its early years, starting at first light. To get the full sensitivity and spatial resolution gain, HARMONI will 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). In this paper, we present the overall design of the SCAO system and discuss the complementary between SCAO and LTAO for HARMONI. Performance and system design trade-offs are discussed. The development process allowing to efficiently going from SCAO to LTAO is

also described. In that respect, the rational for wave front sensor choices is presented as well as the first preliminary conclusions, and overall design choices.

Wed 12 15:40

NFIRAOS

Herriot, Glen; Andersen, Dave; Atwood, Jenny; Byrnes, Peter W. G.; Caputa, Kris; Fitzsimmons, Joeleff; Hill, Alexis; Kerley, Dan; Smith, Malcolm; Dunn, Jennifer; Veran, Jean-Pierre
NRC Herzberg

NFIRAOS is the facility Adaptive Optics system for the Thirty Meter Telescope, is being designed and integrated at NRC Herzberg in Victoria Canada. NFIRAOS is an MCAO system that will feed three client instruments. It is cooled to -30°C and has two deformable mirrors, six laser wavefront sensors, and uses up to three low-order (tip/tilt and/or focus) IR wavefront sensors (OIWFS)on each instrument and up to four guide windows on the science detectors (ODGW) to correct atmospheric turbulence, telescope windshake and quasi-static optical errors. In April 2015 the federal government announced funding for full membership in TMT, and consequently design and construction activity has ramped up. Approximately a dozen major subystems in NFIRAOS are under contract with industry. We present recent intensified engineering work and design revisions to NFIRAOS such as a pyramid WFS for a truth wavefront sensor and for NGS-mode observing without lasers, and NFIRAOS' CPU-based real time computer.

Wed 13 16:00

Exploring the stellar population of nearby and high redshift galaxies with ELTs

Gullieuszik, Marco; Falomo, Renato; Greggio, Laura
INAF - Astronomical Observatory of Padova

The high sensitivity and spatial resolution of future ELTs facilities will offer the unique opportunity to probe directly the stellar populations of the very inner regions of galaxies in the local Universe and to derive color information for resolved structures of high redshift galaxies. We present our project aimed at assessing the scientific output of ELTs in the study of nearby and high-redshift stellar populations. To this end, we simulated imaging observations of different stellar populations in the local Universe and in high-redhshift galaxies with E-ELT, TMT, and JWST. Detailed photometric analyses of our simulated images were used to probe the feasibility of several science cases dealing with photometry of resolved stars in crowded fields, and with surface photometry of distant galaxies. We find that the future facilities will allow us to greatly improve our knowledge of the stellar populations in galaxies, especially in the most crowded regions. Accurate photometry of turn-off stars

in nuclear star clusters of intermediate age will be possible up to distances of 3 Mpc, while in the Virgo cluster the analysis of individual red giant branch stars will yield detailed information of the metallicity distribution in the very inner parts of elliptical galaxies. The exquisite spacial resolution will also drive great progress in unresolved stellar populations studies, enabling the measurement of structural parameters, colour profiles, and the detection of signature of star formation sub-structures in galaxies at redshifts up to z=3.

Wed 13 16:20

Statistical and morphological analysis of mock galactic fields in the Global-MCAO perspective

Portaluri, Elisa
Osservatorio Astronomico di Padova

Enable accurate morphological and photometric analysis across a wide Field of View (FoV) is one of the key science requirement for multi-conjugate adaptive optics systems. With this motivation we present a study aimed at the investigation of the performance of Global-MCAO (GMCAO). Such an innovative concept, based on natural guide stars in a wide technical FoV, addresses the need for an increase of the sky coverage which is a key ingredient for future MCAO-based VLT instruments and for the forthcoming E-ELT. Using a tomographic simulation tool we compute a map of the Strehl Ratio in a 250´ ´ × 250´ ´ area, matching the Chandra Deep Field South survey. Mock images of star and galactic fields are then built using such a map and analysed as if they were real and observed with the E-ELT instrumentation. We perform the source detection, two-dimensional light-profile modelling and a catalogue compilation using the GALAPAGOS code and we then compare the recovered parameters and statistics with the intrinsic data. The good match of our results claims that GMCAO is a reliable approach that can rebuild the AO concepts and can provide a frame of reference for a number of science cases.

Wed 13 16:40

Visible Wavelength AO Systems and Science For ELTs

Close, Laird; Males, Jared; Morzinski, Katie
University of Arizona

We will review the exciting new scientific avenues now traveled by astronomers using Adaptive Optics on large telescopes (such as MagAO, and ZIMPOL) in the visible (lambda=0.6-1 micron). Today AO in the visible has opened new and exciting science discoveries from the detection of H-alpha (0.6563 micron) accretion from well inside the 90 mas gaps of transitional disks to the exquisite mapping of debris disk surfaces in reflected light. Yet visible AO's greatest gains may come from the ELT AO systems. Only the visible

will yield the highest spatial resolutions (5 mas) possible from the ELTs. This will be transformative in terms of the resolution of Venus' orbit (0.75 AU) at the distance of all the nearest major star forming associations. The bright inner asteroid belts (where Terrestrial planets are assembled in habitable zones) will be finally be imaged directly in reflected light around almost all "hot component" debris disk stars. Massive planets themselves will be detectable in reflected light as well. This will also be a wavelength space not provided by JWST nor by the likely de-orbited HST. We will highlight some of the significant technical challenges of ELT visible light AO correction such as "adaptive" ADC designs, NGS WFS sensor challenges, vibration and Non-Common Path (NCP) mitigations, piston M1 errors, and astrometric stability. In the visible the science camera/spectrograph design can be simpler than in the NIR which, in turn, can yield more compact designs with lower NCP errors. Simultaneous Visible and NIR science use, such as been well demonstrated with the facility VisAO and NIR Clio2 cameras on the MagAO system, will also be explored.

Wed 14 17:00

Operational optical turbulence forecasts for the E-ELT Service Mode

Masciadri, Elena; Lascaux, Franck; Turchi, Alessio; Fini, Luca
INAF-Arcetri Astrophysical Observatory

In this contribution we present the most relevant results obtained in the context of a feasibility study (MOSE) undertaken for ESO. The principal aim of the project has been to define the performances of an atmospherical non-hydrostatical mesoscale model (Meso-NH) in forecasting all the main atmospherical parameters relevant for astronomical applications and the optical turbulence with the associated integrated astroclimatic parameters above Cerro Paranal (site of the VLT) and Cerro Armazones (site of the E-ELT). Considering the promising results obtained so far, this study sets-up the bases for the implementation on these two sites of an automatic system to be run nightly in an operational configuration to support the scheduling of scientific programs as well as of instrumentation of the E-ELT. The plan is to apply the system first on Cerro Paranal, where an Observatory is already operative and to Cerro Armazones in the near future. We are, at present, responsible for the implementation of a similar automatic system at Mt.Graham, site of the LBT. These systems will certainly permit us to make a step ahead in the field of the Service Mode for the new generation telescopes.

Wed 15 20:00

AO-coupled single mode fibres: enabling photonic spectrographs for ELTs

Schwab, Christian; Jovanovic, Nemanja; Cvetojevic, Nick; Gross, Simon; Norris, Barnaby; Withford, Michael; Lawrence, Jon; Guyon, Olivier
Macquarie University

Single mode fibres offer unique advantages over multimode fibres for coupling a telescope to a spectrograph. In particular, high resolution spectrographs can benefit greatly from the superior stability a single mode feed provides. However, coupling starlight into single mode fibres has traditionally been very inefficient. The new generation of AO systems with significant Strehl numbers in the NIR is changing this paradigm. This impacts the design of novel instrumentation. This is particularly important for ELTs, as the instrument size scales linearly with fibre aperture, and single-mode-fed spectrographs are much smaller than their seeing-limited counterparts, leading to tremendous benefits in performance and cost. Further, single mode feeds enable the use of photonic devices that provide added functionality compared to bulk, free space optics as the efficiency of single mode fibre coupling improves, photonic devices will become common components for IR spectrographs. Our team has performed on-sky tests of single mode fibre feeds with SCExAO at the Subaru telescope we were able to demonstrate efficient coupling to single mode fibres in the NIR and collect spectra with a photonic on-chip spectrograph. Here, we report on results from our tests at Subaru, discuss implications for AO systems at ELTs, and present options for novel IR spectrograph designs.

Wed 15 20:20

Design and Development Status of MKID Integral Field Spectrographs for High Contrast Imaging

Meeker, Seth; Mazin, Benjamin; Jensen-Clem, Rebecca; Walter, Alex; Szypryt, Paul; Strader, Matthew; Bockstiegel, Clint
UCSB Physics Dept.

We report on the design and development of two Microwave Kinetic Inductance Detector (MKID) integral field spectrographs (IFSs) for high-contrast astronomy applications. MKIDs are the most promising technology for overcoming the current contrast ceiling in coronagraphic instruments imposed by atmospheric speckles that vary on 1-second timescales. These speckles vary too slowly to average out with long exposures, and too quickly to control in real time with conventional focal plane detectors or to subtract reliably with differential imaging. DARKNESS is a 10,000 pixel MKID IFS that will integrate with the coronagraphs at Palomar Observatory (Project 1640 and the Stellar Double Coronagraph), as well as directly with the Palm-3000 extreme AO system. With DARKNESS we will demonstrate how the high time resolution of MKIDs allows the discrimination of speckles from faint companions during post-processing using a technique similar to the "dark speckle" approach. First light is scheduled for Winter 2016. MEC is a 20,000 pixel MKID IFS that will integrate with the Subaru Coronagraphic Extreme AO (SCExAO) system at the Subaru Telescope. With MEC we will use the high

time resolution and near-instantaneous readout of MKIDs to perform focal-plane speckle nulling at the speed necessary to control atmospheric speckles in real-time. With MEC+SCExAO we expect to achieve the contrast ratios required to image nearby known radial velocity planets in reflected light. An instrument with these capabilities on an ELT would be able to detect Earth-size planets in M-dwarf habitable zones. First-light for MEC is scheduled for Summer 2016.

Wed 15 20:40

SHARK-NIR Channel: an high contrast imager with coronographic capabilities for the Large Binocular Telescope

Farinato, Jacopo
INAF - OAPD

A new coronagraphic instrument for the Large Binocular Telescope is undergoing the conceptual design phase. SHARK-NIR channel will be installed in one arm of LBT and it is designed to use different coronagraphic techniques, both to match as much as possible the different requirements of the different science cases, and to explore the capabilities of such techniques for the next-generation of ELTs. By exploiting the combination with SHARK-VIS channel mounted at the other LBT arm, the instrument will offer simultaneous coronagraphic observations at different wavelengths characterized by high contrast, even for relatively faint targets. This will be achievable thanks to the very efficient AO systems already operating at LBT furthermore, the latter will be soon upgraded with new detectors, promising even better performance in terms of limiting magnitude. In this paper we present the status of the SHARK-NIR channel design.

Thu 16 09:00

Optimizing LGS AO Performance in the Context of Evolving Turbulence and Sodium Profiles

Wang, Lianqi
TMT Observatory

The time evolution of the sodium profile greatly impact the accuracy of laser guide star (LGS) wavefront sensor (WFS) measurements, for either the traditional thresholded center of gravity or the more advanced constraint matched filter/correlation algorithms. As a result, circularly symmetric wavefront aberrations will be induced in the adaptive optics (AO) corrected science wavefront for center launch LGS. In this paper, we describe our scheme to mitigate this issue by updating pixel processing parameters and employing a truth WFS during LGS AO operation. We also present simulation results using the sodium profiles measured by the UBC lidar. In addition, the time evolution

of the turbulence profile will also have an impact on the pixel processing accuracy for the advanced algorithms, as well as the minimum variance wavefront reconstruction. We present simulation results showing how often we have to update the corresponding parameters to minimize the effect.

Thu 16 09:20

Simulations of Adaptive Optics systems for the European Extremely Large Telescope and its instruments

Le Louarn, Miska
European Southern Observatory

In this talk, I will present an overview of the latest simulation results obtained for the E-ELT's AO system. Different areas of the telescope and instruments will be covered. For example, simulations showing how a single conjugated AO system can be used to detect a scalloping error will be shown. We show that when the scalloping error modes are entered in the reconstruction modal basis, the DM shape can be used to estimate the scalloping error through a simple matrix vector multiply. Temporal averaging allows to get rid of the atmospheric noise on the scalloping measurement and to get a measurement accuracy of about 20nm rms. In a second part, I will focus on a few results obtained on tomographic AO systems, for example the sensitivity to the number of DMs and their pitch in multi-conjugate AO, and the impact of outer scale on Laser tomography AO.

Thu 16 09:40

A Fresnel propagation analysis for SPEED

Beaulieu, Mathilde; Abe, Lyu; Martinez, Patrice; Gouvret, Carole; Martinache, Frantz; Preis, Oliver; Dejonghe, Julien; Vakili, Farrokh
Observatoire de la Cote d'azur

Direct detection and characterization of exoplanets is a major scientific driver of the next decade. Direct imaging requires challenging techniques to observe faint companions around bright stars. The development of future large telescopes will increase the capability to directly image and characterize exoplanets thanks to their high resolution and photon collecting power. The E-ELT will be composed of a segmented 40 m-diameter primary mirror. High contrast imaging techniques for E-ELT will thus need to deal with amplitude errors due to segmentation (pupil discontinuities between the segments). A promising technique is the wavefront shaping. It consists in the use of deformable(s) mirror(s) to cancel the intensity inside the focal plane region. Algorithm improvements and laboratory demonstrations have been developed since the last 20 years. The use of 2 DMs in non-conjugated planes will allow correcting not only for phase aberrations but also for the amplitude errors present in segmented pupils. Lagrange laboratory has begun in 2013

the development of an instrumental project called SPEED (Segmented Pupil Experiment for Exo-planet Detection). Its goal is to develop and test high-contrast imaging techniques optimized for segmented pupil. In this paper we present a detailed end-to-end simulation for the optimization of the SPEED experiment optical design. In particular, we pay attention to the optimal separation between the two DMs necessary for phase and amplitude correction. The trade-off between various parameters (field of correction, field of view, size constraints,...) is presented and discussed

Thu 17 10:40

Forecasting optical turbulence behaviour by fractional time series analysis

Doelman, Niek; Osborn, James
1) TNO Technical Sciences, 2) Leiden Observatory

Optical turbulence parameters , such as seeing angle, outer scale, isoplanatic angle and coherence time show temporal variability. Modelling and prediction of the temporal behaviour of the parameters is essential for the following reasons: (1) the efficient scheduling of scientific programs and use of astronomical instruments, (2) the tuning of AO systems and instruments, (3) the simulation of astronomical instrument performance under time-varying turbulence.

Furthermore, turbulence modelling and prediction can be used to: (4) improve the adaptive tracking performance of Linear Quadratic Gaussian (LQG)-type controllers, as they need to be tuned towards the specific turbulence conditions.

We have analysed integrated turbulence data from the Stereo-SCIDAR instrument (Durham University), installed at the 2.54m INT telescope, La Palma (2014). Before model fitting, the pre-processing of data is crucial, in particular regarding: the non-uniform sampling intervals, missing samples and the non-negative values. It has turned out that a fractionally integrated stochastic model gives an accurate description of the temporal behaviour of the integrated seeing angle over 11 nights of Stereo-SCIDAR observations. (More turbulence data from recent 2015 observations are planned to be included in this analysis).

Based on the characteristics of this stochastic model we can conclude that the time series of the seeing angle is non-stationary. This implies that the variance of the forecast error will a) increase with the prediction horizon and b) will diverge for long predictions horizons. Similar modelling and forecast results have been obtained for the isoplanatic angle and the coherence time from the Stereo-SCIDAR measurements at INT. Moreover, using data from 9 observing nights of the Generalized Seeing Monitor (GSM) at Paranal (2007), we have found that the temporal evolution of the turbulence outer scale can be captured by a similar stochastic model. Outer scale modelling and forecasting is of particular interest to Extremely Large Telescopes.

The paper discusses the time series pre-processing, the modelling procedure and the impact on turbulence parameter forecasting.

Thu 17 11:00

GreenFlash: Energy efficient high performance computing for real-time science

Gratadour, Damien; Dipper, Nigel; Biasi, Roberto; Deneux, Hugues
LESIA - Observatoire de Paris

Almost all instrumentation for the European Extremely Large Telescope (E-ELT) will require adaptive optics to reach its science goals. Whilst the requirements for each instrument will differ, a substantial core of the software and hardware systems, including the interface to the telescope control systems, can be common. The main goal of Green Flash is to design and build a prototype for a Real-Time Controller (RTC) targeting the E-ELT Adaptive Optics (AO) instrumentation. With Green Flash, we will propose technical solutions, assess these enabling technologies through prototyping and assemble a full scale demonstrator to be validated with a simulator and tested on sky. With this R&D program, funded though the Horizon 2020 European program, we aim at feeding the E-ELT AO systems final design studies with technological validations supporting the designs of the corresponding RTC modules. Our strategy is based on a strong interaction between academic and industrial partners. Components specifications and system requirements are derived from the AO application. Industrial partners lead the development of enabling technologies aiming at innovative tailored solutions with potential wide application range. The academic partners provide the missing links in the ecosystem, targeting their application with mainstream solutions. This increases both the value and market opportunities of the developed products. A prototype harboring all the features is used to assess the performance. It also provides the proof of concept for a resilient modular solution to equip a large scale European scientific facility, while containing the development cost by providing opportunities for return on investment. We will present the project goals, implementation and expected outputs.

Thu 17 11:20

Updates on the performance of fast iterative reconstruction algorithms for ELT AO systems

Saxenhuber, Daniela; Ramlau, Ronny
Johannes Kepler University

In this talk, we give an overview of the latest performance results of fast iterative algorithms for atmospheric tomography in ELT Adaptive Optics Systems, such as MCAO, LTAO and MOAO. Several adaptations and applications of the Austrian Adaptive Optics (AAO) reconstructors, such as the Kaczmarz, Wavelets- and Gradient-based method are shown. In particular, a new algorithm for the DM fitting step in MCAO, which improves performance in terms of speed and quality, as well as new algorithms for determining the optimal layer heights and cn2-profiles are presented. Studies of the influence

of turbulence profiles on the reconstruction quality for different atmospheric profiles and the comparison of several compression algorithms suggest that reconstructions on fewer atmospheric layers yield comparable quality with lower computational effort. Simulation results were obtained on the ESO end-to-end simulation tool OCTOPUS.

Thu 17 11:40

Performance assessment for the linear control of adaptive optics systems: noise propagation and temporal errors.

Juvenal, Rémy; Kulcsar, Caroline; Raynaud, Henri-François; Conan, Jean-Marc; Sivo, Gaetano

Laboratoire Charles Fabry, Institut d'Optique Graduate School

We propose a detailed study of the temporal and noise propagation errors entering the error budget of Single Conjugated Adaptive Optics (SCAO) systems. A transfer-function oriented method is developed for the computation of these errors, in a general linear control context. We apply this formalism to the performance comparison between Linear Quadratic Gaussian (LQG) and Integral action controllers. Simulation results are first presented, corresponding to the tip-tilt loop of a typical SCAO system, but any specific low order loop could be considered as well. We then assess the relevance of these two error terms calculation by processing on-sky tip/tilt data from GeMS.

Thu 18 13:30

Laser guide star adaptive optics at Lick Observatory

Gavel, Donald; Dillon, Daren; Kupke, Renate; Rudy, Alex

UC Observatories

This is an overview of the adaptive optics system at the Shane telescope (ShaneAO) along with R&D efforts on the technology and algorithms for that will advance AO into wider application for astronomy. Diffraction-limited imaging and spectroscopy from ground based large aperture telescopes will open up the opportunity for unprecedented science advancement. The AO challenges we are targeting are correction down to visible science wavelengths, which demands high-order wavefront correction, and dim object viewing over the whole sky, which demands bright artificial laser beacons. We discuss our ongoing development of MEMS based AO correction, woofer-tweeter architecture, wind-predictive wavefront control algorithms and a guide star laser tuned for optical pumping of the sodium layer. We present the latest on-sky results from the new AO system and present status and experimental plans for the optical pumping guide star laser.

Thu 18 13:50

The horizontal structure function of the sodium centroid in the upper mesosphere

Pfrommer, Thomas; Hickson, Paul; Holzlöhner, Ronald
European Southern Observatory

The upper mesosphere and lower thermosphere exhibits complex dynamics, driven by strong zonal winds and wind shear, gravity waves, tides, solar forcing, and global energy transport. Neutral sodium exists within an altitude range of about 85 to 100 km. Above this, sodium occurs only in ionized form while below it is bound mostly in hydroxyl molecules.

For astronomical applications using laser guide star adaptive optics (LGSAO), this neutral sodium is used to create bright guide stars, via resonant excitation. With larger telescope apertures such as for extremely large telescopes (ELTs), the guide star is no longer seen end-on but appears as an elongated streak on wavefront sensors. In such cases the internal structure of the sodium layer is partly resolved and density fluctuations cause the sodium centroid to vary.

In earlier work, we reported on sodium centroid temporal variations, however the mesospheric dynamics also produces spatial variations. Such fluctuations appear on horizontal scales ranging from meter-scale to hundreds of meters or more. This spans the scale of LGS asterisms, resulting in differential centroid variations and focus errors for LGSs in the asterism.

The tomographic reconstruction of atmospheric turbulence experiences uncertainties due to this effect and a direct decrease in adaptive optics (AO) performance is the consequence. These errors increase rapidly with telescope aperture diameter and are thus particularly important for ELT AO systems and their planned wide field AO systems.

In the past, we have presented data from the 6-m Large Zenith Telescope, which studied this phenomenon using a photon-counting system on a small (1 arc min diameter) field of view. Here, we will present updated results on measurements using a 5 arcmin wide-angle lidar receiver, based on new avalanche photodiode technology. We will report on the design, the installation and observations. Extensive effort has been taken to understand and reduce systematic effects. The measurement campaigns stretch over a period from summer 2014 to summer 2015.

Thu 18 14:10

The ESO Laser Test Bench

Holzlohner, Ronald; Lewis, Steffan; Bonaccini Calia, Domenico; Pfrommer, Thomas; Guidolin, Ivan
European Southern Observatory (ESO)

Note to the organizing committee: This contribution is somewhat technical and may be best suited for the Laser Workshop The PARLA sodium laser

guide star system has been reliably operating since Spring 2013 on UT4 of the VLT. In order to fully master the Raman fiber laser technology developed by ESO, which is also powering the 4LGSF laser systems, we are building a Laser Test Bench. This assembly includes a 20 watt inhouse built two-stage Raman fiber amplifier based on polarization maintaining fibers and a frequency doubling unit identical to that used in PARLA. The purpose of the Test Bench is to demonstrate full technical control over all components along the beam path, validate spare parts, train ESO staff and also to provide a laser source for future lab experiments. Our presentation will highlight technical aspects and lessons learned in fiber laser construction and reliability validation.

Thu 18 14:30

New concepts of modified Shack-Hartman for an elongation-free wavefront sensing of Na-Laser guide stars

Fusco, Thierry; Pueyo, Laurent; Correia, Carlos; Hugot, Emmanuel; Jahn, Wilfried; Neichel, Benoit; Ferrari, Marc
ONERA/LAM

Laser Guide Star (LGS) WaveFront Sensing (and especially multi LGS WFS) is a key aspect for the next generation of Wide Filed AO (WFAO) systems on Extremely Large Telescopes (ELT). One of the main limitation of Na-LGS, especially for 30-40 m class telescopes is the spot elongation induced by the geometrical projection of the width of the illuminated Na layer onto the WFS sub-apertures. In addition with an inevitable loss of performance due to the physical structure itself, this spot elongation leads to very complex and costly detectors in order to accommodate the large spot extension in each sub-aperture. Moreover, some trade-offs to minimize the number of pixels with either undersampling or truncation of the elongated SH-spots will induce non-linearity and bias effects which, through the propagation through the tomographic reconstruction process, will dramatically affect the final WFAO performance. We propose here innovative optical modifications of the SH-WFS concept which will significantly reduce the spot elongation before the physical detection by the CCD without any significant loss in flux nor performance. These approaches, based on free form optics and complex amplitude remapping technics should allow obtaining a WFS design with 16 to 25 less pixels than the current ones and thus making possible the use of already existing devices. It will also avoid the use of complex centroiding measurements making the whole WFS process simpler, faster and more robust.

Thu 19 15:30

Recent progress on astronomical PZT DM of the IOE,CAS

Guan, Chunlin; Zhang, Xiaojun; Fan, Xinlong; Zhou, Hong; Mou, Jinbo; Xue, Lixia; He, Gang; Wei, Kai; Xian, Hao; Rao, Changhui; Zhang, Yudong; Ling, Ning
The Institute of Optics and Electronics, The Chinese Academy of Sciences

Institute of Optics & Electronics (IOE), Chinese Academy of Sciences (CAS) has nearly 30 years experience on piezoelectric deformable mirror development since 1980s. Several different kinds of DMs have been used in many different systems. A brief history of piezoelectric DMs development in IOE and several recent achievements, and the main characters, performance and test results of the DMs for astronomy will be presented.1). Adaptive Secondary Mirror (ASM). A 73-element ASM prototype with 12 microns stroke for 1.8m telescope has been fabricated. It will be installed onto telescope with a compact AO system 2). High-order DM. DM with 913-actuator for broad temperature range has been fabricated and tested in laboratory 3).Novel small-spacing(3mm) DM. A novel 3mm-spacing DM with 1085-actuator has been fabricated and tested in laboratory.

Thu 19 15:50

Deformable mirrors development at ESO

Vernet, Elise
European Southern Observatory

Deformable mirrors are in use at Paranal and more will come in the next years. I will present how the needs in term of performance have evolved in the last decade. The laboratory results of the DSM will be outlined. I will describe ESO needs in term of performance for the future ELT M4 and what are the needs for the future ESO instruments adaptive optics systems. I will finish with the development plan we have established at for deformable mirror technologies in the next five years.

Thu 19 16:10

MEMS Deformable Mirrors for ELT Instrumentation

Bierden, Paul; Conelissen, Steven; Ryan, Peter; Lam, Charlie
Boston Micromachines Corp

Boston Micromachines continues to work on the design and fabrication of micro-electromechanical (MEMS) deformable mirrors for astronomical instrumentation. A driving factor for this development is the need for MEMS DM's in planned Adaptive Optics instruments on the Extremely Large Telescopes. Of key importance for the instruments are high-actuator counts, enhanced reliability, reduced surface finish, and minimized optical cross section. The mirrors the Boston Micromachines have been developing address each these

needs. The presentation will discuss the approaches taken and the results achieved including surface figure, electro mechanical performance, and actuator yield. Also, ongoing work for the reduction in optical footprint through the use of though wafer electrical interconnects and high density flex-cables will be discussed. Finally, future plans for mirror development and instrument insertion will be presented.

Thu 19 16:30

Emulating an extreme density AO loop with a Spatial Light Modulator and GPUs

Sevin, Arnaud; Bernard, Julien; Perret, Denis; Laine, Maxime; Gratadour, Damien; Gendron, Eric
LESIA / Observatoire de Paris

With Extremely Large Telescopes (ELT) under construction, studies on new strategies to control the waveform are becoming critical. To validate them in the laboratory, access to high-density deformable mirrors with thousands of actuators is now mandatory. Several technologies are envisioned for ELTs with various actuators geometries and shape. In this paper, we will present an innovative approach to simulate such deformable mirrors using Liquid Crystal On Silicon Spatial Light Modulator (LCOS-SLM). Such devices provide tens of thousands of degrees of freedom and can be driven at framerates up to about 120Hz. To meet this challenging goal, GPUs appear as a solution of choice, since they natively support efficient DVI output, the standard interface used with SLMs. Additionally, GPUs provide high compute performance that can be leveraged to implement a variety of shaping models at relatively high framerates. However, to emulate a complete AO loop, such system must be coupled to a high density wavefront sensor (WFS), of which the pixel data must be transferred efficiently to the GPU. We will present a lab demonstrator hosting multiple GPUs and an off-the-shelf FPGA development board on which an efficient GPU aware data transfer scheme has been implemented to provide low-latency transfer from the WFS camera to the GPUs. The latter are used to process the WFS pixel data, derive wavefront measurements, reconstruct the wavefront shape and project it to a given deformable mirror geometry simulated on the SLM. We will present the performance achieved for various system dimensioning from 5k and up to 20k actuators systems.

Thu 19 16:50

Deformable Mirror Designs for Extreme AO

Cavaco, Jeffrey; Bruno, Terry
Northrop Grumman/Xinetics

One of the science missions for the next generation of extremely large ground based telescopes (30-42m apertures) is the imaging and spectroscopy of exoplanets. To achieve that goal an Adaptive Optics (AO) subsystem with a

very large number of corrected modes is required. To provide contrast ratios in the range of 10-9 or better for a 42m telescope an AO system with 25,000 to 60,000 channels will be needed. This is approximately an order of magnitude beyond the current state of the art. Adaptive Optics Associates Xinetics has developed the Photonex Module Deformable Mirror (DM) technology specifically to address the needs of extreme AO for high contrast applications. A Photonex Module is a monolithic block of electrostrictive ceramic. Actuator spacings of 1mm or less have been achieved. The individual modules can be edge butted and bonded to achieve high actuator count. The largest DMs fabricated to date have 4096 actuators in a 64X64mm array. In this paper the engineering challenges in extending this technology by a factor of ten or more in actuator count will be discussed.

Thu 19 17:10

Recent developments on piezo-stack deformable mirrors for ELTs

Pagès, Hubert; Antonini, Tania; Aribi, Tarik; Aubry, Marie; Bastard, Arnaud; Beaufort, Emmanuel; Cousty, Raphaël; Dutey, Gabrielle; Groëninck, Denis; Krol, Hélène; Marchet, Nicolas; Moreau, Aurélien; Palomo, Richard; Sinquin, Jean-Christophe
CILAS

We present recent developments on piezo-stack deformable mirrors (DMs) performed during the last two years in collaboration with European Southern Observatory (ESO) and Thirty Meter Telescope (TMT). CILAS piezo-stack technology is relevant for very high order correction at high frequency, which is required for future Extremely Large Telescopes (ELTs). Such DMs are also well-adapted for relatively low operational temperature (down to -30C). We present recent experimental results related to the performances and the reliability of new piezo actuators. These actuators are especially relevant for high order DMs featuring several thousands of actuators. Modelling analysis and operational feedback of previous DMs allowed improving the design and the fabrication of CILAS piezo-stack DMs. Performances of CILAS technology already demonstrated on previous operational DMs combined with improvements on design and on new actuators lead to promising DMs for future needs. We focus on preliminary designs and modelling of next DMs for adaptive optics (AO) systems on ELTs: multi-conjugate DMs for Narrow Field InfraRed Adaptive Optics System (NFIRAOS) on TMT and DMs for Multi-conjugate Adaptive Optics RelaY (MAORY) on European Extremely Large Telescope (E-ELT).

Fri 20 09:00

The LINC-NIRVANA MCAO System: On Its Way to Sky

Herbst, Tom; Bertram, Thomas; Bizenberger, Peter; Briegel, Florian; Hofferbert, Ralph; Kuerster, Martin; Ragazzoni, Roberto; Weigelt, Gerd; Andreas, Eckart
MPIA

We present an update on LINC-NIRVANA (LN), an innovative, adaptive optics system and infrared imager for the Large Binocular Telescope (LBT). LN employs natural guide stars in a layer-oriented, multiple field-of-view, Multi-Conjugate Adaptvie Optics (MCAO) configuration to deliver a diffraction-limited field of view two arcminutes across, although the current camera field is considerably smaller. The instrument accepts light from both telescopes of the LBT and is designed for interferometric combination with off-axis fringe tracking. When implemented, this will allow panoramic Fizeau-mode imagery over much of the sky with the 10 mas spatial resolution corresponding to a 23-meter diameter telescope.

LINC-NIRVANA completed its final, instrument-level tests in Heidelberg in late spring, and is currently on its way to the summit of Mt. Graham. We report on these tests, as well as on laboratory and early telescope results from the High-Layer and Ground-Layer wavefront sensors, respectively. We discuss plans for re-integration, commissioning, and early science on sky, and present upgrade options to increase the astronomical productivity of the instrument.

Fri 20 09:20

The Visible channel of SHARK and the 4runner experiment

Pedichini, Fernando
INAF OAR

In the framework of the SHARK project the visible channel is a novel instrument exploiting the performances of the LBT AO at visible wavelengths. Together with the design study of this innovative instrument tailored for high frame rate imaging and coronagraphy the results of its pathfinder experiment the 4runner will be presented. These data acquired during the spring of 2015 show sharp psfs at 630 nm with resolution close approaching the LBT diffraction limit and Strehl factor of about 50%

Fri 20 09:40

On-sky operation, improvement and final performance of SAXO, the SPHERE extreme AO system – lesson learned for the future ELT instrumentation

Fusco, Thierry; Sauvage, Jean-François; Mouilelt, David; Beuzit, Jean-Luc; Dohlen, Kjetil; Petit, Cyril; Costille, Anne; Girard, Julien; Kasper, Marcus
ONERA/LAM

The aim of the Spectro-Polarimetric High-contrast Exoplanet Research (SPHERE) instrument is to detect extremely faint astronomical sources (i.e., giant extra-solar planets) in the vicinity of bright stars. The detection capabilities of an exoplanet hunter are largely controlled by its adaptive optics (AO) system. Better AO correction provides improved coronagraph extinction and fewer residual defects. The challenging SPHERE science goals require a very high-order performance AO system to feed a quasi-perfect flat wave front, corrected for atmospheric turbulence and internal defects, to the scientific instruments. In May 2014 SPHERE was installed on the third unit telescope (Melipal) of the Very Large Telescope (VLT) in Chile. After four months of extensive and comprehensive tests (for robustness, performance, and ease of use) the instrument is now available to the astronomical community for observations (until April 2015). The AO system on the instrument is known as the Sphere AO for eXoplanet Observation (SAXO) and is the 'heart' of the instrument, which 'beats' 1200 times per second to provide unprecedented image quality from a large ground-based telescope operating at optical/near-IR (NIR) wavelengths. As such, SPHERE presents tremendous potential for exoplanet discoveries. We present here the various improvements and optimisations implemented on SAXO and its environment during the four SPHERE commissioning runs in order to achieve the ultimate AO performance. In a few months we went from the first 75 % SR (Hband) max value, obtained in COM1, up to more than 90% routinely achieved now. Combining IRDIS scientific data and SAXO telemetry (high frame rate residual slopes and voltages, low frequency IR WFS pixels) obtained during the AIT period in Europe, the four commissioning runs as well as the Science Verification Period, a comprehensive view of SAXO performance is proposed. Ultimate performance, evolution with respect to the atmospheric conditions and to the GS flux are described and analysed. Comparisons with end-to-end simulations and predicted performance show that SAXO meets (and for some of them exceed) its initial requirements. Using the experience acquired during 4 commissioning and almost one year of operation we will draw the main lines of what could be a future eXtrem AO system on the ELT with the key points to study and the major progress to achieve if we want to be able to image telluric planet from the ground in a not too far future

Fri 20 10:00

Spatial and temporal unexpected wave-front perturbations on SPHERE instrument: a sightview of E-ELT limitations.

Sauvage, Jean-François; Fusco, Thierry; Guesalaga, Andres; Wizinowich, Peter; Neichel, Benoit; Dohlen, Kjetil
ONERA-DOTA

SPHERE is the VLT second generation planet hunter instrument. Installed since may 2014 on UT3, the system has been commissionned and verified for more than one year now and routinely delivers unprecedented images of star

surroundings, exoplanets and dust disks. The exceptionnal performance required for this kind of observation make the appointment: a repeatable Strehl ratio of 90% in H band, a rough contrast level of 10-5@0.5 arcsec, and reaches 10-6 at the same separation after differential imaging (SDI, ADI). The instrument also presents high contrast levels in the visible and an unprecedented 17 mas diffraction-limited resolution at 0.65 microns wavelength.

SAXO is the SPHERE XAO system, allowing the system to reach its final detectivity. Its high performance and therefore highly sensitive capacities turns a new eye on telescope environement. Even if XAO performance are reached as expected, some unexpected limitations are here described and discussed. Spatial limitation: wave-front aberrations have been identified, deviating from kolmogorov statistics, and therefore not easily seen and compensated for by the XAO system. The impact of this limitations results in a degraded performance in some turbulence conditions. Solutions are developped to propose a new operation procedure reducing this limitation. Temporal limitation: high amplitude vibrations on the low order modes have been issued, due to telescope environment and XAO behaviour. Again, a solution is developped and an assessment of its performance is dressed. The potential application of these solutions to E-ELT is proposed.

Fri 21 10:40

Dissecting Star-forming regions with the GeMS MCAO instrument: lessons learned for optimal post-processing of WFAO data

Bernard, Anaïs; Neichel, Benoit; Fusco, Thierry; Mugnier, Laurent; Samal, Manash; Andersen, Morten; Zavagno, Annie; Plana, Henri
Laboratoire d'Astrophysique de Marseille

The advent of a new generation of Wide Field AO (WFAO) systems marks the beginning of a new era in high spatial resolution imaging. By using multiple Laser Guide Stars, WFAO significantly increases the field of view of the AO-corrected images, and the fraction of the sky that can benefit from such correction. The newly commissioned Gemini South Multi-Conjugate Adaptive Optics System (GeMS) combined with the infrared camera GSAOI is delivering almost diffraction-limited images over a field of 2 arc-minutes across. In this paper, we first present recent observations of the young star-forming region N159W located in the Large Magellanic Cloud. We obtained deep JHKs images from the GeMS/GSAOI instrument and developed reduction tools, in order to photometrically study the properties of the stellar members of the cluster and to bring new elements to our understanding of the process of massive star formation. However, despite the excellent performance of the GeMS/GSAOI system, some variable residues are still limiting the correction quality over the field. In particular, GSAOI is severely affected by distortion that can strongly degrade the resolution when combining multiple frames and can reduce the sensitivity. The accuracy of the distortion correction of an instrument is critical for its use for high- precision astrometry and photometry.

In a second part of this paper, we investigate an optimal way to correct for the distortion following an inverse problem approach. The formalism as well as first simulation results will be presented.

Fri 21 11:00

Natural Guide Star Point Spread Function Reconstruction for the Keck Telescope Adaptive Optics System: Final Results.

Jolissaint, Laurent; Ragland, Sam; Wizinowich, Peter
HEIG-VD

The long project of NGS PSF reconstruction for the Keck telescope AO system has final reached its goal. We are now able to reconstruction the PSF from the loop telemetry data with a decent to excellent level of accuracy, depending on the conditions. In this paper, we present the theory we have developed for this system, and discuss all the numerous issues we had to face, and solve, issues that any other PSF-R project would most probably face as well. Comparisons of reconstructed and on-sky PSF profiles and metrics are shown limitations are discussed, as well as ideas for possible improvements.

Fri 21 11:20

Astrometry with MCAO at Gemini and ELTs

Fritz, Tobias
University of Virginia

MCAO increases the power of astrometry in sparse fields, especially in combination with ELTs. Today the MCAO system, GeMS together with its camera GSAOI, is in operation on Gemini South. We will present the Gemini Large (three year) Program "Probing the dark halo of the Milky Way with GeMS/GSAOI". In this program we target stars in the Sagittarius stream, five globular clusters and four dwarf galaxies. The aim is to measure absolute proper motions of sufficient accuracy to constrain the shape and depth of the Galactic potential. We present what we achieved with the data which we collected during the first year of observations. We show the astrometric stability on different timescales, the two hours of each observation, and up to several months between different GSAOI observations. We will employ HST/ACS observations and archival data to increase that timescale to five years. We also present what is currently limiting the centroiding precision. We therefore concentrate on the background galaxies, because their lower SNR is usually the limiting factor. Finally, we will discuss future possibilities with ELTs and MCAO. For example we will analyze what accuracy is necessary for solving the cusp versus core problem in dwarf galaxies.

Fri 22 13:30

OCAM2S: an integral shutter ultrafast and low noise wavefront sensor camera for laser guide stars adaptive optics systems

Gach, Jean-Luc; Feautrier, Philippe; Buey, Tristan; Rousset, Gérard; Gendron, Eric; Morris, Tim; Basden, Alastair; Myers, Richard; Vidal, Fabrice; Chemla, Fanny
First Light Imaging / LAM

To date, the OCAM2 system has demonstrated to be the fastest and lowest noise production ready wavefront sensor, achieving 2067 full frames per second with subelectron readout noise. This makes OCAM2 the ideal system for natural as well as continuous wave laser guide star wavefront sensing. In this paper we present the new gated version of OCAM2 named OCAM2-S, using E2V's CCD219 sensor with integral shutter. This new camera offers the same superb characteristics than OCAM2 both in terms of speed and readout noise but also offers a shutter function that makes the sensor only sensitive to light for very short periods, at will. We will report on gating time and extinction ratio performances of this new camera. This device opens new possibilities for Rayleigh pulsed lasers adaptive optics systems. With a shutter time constant well below 1 microsecond, this camera opens new solutions for pulsed sodium lasers with backscatter suppression or even spot elongation minimization for ELT LGS. This camera has been successfully used for the first time on the CANARY instrument on the William Herschel Telescope. The final phase of CANARY is a demonstrator of a single MOAO channel for the proposed EAGLE instrument on the future European ELT. We will report on-sky performance with this instrument.

Fri 22 13:50

Measuring Segment Piston with a Dispersed Fringe Sensor on the Giant Magellan Telescope

van Dam, Marcos; McLeod, Brian; Bouchez, Antonin
Flat Wavefronts

The Giant Magellan Telescope (GMT) consists of seven 8.4 m segments with a separation of about 0.4 m. A unique challenge for GMT lies in phasing these segments and, in particular, how to measure segment piston optically. Making segment piston measurements is relatively straight-forward when using diffraction-limited light, such as wavefront-corrected light at near infrared wavelengths. Unfortunately, we don't have that luxury, since all of that light is passed to the science instrument. Instead, we must use stars 6'-10' from the optical axis when guiding with laser guide stars. The segment piston measurement can be made in two different ways using subapertures that span adjacent segments with dispersed broadband light: by taking the Fourier phase of the dispersed fringes, or by measuring the angle of the fringes. We explore the

properties of the two approaches, discuss their relative advantages, and evaluate their performance using end-to-end simulations in YAO.

Fri 22 14:10

Calibrating the Non-Common Path Aberrations on the MOAO system RAVEN and first science results using RAVEN

Lamb, Masen; Andersen, David; Veran, Jean-Pierre; Correia, Carlos; Lardiere, Olivier
University of Victoria/NRC Herzberg

Contemporary AO systems, such as the Multi-Object Adaptive Optics system (MOAO) RAVEN currently associated with the Subaru Telescope, can suffer from significant Non-Common Path Aberrations (NCPA). These errors ultimately affect image quality and arise from optical path differences between the wavefront sensor (WFS) path and the science path. A typical correction of NCPA involves estimating the aberration phase and correcting the system with an offset on the deformable mirror (DM). We summarize two methods used to correct for NCPA on an experimental bench. We also successfully calibrate the NCPA on RAVEN using one of these methods. Finally, we report on some first science results with RAVEN, obtained after NCPA correction.

Fri 22 14:30

GMCAO for E-ELT: a feasibility study

Viotto, Valentina
INAF - OAPD

In this paper we discuss the feasibility and the performance assessment of a possible MCAO system for E-ELT, based on the novel concept of Global MCAO, which takes advantage of a very wide technical FoV to perform adaptive optics correction using only natural guide stars, with the aim to increase the sky coverage. The technique envisages the definition of Virtual-DMs, as tools for the global reconstruction. This investigation has been carried out during a feasibility study we performed for ESO, in which we combined computations, simulations and literature. The aim of this analysis is to identify and review the main parameters and the technical issues which would act as error sources in a real GMCAO system, evaluating their contribution to the overall performance. The study involves both issues related to the Pyramid WFS in general, and to the GMCAO case in particular, including the wavelength and FoV size selection, the number of guide stars and reconstructed Virtual-DMs, and actual components parameters.

Fri 22 14:50

Dark Wavefront Sensing

Ragazzoni, Roberto
INAF - Astronomical Observatory of Padova

We would like to describe the concepts and considerations that could leads to the development of a novel kind of classes of wavefront sensors in which the information is retrieved by the absence of photons rather than from their presence. In quantum optics the concept of "sensing" an object without actually having photons interacting with it is already known. The potentiality in terms of sensitivity has been already pointed out. Under the conditions that background counts are small enough (something that evolved with time with respect to a couple of decades ago, as today close to zero RON detectors are available, although sky bacground would continue to impose some limit to this approach) detecting "no photons" can be made with an SNR larger than detecting a "given amount of photons" in a number of practical situations. While we review the case of the coronograph coupled with a conventional WFS -a case already proposed in the literature- we explore variations on the theme of the Smartt wavefront sensor and in particular we explore the case of a double channel WFS where two images of the pupil are exploited and the flat wavefront is perceived as no photons on the pupils. The presence of a signal on subapertures on one pupil or the other indicates the sign of the wavefront perturbation. The system can be tuned in its sentitivity and -potentially- adjusted in order to have the two detectors working with close to zero flux on them while in closed loop operations. As the "signal" is coming from the condition of no photons we described these as "Dark" WFS.

Poster Session 1 Mon – AO instruments and pathfinders

Prototyping the GMT phasing camera with the Magellan AO system

Kopon, Derek; McLeod, Brian; van Dam, Marcos; Bouchez, Antonin; Close, Laird; Males, Jared
Harvard Smithsonian Center for Astrophysics

We present the design of a prototype dispersed fringe sensor that will measure wavefront phase differences in the I-band by looking at stars 6'-10' off-axis of a natural guide star corrected by the Magellan AO system. This prototype will validate the design of the GMT phasing edge sensors in realistic on-sky conditions.

Poster Session 1 Mon – AO instruments and pathfinders

Laboratory tests on HeNOS, the MCAO test bench for NFIRAOS

Rosensteiner, Matthias; Turri, Paolo; Andersen, David; Veran, Jean-Pierre; Herriot, Glen
NRC Herzberg Astronomy and Astrophysics

The MCAO laboratory test bench HeNOS is a scaled down version of NFIRAOS, the designated first light instrument for TMT. It includes four LGSs, three NGSs and two DMs, has several turbulence screens and can produce realistic spot elongation. Wit this setup the goal is to verify the simulation predicting the performance of NFIRAOS and demonstrate calibration procedures, NCPA correction and long term effects on the bench. We give an overview of the system, an update on the recent advances with respect to the characterization and an outlook on the next steps.

Poster Session 1 Mon – AO instruments and pathfinders

An Integrated MASS/DIMM Monitor Based on a Low-Noise CCD Detector

Guesalaga, Andres; Osborne, James; Sarazin, Marc; Neichel, Benoit; Perera, Saavidra; Wilson, Richard; Wizinowich, Peter
Pontificia Universidad Catolica de Chile

We propose a novel design for a turbulence profiler. Using a single detector, images of the pupil (scintillation, MASS function) and stars (image motion, DIMM function) are formed in the detector plane. Different processing strategies are evaluated, including spatial segmentation and Fourier analysis. The different approaches are tested via simulation and on-sky data from the Durham Stereo-SCIDAR monitor (for the scintillation information). Overall, the method outperforms the classical photomultiplier configuration, but it is

shown that the photon noise plays an important role in the accuracy of the method, imposing stringent requirements on the pixel size, which must be significantly smaller than the speckle size formed from turbulence close to the ground (Fresnel law for speckle size).

Poster Session 1 Mon – AO instruments and pathfinders

INO's Pyramidal Wavefront Sensor Demonstrator: first Closed-loop On-sky Operation at Mont-Mégantic Telescope and near-simultaneous comparison with a Shack-Hartmann WFS system

Martin, Olivier; Turbide, Simon; Lagacé, François; Lévesque, Frédéric; Anctil, Geneviève; Chateauneuf, François; Brousseau, Denis; Deschênes, William; Thibault, Simon; Véran, Jean-Pierre
Institut National d'Optique

Wavefront sensing is one of the key elements of an Adaptive Optics System. As an alternative to the commonly encountered, commercially available Shack-Hartmann WFS (SH-WFS), the more recent Pyramid-WFS (P-WFS) is proving to be a very attractive technology, thanks to its high-sensitivity and robustness against aliasing. At INO, center for applied research in optics and technology transfer in Quebec City, Canada, we have developed a P-WFS prototype with compactness, flexibility and robustness in mind, so that the WFS module could be characterized both on a laboratory test-bed and in actual on-sky conditions on a telescope AO facility. Our P-WFS is currently installed on experimental AO system developed by Laval University in Quebec for the 1.6-m Mont-Mégantic telescope, which also includes a commercial high-speed SH-WFS. The architecture is such that both WFSs can take measurements simultaneously, and either one can be used to drive the deformable mirror. Here we present the latest developments of the INO P-WFS module that integrates a fast piezo-electric modulation mirror and high-sensitivity EMCCD camera, then the first experimental results of on-sky close-loop operation in parallel with a commercial SH-WFS. The on-sky direct comparison between the well-established SH-WFS and the more recent, less well-understood P-WFS will provide unique and invaluable insights for guiding the development of AO systems for Extremely Large Telescopes, including NFIRAOS, the first-light AO system for the TMT, which will use a P-WFS as high-order natural guide-star WFS.

Poster Session 1 Mon – AO instruments and pathfinders

Progress with the 4m high-order AO demonstrator, CHOUGH

Bharmal, Nazim; Hölck, Daniel; Myers, Richard; Morris, Timothy; Dubbledam, Marc; Basden, Alastair; Younger, Edward
University of Durham

We report the progress of the Canary High-Order Upgrade (CHOUGH) addition to the CANARY AO experiment at the 4.2m WHT telescope, La Palma. While CANARY has been developed to investigate several tomographic configurations relevant to the E-ELT, it also has the ability to host guest AO instruments and provide them with relevant infrastructure. CHOUGH is a self-contained experimental AO system which relies on an external feed of light to obtain a Strehl >=0.5 in the visible. Within CANARY, CHOUGH picks off light after a 240-actuator deformable mirror and delivers the on-axis beam into the internal relay which feeds various sub-systems. These are: pick-off optics, ADC, 1k-actuator DM, spatially-filtered SH WFS, calibration interferometer, and narrow-field imaging camera. As these are mounted on a separate breadboard, the components are integrated and transportable as a unit distinct from CANARY. With another source, CHOUGH can be re-used which enables additional compatibility with DRAGON, the DU laboratory test-bench that emulates the WHT. In this paper the progress on the design, procurement, and performance of the CHOUGH sub-systems and the experiment as a whole is given. Attention is given to the algorithms that will be used and the control methods that will be utilized on-sky. The modular nature of the design leads to potential upgrade paths and a brief discussion is made of new directions of on-sky research that could be carried out with replacement sub-systems and new instrumentation.

Poster Session 1 Mon – AO instruments and pathfinders

The error budget verification of HeNOS, the NFIRAOS test bench

Turri, Paolo; Andersen, David; Véran, Jean-Pierre; Rosensteiner, Matthias; Herriot, Glen
University of Victoria

The Herzberg NFIRAOS Optical Simulator (HeNOS) is a test bench built at NRC Herzberg in support of NFIRAOS, the multi-conjugate adaptive optics module on TMT. It includes two ALPAO deformable mirrors, four laser guide stars, a dense field of natural guide stars, a single Shack–Hartmann wavefront sensor that simultaneously senses the four LGS and three rotating phase screens to simulate the atmospheric turbulence. The purpose of the bench is to test algorithms to be used in NFIRAOS and to verify the performance of the predicted correction. Here we present the error budget analysis and verification for the single-conjugate mode, a necessary step to verify the system behaviour before starting MCAO operations.

Poster Session 1 Mon – Astronomy with AO

Confirming Dual Active Galactic Nuclei in Galaxy Mergers

McGurk, Rosalie
Max Planck Institute for Astronomy

We use AO imaging with spatially resolved spectroscopy and X-ray observations to confirm if galaxy pairs with double-peaked [OIII] contain two AGNs. This will allow us to better constrain the statistics of dual AGNs and to predict how AO with ELTs will improve our detections of dual AGNs.

Poster Session 1 Mon – Astronomy with AO

LGS Observations of Asteroid (87) Sylvia and its Moon Romulus with the SOR 3.5 m Telescope

Drummond, Jack
AFRL

First detected by the Starfire's 3.5 m telescope with adaptive optics using a laser guide star on 23 March, 2015, the 30 km diameter moon (V=17.5) around the 275 km diameter main belt asteroid (87) Sylvia (V=12.5) was subsequently followed on five more nights from March through May. Discovered in 2001 at Keck, Romulus has been well-observed since by the 8 m VLT and Gemini telescopes and the 10 m Keck, but the 3.5 m SOR telescope is the smallest ever to image any asteroid's moon. Although the mass and density of Sylvia can be calculated from the 3.6 day orbit derived with the SOR data alone, combining the SOR observations with previous observations greatly reduces the uncertainties of all parameters. The painstaking observations and image analysis will be recounted.

Poster Session 1 Mon – Astronomy with AO

PSF reconstruction for AO photometry and astrometry

Ascenso, Joana; Neichel, Benoit; Silva, Manuel; Garcia, Paulo; Fusco, Thierry
CENTRA SIM / Faculdade de Engenharia da Universidade do Porto

Existing tools to extract accurate photometry and astrometry from adaptive-optics images currently hinge on the presence of bright, isolated stars in the image from which to create a reliable model of the peculiar AO point spread function. For many science cases these stars are often missing, leaving the task of PSF-fitting very poorly constrained. I will review the existing methods for PSF photometry, their limitations for AO-assisted images, and present the results of a systematic study with synthetic (GL)AO data to assess the improvements of adding information about the PSF from the AO telemetry and PSF reconstruction algorithms to the PSF-fitting post-processing tools.

Poster Session 1 Mon – Astronomy with AO

Estimating Outer-Scale Distribution (L0(h)) Using the GeMS Profiler

Guesalaga, Andres; Neichel, Benoit; Fusco, Thierry; Valenzuela, Javier; Oberti, Sylvain; Masciadri, Elena; Corrreia, Carlos; Sauvage, Jean Francois
Pontificia Universidad Catolica de Chile

We analyze the altitude distribution of the turbulence outer scale (L0(h)) at Cerro Pachón from Gemini South MCAO (GeMS) loop data. GeMS turbulence profiler is fed with telemetry from their 5 WFSs and from the voltages applied to the deformable mirrors, providing estimations of r0, Cn2(h), wind speed/direction for every layer, isoplanatic angle and the outer scale distribution L0(h). It is shown that this last parameter ranges from less than 1 meter at the ground up to values above 25m (the telescope cannot detect differences above this value). The technique is based on auto and cross correlations of the pseudo-open-loop slopes that allow to disentangle the multiple constituents of the global L0. Special consideration is given to the dome seeing, a major player in the construction of the outer scale profile. Finally, the impact that this information could have on ELTs system definition and design, performance estimation and PSF reconstruction is also addressed.

Poster Session 1 Mon – Astronomy with AO

Full AO-loop study with an optmized Pyramid-WFS: toward the first SCAO systems for the E-ELT

Bond, Charlotte; El Hadi, Kacem; Sauvage, Jean-François; Fusco, Thierry; Coreia, Carlos; Fauvarque, Olivier; Neichel, Benoit
Laboratoire d'Astrophysique de Marseille

Within the E-ELT framework studies, the Laboratoire d'Astrophysique de Marseille (LAM) is highly involved in the preparation of the SCAO system of HARMONI, the E-ELT's 1st light IFU. The current baseline WFS for this AO system is a Pyramid WFS using a high speed and sensitive OCAM2 camera (FR of 1.5 kHz and RON close to zero).

This paper presents the complete laboratory characterization of an AO system based on Pyramid-WFS. We combine this hands-on approach with theoretical and simulation modeling of Pyramid behavior with respect to the choice of observables (numerical combination of standard Pyramid signals). From this know-how, we propose in this paper early considerations for E-ELT first instrumentation about upgraded Pyramid-WFS based AO system (NCPA compensation, Optimal modal gains).

Poster Session 1 Mon – Astronomy with AO

The role of high angular resolution in solar system studies

Conrad, Albert
LBTO

High angular resolution from large optical/infrared (0.3 – 5 mm) telescopes on the Earth's surface stands as a key technology for solar system studies. As we go beyond 8-10 meter apertures, what new solar system science is enabled? We first provide an overview of the science cases enabled by the next generation of high angular resolution for Mars, within the asteroid population, within the Jovian and Saturnian systems, and beyond to the ice giants and the TNO population. As a case study, we present first ever resolved images of an Io eruption site taken from the ground images of Io's Loki Patera taken with Fizeau imaging at the 22.8 meter LBT [Conrad et al., AJ, 2015]

Poster Session 1 Mon – Astronomy with AO

Science with SOAR AO

Tokovinin, Andrey
NOAO

Results and experience from 2.5yr of operation of the SAM instrument with Rayleigh LGS.

Poster Session 1 Mon – Current designs for ELT AO systems

Leveraging high performance computing techniques for adaptive optics

Gratadour, Damien; Ltaief, Hatem
LESIA - Observatoire de Paris

High Performance Computing (HPC) has become a driving technology for large scientific instruments such as the European Extremely Large Telescope (E-ELT). Designing, optimizing, building and eventually operating and exploiting some critical telescope sub-systems, such as the Adaptive Optics (AO) module, require access to HPC resources from early simulations for system design to the real-time control of the optics for routine operations. Additionally, efficient real-time visualization tools will be required by the operator to control such large scale AO system and to diagnose any operational issues. To that end, our team inat LESIA, Observatoire de Paris has developed a strong collaboration with the Extreme Computing Research Center (ECRC) at KAUST. Bridging HPC and astronomical instrumentation has led us to propose innovative and efficient solutions to the most challenging simulation problems in the context of the instruments design to find the proper trade-off between cost and achievable scientific performance. We are now leading a pilot study, drawing the lines for a longer term research program focusing on efficient pipelined data processing and visualization strategies for AO. We will present the results obtained so far and how this research could be extended to develop new efficient strategies for the instrument operations.

Poster Session 1 Mon – Current designs for ELT AO systems

TOPTICA's Robust Sodium Guide Star Laser

Enderlein, Martin; Schwerdt, Robin; Ernstberger, Bernhard; Kaenders, Wilhelm G.; Wei, Daoping; Karpov, Vladimir; Clements, Wallace R. L.
TOPTICA Photonics AG

TOPTICA Photonics AG and partner MPB Communications Inc. have finalized a next-generation sodium guide star laser system development under a development contract with the European Southern Observatory (ESO) and W. M. Keck Observatory. The laser is based on a narrow-band diode laser, polarization-maintaining Raman fiber amplifier (RFA) technology and resonant second-harmonic generation (SHG). Using patented technology for the suppression of stimulated Brillouin scattering in the RFA, and SHG efficiencies $> 80\%$, it emits > 22W of narrow-linewidth (5MHz) continuous-wave radiation at sodium resonance. Due to the SHG resonator acting as spatial mode filter and polarizer, the output is diffraction-limited with RMS wavefront error $< 1/25\,\lambda$ and a polarization extinction ratio > 20 dB. Integrated is a repumping scheme generating a sodium D2b sideband for boosting guide star return flux. The sideband generation being based on sum-frequency generation in the patented doubly-resonant SHG resonator, no additional optical wave front distortions are introduced. A spectral detuning option allows for measuring and subtracting the Rayleigh scattering background. Apart from this unique optical design, a major effort has been dedicated to integrating all optical components into a ruggedized and reliable system, providing a maximum of convenience for telescope operators. With a cooling-water flow of less than 5l/min and an overall power consumption of only 700W, the infrastructure demands on site are minimal. Each system is built in a modular way, based on the concept of line-replaceable units (LRU). The system software as well as an intuitive service GUI featuring fully automated health check routines allow for remote control (via Ethernet) and error tracking down to at least the LRU level. Thus, in case of a failure, the faulty LRU can be identified and replaced within four hours. With the remote pumping option, the small 80-kg laser head consisting of RFA and second-harmonic generation stage can be separated by up to 27 m from the larger (600-kg) electronics cabinet. This minimizes the effort for integration with existing telescope infrastructure. The end result is a system designed throughout to provide convenient, turnkey operation in remote and harsh locations such as the Chilean Atacama desert or the summits of Hawaii and can be complemented by customized service contracts. Until mid-2015, five laser systems have been delivered and each undergone long-term testing by the customer. We will report on the first telescope commissioning and present a comparison of characteristics and long-term test results of the first batch of systems, demonstrating the reproducibility of excellent optical characteristics and the robustness of the design hoping to establish this as a de facto standard.

Poster Session 1 Mon – Current designs for ELT AO systems

NFIRAOS Off-Axis Parabola Mounts and OAP

Testbench Design

Lavigne, Jean-Francois; Bibeau, Louis-Philippe; Larouche, Martin; Thériault, Guillaume; Atwood, Jenny; W. G. Byrnes, Peter; Hill, Alexis; Herriot, Glen; Véran, Jean-Pierre
ABB

The Narrow Field Infrared Adaptive Optics System (NFIRAOS) is the Thirty Meter Telescope (TMT) facility adaptive optics system. It will provide a diffraction limited point-spread function[s] over a field-of-view diameter of 17 to 30 arcsec. It will be mounted on a Nasmyth platform and will have three ports to interface with instruments. It will operate at -30°C to remain below 15% of the telescope and sky background emissivity. NFIRAOS is a Multi-conjugate AO system that will correct the turbulence with deformable mirrors conjugated to the ground (DM0) and to 11 km (DM11). To do so, it will use six off-axis parabolas with diameters of 660 mm (OAPs) to collimate and reimage the telescope focal plane. ABB is under contract with NRC-Herzberg to bring the design to a final design review level and to develop a testbench to test the OAPs in their mount at ambient, 0°C and -30°C. The OAP specifications, the selected mount design and the test strategy are presented.

Poster Session 1 Mon – Current designs for ELT AO systems

WFS sensitivity to segmented pupil : "characterization of PTT mirror with three different sensors: HASO, Pyramid and ZELDA"

Galland, Nicolas; El Hadi, Kacem; Dohlen, Kjetil; Sauvage, Jean-François; Fusco, Thierry; Marchis, Franck; N'Diaye, Mamadou
Institut d'Optique Graduate School

The Laboratoire d'Astrophysique de Marseille (LAM) is developing several R&D activities for E-ELT instrumentation, in particular, different WFS concepts are investigated (Pyramid, ZELDA, a Zernike phase mask sensor, Phase diversity or still NL Curvature) and an ESO-EELT M1 mirror segment (1.5 m) has been demonstrated. Segmented mirrors are not only the solution for the problem of ELTs monolithic size but also for other questions related to fabrication, optics replacement and transport. And, they are widely used today for other applications: fiber coupling, LGS beam shapping, etc. Their only problem is how to assure the cophasing of segments to take advantage of the full optimum size. Using three different WFS (HASO, Pyramid and ZELDA) with a PTT mirror from Iris AO, the present work aims to study their sensitivity to a segmented pupil: segment phasing, stability, saturation, flat, or still the addressing mode are then performed and compared.

Poster Session 1 Mon – Current designs for ELT AO systems

NFIRAOS Test Cameras Sub-System Design

Lavigne, Jean-Francois; Gagné, Martin; Larouche, Martin; Thériault, Guillaume; Atwood, Jenny; W. G. Byrnes, Peter; Hill, Alexis; Herriot, Glen; Véran, Jean-Pierre
ABB

The Narrow Field Infrared Adaptive Optics System (NFIRAOS) is the Thirty Meter Telescope (TMT) facility adaptive optics system. It will provide a diffraction limited point-spread function[s] over a field-of-view diameter of 17 to 30 arcsec. It will be mounted on a Nasmyth platform and will have three ports to interface with instruments. It will operate at -30°C to remain below 15% of the telescope and sky emissivity. NFIRAOS will require a test camera sub-system installed at one of its instrument port at different steps of its integration, test and early operation. This sub-system dubbed NSEN will be composed of a high-resolution wavefront sensor, and an acquisition system composed of a wide field camera and of a diffraction limited camera. ABB has been awarded the contract by NRC-Herzberg to bring NSEN to a final design level. The sub-system design, its major challenges and its test strategy will be presented.

Poster Session 1 Mon – Current designs for ELT AO systems

A low-latency link between the nodes of a heterogeneous real-time computing platform for adaptive optics.

Perret, Denis; Lainé, Maxime; Gratadour, Damien; Sevin, Arnaud; Le Ruyet, Bertrand
LESIA CNRS Observatoire de Paris-Meudon

As the diameter of the telescope mirror increases, adaptive optics becomes a key facility to achieve the scientific objectives, and it brings an unprecedented complexity, specially in its most advanced forms, i.e. MOAO, LTAO and GLAO. A servo-loop involving several deformable mirrors with thousands of actuators each, at frequencies as high as several kHz requires highly parallelized computations, and data paths offering high bandwidth and low latencies. Beside this, advanced ways of publishing data across the system, less constrained by latency, are needed for performance monitoring and telemetry. In this paper, we present a low-latency link between the nodes of a heterogeneous real-time computing platform for adaptive optics. In particular, we describe a zero-copy scheme involving a wavefront sensor using a standard communication protocol such as GigE Vision or Camera Link, an FPGA-based frame-grabber, a GPU (Graphics Processing Unit) and a deformable mirror controller, avoiding the bottleneck of data transfers to/from host RAM and CPU-GPU processes. We show that the results we get are compatible with the size of the problem in ELT's AO instruments. Then we propose a

method of latency and bandwidth monitoring in which the FPGA performs the measurements and publishes them on a independent network. Finally, we introduce a innovative data-stream oriented development environment for FPGAs, proposed in collaboration with an industrial partner, that brings together the determinism intrinsically offered by programmable logic devices and the flexibility of a high-level programming language, and we evaluate its ability to address the technical challenge brought by the next generation AO instruments.

Poster Session 1 Mon – Current designs for ELT AO systems

Creating the Right Atmosphere: An Autoregressive Technique For Making Simulated Atmospheres Match Telemetry

Srinath, Srikar; Poyneer, Lisa; Rudy, Alexander; Ammons, S. Mark
UCSC

We present an autoregressive (AR) method for the generation and time evolution of atmospheric phase screens that are tailored to match telemetry gathered by Adaptive Optics (AO) systems such as the Gemini Planet Imager (Gemini-S telescope) and ShaneAO (Shane 3-meter, Lick Observatory). Closed-loop telemetry from the wavefront sensors of these Adaptive Optics (AO) systems is analyzed using a Fourier wind identification technique to extract wind layers, and the wind vector in each layer. Wind vector information is fed into the AR atmosphere generator which can modify the power in individual Fourier modes and whose computational efficiency enables more realistic simulations of arbitrary length. Fidelity to real-world conditions is verified through spatial and temporal PSDs and the comparison of extracted parameters such as structure functions and coherence length. The utility of this method for simulating optical pipelines of extremely large telescopes is explored.

Poster Session 1 Mon – Laser guide star systems

ARGOS: Set up and performance of the hologram based calibration source

Peter, Diethard; Schwab, Christian; Bonaglia, Marco
MPIA

ARGOS is the ground layer adaptive optics system being installed at the LBT. On each side of the LBT the system uses three green (532 nm) lasers off axis by 2 arcmin per side of the LBT, as light sources on sky.To be able to test and calibrate the system during daytime a calibration unit, which is mimicking the laser constellation on sky, is required. As the LBT has a Gregorian design the prime focus is an ideal place for the Calibration Unit. However, because of the fast F/1 optics the concept of this Calibration Unit

faces several challenges:The unit has to be small, temperature stable, and must produce three F/1 beams with strong Coma on each of the three beams. In addition it has to produce a diffraction limited on-axis beam. The unit is realized with an optical design using lenses with short focal lengths and a hologram. We will describe how we overcame the challenges either by design or by appropriate alignment procedures. The quality of the beams as measured on the ARGOS wave front sensor, including the side effects of using a computer generated hologram, will be reported.

Poster Session 1 Mon – Laser guide star systems

Optimal mirror deformation for multi conjugate adaptive optics systems

Raffetseder, Stefan; Ramlau, Ronny; Yudytskiy, Mykhaylo; Obereder, Andreas
Johann Radon Institute for Computational and Applied Mathematics (RICAM)

Multi Conjugate Adaptive Optics systems (MCAO) will be installed at all future Extremely Large Telescopes (ELT). They compensate in real- time for the optical distortions caused by atmospheric turbulence over a wide field of view. MCAO is based on a reconstruction of the atmospheric turbulence profile followed by the optimal fitting of multiple deformable mirrors (DMs). We present a novel method to treat the optimal mirror deformation problem for MCAO. Contrary to the standard approach, we apply quadra- ture rules to obtain a more sophisticated discretization scheme. Using numerical simulations in the context of the European Extremely Large Telescope (E-ELT) we show that our method leads to a significant im- provement in the reconstruction quality over the standard approach and allows to reduce the computational cost.

Poster Session 1 Mon – Laser guide star systems

ARGOS: Performance of the vibration compensation for the laser launch path

Peter, Diethard; Kulas, Martin; Gaessler, Wolfgang
MPIA

Present and future adaptive optics systems aim for the correction of the atmospheric turbulence over a large field of view combined with large sky coverage. To achieve this goal the telescope is equipped with multiple laser beacons. Vibrations on the laser launch-path can spoil the performance of such an AO-system. To overcome this problem for the ARGOS laser system at the LBT we installed an accelerometer based feed forward system to compensate the effect of the vibrations. The goal is to reduce the residual RMS jitter on sky by a factor of 5 or more. We will present results of simulations based on real acceleration data from the telescope as well as on sky results.

Poster Session 1 Mon – System control & algorithms

The use of CPU, GPUs and FPGAs in real time control of adaptive optics systems

Rodríguez Ramos, Luis Fernando; Diaz Garcia, Jose Javier; Fernández Valdivia, Juan Jose; Rodriguez Ramos, José Manuel
Institute of Astrophysics of the Canary Islands

Conventional CPUs, GPUs and even FPGAs has been successfully used in real time control for AO at IAC for a number of projects (EDIFISE, AOLI, AOconFPGA, GTCAO). A comparative description will me made on the talk, pointing out advantages and drawbacks of each solution, according to experience.

Poster Session 1 Mon – System control & algorithms

Local Ensemble Transform Kalman Filter: a fast non-stationary control law for SCAO and XAO systems on ELTs.

Gray, Morgan; Petit, Cyril; Correia, Carlos; Neichel, Benoit; Rodionov, Sergey; Bocquet, Marc; Bertino, Laurent; Ferrari, Marc; Fusco, Thierry
Laboratoire d'Astrophysique de Marseille (LAM)

We have recently proposed a new algorithm for Adaptive Optics (AO) systems control, based on the Linear Quadratic Gaussian (LQG) approach and the Ensemble Transform Kalman Filter (ETKF), giving the ability to calculate the Kalman gain at each update step and therefore allowing to deal with non-stationary behavior of the atmospheric turbulence (and other disturbances). In order to reduce dramatically the computation burden in the case of an Extremely Large Telescope (ELT), we have then derived a version with localizations by domain decomposition, which is called the "Local ETKF": this is a spatially distributed estimation leading to a hierarchical control scheme. The data assimilation is split into various local domains on the pupil of the telescope and all calculations of the update step on each domain are performed independently. This data assimilation scheme enables massive parallel computation of markedly less data during the update stage. Therefore, on each domain, the numerical complexity becomes linear over n_{dom} and p_{dom} (the dimensions of local estimate and local observation vectors). This intrinsic parallel algorithm adapts the LQG approach with the Kalman Filter (KF) to large scale systems (ELTs) dealing with a non-stationary turbulence. Each reconstructed wavefront on each partition of the whole pupil will have an unknown piston mode. We have thus implemented a first fast and simple least squares method by using estimates given by crossed partitions, which enables to cancel these differential pistons and to reach the optimal performance given by the KF. We will present the mathematical formulation, first simulation results for a zonal Single Conjugate AO system in order to demonstrate the potential of this new approach for an AO control law on ELTs. We

will also discuss the perspectives for eXtreme AO systems like SPHERE and give in this case the performance compared to the usual LQG based method. Finally, we will briefly outline some possible extensions on tomographic AO systems.

Poster Session 1 Mon – System control & algorithms

Optimal Wavefront Correction for large-scale Adaptive Optics Systems using a Spline based Deformable Mirror Model

Brunner, Elisabeth; De Visser, Cornelis; Verhaegen, Michel
Delft University of Technology

For large scale AO systems in future ELTs, classical methods used to compute the deformable mirror (DM) actuator commands from wavefront sensor (WFS) measurements reach their limitations in computational complexity even if implemented on parallel hardware. Alternative approaches allowing wavefront reconstruction with linear complexity generally need a second projection step since only certain shapes limited by mirror surface and actuator structure can be produced. We present a one step version of SABRE (Spline based Aberration Reconstruction). The original SABRE locally models the wavefront with B-spline functions on triangular partitions defined on the SH subaperture array. The solution of the equation governing the dynamics of the DM, which can be of the type of a Poisson partial differential equation (PDE), are locally approximated with a second B-spline model weighted by time dependent B-coefficients. The system is reduced to a finite set of ordinary differential equations (ODEs) describing the solution to the PDE along with a set of linear constraints imposing smoothness across the domain. A projection between the two spline models gives a direct relation between SH slopes and the B-coefficients describing the DM dynamics whilst preserving the local nature of the solution which can be computed in a distributed fashion.

Poster Session 1 Mon – System control & algorithms

Handling the saturation of deformable mirrors in astronomical adaptive optics: a constrained Receding Horizon Control approach

Correia, Carlos; Konnik, Mikhail; De Dona, Jose; Gray, Morgan; Fusco, Thierry
LAM

Most modern astronomical adaptive optics (AO) systems use a Proportional-Integrating (PI) control for its simplicity, ease of implementation and acceptable performance. Recently, the Linear Quadratic Gaussian (LQG) control approach has been shown to provide superior performance compared to PI control, both in numerical simulations and in on-sky tests. These control

approaches have one drawback: inability to optimally handle saturation of deformable mirrors (DM).

We consider another control approach, namely Receding Horizon Control (RHC). The RHC formulates the AO control problem as an online optimisation problem: RHC makes a plan into the future and computes the control inputs that are optimal within DM constraints N steps ahead, executes the first control move, then shifts the prediction horizon one step further and replans. That is, unlike LQG, the RHC technique provides control signals for a DM that are optimal within the prescribed stroke limitations. In the unconstrained case (with no saturation), the RHC will provide the same matrix of gains and performance as LQG (with less numerical problems due to robust optimisation algorithms).

The RHC formulation of AO control allows to reduce the requirements for the DM stroke while preserving as much of the turbulence rejection performance as possible, thanks to online constrained optimisation. It is also possible within the RHC framework to efficiently deal with the problem of stuck actuators (accounting for the stuck or free-floating actuators in the constraints matrices).

The results of end-to-end numerical simulations provide the comparison of LQG and RHC performance for a typical AO system. Currently, we present the results for a small AO system (10x10 actuators DM), however the RHC approach can be efficiently paralleled and is not restricted to small systems. The possibility of using the RHC approach for Tip-Tilt control in woofer-tweeter mode is also discussed.

Poster Session 1 Mon – System control & algorithms

Applying Artificial Neural Networks to some of the Challenges identified in Adaptive Optics for ELTs

Guzman, Dani; Osborn, James; De Cos, Francisco Javier; Basden, Alastair; Dubost, Nicolas; Berdja, Amokrane; Mello, Alexandre; Kanaan, Antonio; Gonzalez, Carlos

Pontificia Universidad Catolica de Chile

Since 2010, we have reported on applying Artificial Neural Networks (ANN) to a number of challenges in Adaptive Optics for ELTs. Originally in the context of Multi-Object Adaptive Optics (MOAO), we developed and presented ANN-based models to command Deformable Mirrors in open-loop, reconstruct wavefronts tomographically and compute centroids in Shack-Hartmann wavefront sensors with elongated spots. We have continued perfecting and improving these techniques, trying to tackle some of their limitations and constraints. We present an overview of the techniques we have developed thus far, with emphasis in reporting our current research in this field as well as the latest developments in ANNs using Graphics Processing Units (GPU), which are useful to apply these techniques to very large problems.

Poster Session 1 Mon – System control & algorithms

Effects of reconstruction layer profiles on atmospheric tomography in E-ELT AO systems

Auzinger, Günter; Le Louarn, Miska; Obereder, Andreas; Saxenhuber, Daniela
Johannes Kepler University

In this poster, we will present new compression algorithms to determine optimal layer heights and turbulence weights for the tomographic reconstruction in wide field AO systems. Among other approaches, a new compression method based on discrete optimization of collecting atmospheric layers to subgroups is discussed. Furthermore, studies of the influence of layer heights and cn2-profiles on the reconstruction quality for different reconstruction algorithms and atmospheric profiles will be shown. Our comparison suggests that reconstructions on fewer atmospheric layers yield comparable quality with lower computational effort, if an appropriate compression algorithm is used. The numerical results were obtained on the ESO end-to-end simulation tool OCTOPUS.

Poster Session 1 Mon – System control & algorithms

Filtering the interaction matrix in an adaptive optics system

Zhang, Xianyu; Gorceix, Nicolas; Goode, Philip
Large Binocular Telescope Observatory

We present a method to reduce the noise in the interaction matrix by calibration of the adaptive optics system. The method utilizes a matching between the actuators on the deformable mirror and the sub-apertures on the wavefront sensor to define a filter matrix. Then, the filter matrix is applied to the sparse interaction matrix to remove the elements that should be zero. This method is useful for high-order systems and/or noise calibration issues. The latter case is illustrated in the problem of on-sky calibration of an adaptive secondary system on a telescope, with a natural guide star, in which the noise in the interaction matrix is increased by the effects of the turbulent atmosphere.

Poster Session 1 Mon – System control & algorithms

COMPASS : a highly efficient numerical development platform for AO

Gratadour, Damien; Puech, Mathieu; Vérinaud, Christophe; Pierre, Kestener; Gray, Morgan; Sevin, Arnaud; Ferreira, Florian; Perret, Denis; Brulé, Julien; Clénet, Yann; Gendron, Eric; Lainé, Maxime; Rousset, Gérard;

Hammer, François; Yang, Yanbin; Carlotti, Alexis; Benoit, Epinat; Gautrais, Thomas; Benoit, Neichel; Sergey, Rodionov; Marc, Ferrari; Petit, Cyril
LESIA - Observatoire de Paris

The COMputing Platform for Adaptive optics SyStems (COMPASS) is a french initiative aiming at enabling a unified numerical development platform for AO. Based on a total integration of software with hardware and relying on a high performance heterogeneous architecture, the COMPASS platform is used to perform end-to-end simulations of the AO system behavior and performance as well as to design and test new concepts for the Real-Time Computer (RTC), a core component of any AO system. It provides critical decision tools for optimizing the opto-mechanical design of the instruments that are under design studies for the E-ELT. The platform relies on a scalable heterogeneous architecture, based on GPUs as accelerators and using commodity components, able to provide sufficient computing power at a reasonable cost. Additionally, one of the key topics of this project is the development of a prototype for a high speed, low latency, image acquisition and processing system dedicated to AO systems and fully integrated in the simulation framework. This project federates the efforts of several french teams with complementary expertise from high performance computing to adaptive optics systems to astrophysics around a high performance development platform. After two years of development, the COMPASS platform has reached maturity and is now used to simulate different AO flavors (SCAO, MCAO, MOAO) at the E-ELT scale. It also provides the ideal testbed for new control strategies for AO, both using the simulation framework and on a lab demonstrator featuring low latency data acquisition interfaces to cameras. We will present the available features, the achieved performance and long term plans for this platform.

Poster Session 1 Mon – System control & algorithms

A Feedback Control Perspective to the Optimal Control of the Spatial Dynamics in Adaptive Optics for Large Scale Telescopes

Verhaegen, Michel; Trajanovski, Stojan
TU Delft

For large scale AO systems in future ELTs, classical methods used to control the spatial dynamics of the wavefront aberrations induced by turbulence aim at minimising the covariance matrix of the wavefront aberrations. This is generally done in a feedforward or open-loop configuration since for that case the covariance matrix of the wavefront error is affine in the control gain matrix. However when implementing the actual control in order to achieve a simple Matrix Vector Multiplication (MVM) strategy the configuration is actually a closed-loop configuration. The resulting loss of performance is discussed in this paper and a new Youla parametrisation of the feedback control scenario is proposed to perform an affine in the parameter optimisation of the covariance

matrix of the wavefront error spatial dynamics while taking a feedback control implementation into consideration. Furthermore the solution presented will also aim at inducing the maximal sparsity into the feedback gain in order to minimise the real-time computational costs of the computed controller. Results with the new control methodology will be presented in a simulation study on a small scale laboratory set-up configuration and in a large scale simulation study using models of the TMT.

Poster Session 1 Mon – System control & algorithms

Laboratory and on-sky test of CuReD and HWR fast wavefront algorithms

Bitenc, Urban; Basden, Alastair; Bharmal, Nazim; Dipper, Nigel; Myers, Richard; Reeves, Andrew; Vidal, Fabrice; Gratadour, Damien; Rousset, Gerard; Morris, Tim; Gendron, Eric
Durham University, CfAI

CuReD (Cumulative Reconstructor with domain Decomposition) and HWR (Hierarchical Wavefront Reconstructor) are novel wavefront reconstruction algorithms, used in the single-conjugate adaptive optics. For a high-order system they are much faster than the traditional matrix–vector-multiplication method.

We have developed three methods for mapping the reconstructed phase into the deformable mirror actuator commands and have tested both reconstructors with the CANARY instrument. We find out that the CuReD reconstructor runs stably only if the feedback loop is operated as a leaky integrator, whereas HWR runs stably with the conventional integrator control. Using the CANARY telescope simulator we find that the Strehl ratio (SR) obtained with CuReD is slightly higher than that of the traditional least-squares estimator (LSE). We demonstrate that this is because the CuReD algorithm has a smoothing effect on the output wavefront. The SR of HWR is slightly lower than that of LSE. We have tested both reconstructors extensively on-sky. They perform well and CuReD achieves a similar SR as LSE. We compare the CANARY results with those from a computer simulation and find good agreement between the two.

The main concern with CuReD and HWR is their noise propagation properties. The wavefront sensor (WFS) used with CANARY only has 7x7 subapertures. At that level, CuReD and HWR were not found to be sensitive to noise more than the traditional MVM method. We will repeat the tests using the DRAGON bench, which is being completed at Durham University. As DRAGON's WFS has 32x32 subapertures, this will provide a key insight into how well CuReD and HWR are capable of controlling noise on a higher order system.

Poster Session 1 Mon – Wavefront sensing

LGSD/NGSD: High Speed Optical CMOS Imagers for E-ELT Adaptive Optics

Downing, Mark; Kolb, Johann; Reyes, Javier; Meyer, Manfred; Marchetti, Enrico; Feautrier, Philippe; Gach, Jean-Luc; Stadler, Eric
ESO

The success of the next generation of instruments for ELT class telescopes will depend upon improving the image quality by exploiting sophisticated Adaptive Optics (AO) systems. One of the critical components of the AO systems for the E-ELT has been identified as the optical Laser/Natural Guide Star WFS detector. The combination of large format, 1760x1680 pixels to finely sample the wavefront and the spot elongation of laser guide stars, fast frame rate of 700frames per second (fps), low read noise (< 3e-), and high QE (> 90%) makes the development of this device extremely challenging. Design studies concluded that a highly integrated Backside Illuminated CMOS Imager built on High Resistivity silicon as the most likely technology to succeed. Two generations of the CMOS Imager are being developed: a) the already designed and manufactured NGSD (Natural Guide Star Detector), a quarter-sized pioneering device of 880x840 pixels capable of meeting first light needs of the E-ELT b) the LGSD (Laser Guide Star Detector), the larger full size device. The detailed design is presented including the approach of using massive parallelism (70,400 ADCs) to achieve the low read noise at high pixel rates of 3 Gpixel/s and the 88 channel LVDS 220Mbps serial interface to get the data off-chip. To enable read noise closer to the goal of 1e- to be achieved, a split wafer run has allowed the NGSD to be manufactured in the more speculative, but much lower read noise, Ultra Low Threshold Transistors in the unit cell. The NGSD has come out of production, it has been thinned to 12 μ m, backside processed and packaged in a custom 370pin Ceramic PGA (Pin Grid Array). Results of tests performed both at e2v and ESO are presented plus progress on developing the NGSD Camera.

Poster Session 1 Mon – Wavefront sensing

Measuring Segment Piston with a Non-Redundant Pupil Mask on the Giant Magellan Telescope

van Dam, Marcos; Tuthill, Peter; Cheetham, Anthony
Flat Wavefronts

The Giant Magellan Telescope (GMT) consists of seven 8.4 m segments with a separation of about 0.4 m. A unique challenge for GMT lies in phasing these segments and, in particular, how to measure segment piston optically. In this paper, we show how a non-redundant pupil mask with one hole per segment can be used to measure segment piston. This leads to a simple sensor both optically and in terms of signal processing. In addition, by making use of the broadband signature of the splodges, we can extend the capture range of the sensor to several waves.

Poster Session 1 Mon – Wavefront sensing

Daylight imaging of space objects with DORA: first results on the AEOS 3.6m telescope

Swindle, Ryan; Hart, Michael; Jefferies, Stuart; Hope, Douglas; Milton, Mark; Durney, Olivier; Williams, Stacie; Nagy, James
Air Force Research Laboratory

High resolution, high contrast images of space objects from ground-based telescopes are severely degraded by the strong atmospheric turbulence found during daylight operation. Our deconvolution from wavefront sensing (DWFS) based algorithm – the Daylight Object Restoration Algorithm (DORA) – augments the DWFS approach through application of the frozen flow hypothesis and enables daylight imaging in relatively stronger turbulence conditions. We present both simulations and first results of a DORA WFS installed on the 3.6m AEOS telescope. Simulation results also include application of DORA to a static wavefront error imposed on imagery due to aberrations from lightweight telescope optics.

Poster Session 1 Mon – Wavefront sensing

MCAO numerical simulations for EST: analysis and parameter optimisation

Montoya, Luzma; Montilla, Iciar; Collados, Manuel
Instituto de Astrofisica de Canarias

In the framework of the European Solar Telescope (EST) we have studied the performances of the multi-conjugate adaptive optics(MCAO) system using numerical simulations. A corrected field of view of 1 arcminute with a minimum Strehl of 50% is required in the whole range of observation angles at visible wavelengths (500nm). The number and position of deformable mirrors (DMs), wavefront field of view, and asterism geometry must be properly settled in order to achieve the MCAO requirements. The proposed MCAO system combines narrow and wide extended Shack Hartman (SH) wavefront sensors taking as reference the sun spot or solar granulation, with a reconstructor based on the Fractal Iterative Method (FrIM). We have used real day-time turbulence profiles obtained with the SHABAR instrument placed at Observatorio del Teide combined with hight-time measurements of high-altitude turbulence. We analyse the effect of the order of turbulence correction on the performance of the system.

Poster Session 1 Mon – Wavefront sensing

Analytical study of high altitude turbulence wide-field wavefront sensing: impact on the design and reconstruction quality of future solar AO systems

Montilla, Icíar; Collados, Manuel; Montoya, Luzma; Tallon, Michel
Instituto de Astrofísica de Canarias

The European Solar Telescope is a 4-m planned facility designed to have high spatial resolution capabilities to understand the mechanisms of magnetic coupling in the chromosphere and the photosphere. It will feature both a conventional and a multi-conjugate adaptive optics (AO) of similar complexity than the systems for night-time Extremely Large Telescopes. A particularity of solar AO is that it uses the solar granulation as a reference therefore the wavefront sensing is performed using correlations on images with a field of view of 10". A sensor collecting such a wide field of view averages wavefront information from different sky directions, affecting the sensing of high altitude turbulence, the sampling of which does not depend anymore on the size of the subapertures only, but rather on the size of the projection of the extended field of view. Understanding this effect is crucial for the design of future solar facilities, i.e. to choose the adequate height of the DMs on MCAO systems, and also to predict the quality of the reconstruction that such system would be able to achieve. For that reason, we have studied wide field sensing and found the analytical equations that describe the process, in order to use this information as an input to improved designs of solar AO systems.

Poster Session 2 Tue – AO instruments and pathfinders

A Solution to the MCAO Partial Illumination Issue, with Laboratory Results.

Radhakrishnan Santhakumari, Kalyan Kumar; Bertram, Thomas; Arcidiacono, Carmelo; Herbst, Tom; Ragazzoni, Roberto; Berwein, Jürgen; Kittmann, Frank
Max Planck Institute for Astronomy

Telescopes or instruments equipped with Multi-Conjugated Adaptive Optics (MCAO) provide uniform turbulence correction over a wide field of view (FoV), thereby increasing the sky coverage and enabling previously impossible science. LINC-NIRVANA (LN), the German-Italian near-infrared high-resolution imager for the Large Binocular Telescope (LBT), which also has the capability to achieve beam combination, has an advanced and unique MCAO module. The ground and a high atmospheric layer are corrected using only natural guide stars within two different FoVs via pyramid wavefront sensing with the help of two pairs of wavefront sensors. Two Ground-layer Wavefront Sensors (GWS) conjugated to the telescope pupil 100m above LBT drive the adaptive secondary mirrors, and two High-layer Wavefront Sensors (HWS) conjugated to a higher layer 7.1km above the telescope control a pair of Xinetics deformable mirrors on the LN bench. At the ground-layer (and therefore at the GWS), the footprints of the stars overlap completely, and every star footprint illuminates the full FoV. However, at 7.1km above the telescope pupil, the footprints do not overlap: every star illuminates a different region of the FoV. And there may not be enough stars to cover the

entire 2 arcminute corrected field. This results in having some regions in the FoV not illuminated and therefore we cannot sense the aberrations caused by the atmosphere in these areas. The heart of the "partial illumination issue" is determining the optimum way of correcting the high layer, given this limited information. In this paper, we propose a solution for this issue and discuss laboratory results from the aligned LN bench in the lab at MPIA. We will also test our solution on sky when LN is integrated at LBT in the second half of 2016.

Poster Session 2 Tue – AO instruments and pathfinders

Non Maxwell-Boltzmann Modeling of Sodium Guidestar Returns and Implications for Guidestar Linewidth

Hackett, Shawn; Johnson, Robert
Air Force Research Lab

To date, modeling of sodium guidestar mesospheric excitation has assumed that the distribution within the sodium ground states (F = 1 or F = 2) and the distribution between the two ground states was well modeled by a Maxwell-Boltzmann distribution. Recent experimental evidence from Starfire Optical Range and the modeling results of Bhamre et al show that the Maxwell-Boltzmann distribution is not a good approximation for the velocity distribution within ground states after optical excitation by a narrowband laser (linewidth < 1 MHz). A model is presented to account for the non-Boltzmann effects on the velocity groups of the Doppler profile of the mesospheric sodium atoms. The model is shown to agree fairly well with data provided from the 3.5m telescope and narrowband laser guidestar at Starfire Optical Range. These results challenge the efficacy of reducing the linewidth of sodium laser guidestars below 1 Mhz.

Poster Session 2 Tue – AO instruments and pathfinders

Commissioning of ARGOS at LBT: AO procedures and on-sky performances

Busoni, Lorenzo; Bonaglia, Marco; Borelli, Jose; Deysenroth, Matthias; Esposito, Simone; Gaessler, Wolfgang; Kulas, Martin; Mazzoni, Tommaso; Orban de Xivry, Gilles; Peter, Diethard; Rabien, Sebastian; Rahmer, Gustavo; Ziegleder, Julian
INAF Osservatorio Astrofisico di Arcetri

ARGOS is the Laser Guide Star Adaptive Optics system of the Large Binocular Telescope. It provides a Ground Layer correction to the 2 LUCIs, LBT's near-infrared multi-object spectrographs.

ARGOS is currently in its commissioning phase: the first system began on-sky test on the right eye of the telescope in Summer 2014, while the left system is going to begin on-sky operations in Fall 2015.

In this paper we present an overview of the commissioning's achievement obtained so far, focusing particularly on adaptive optics aspects. We describe the procedures used to calibrate and operate the system and the strategies to acquire LGSs and NGS. We focus on the management of the several control and offloads loops necessary to operate the ARGOS system on sky.

Poster Session 2 Tue – AO instruments and pathfinders

System analysis of the Segmented Pupil Experiment for Exoplanet Detection - SPEED - in view of the ELTs

Preis, Olivier; Martinez, Patrice; Gouvret, Carole; Dejonghe, Julien; Beaulieu, Mathilde; Janin-Potiron, Pierre; Spang, Alain; Martinache, Frantz; Fantei-Caujolle, Yan; Marcotto, Aurélie; Abe, Lyu; Carbillet, Marcel
Laboratoire Lagrange - Observatoire de la Côte d'Azur

SPEED is a new experiment in progress at the Lagrange Laboratory to study some critical aspects to succeed in very deep high-contrast imaging at close angular separations with the next generation of ELTs. The SPEED bench will investigate optical, system, and algorithmic approaches to minimize the ELT primary mirror discontinuities and achieve the required contrast for targeting low mass exoplanets. The SPEED project combines high precision co-phasing architectures, wavefront control and shaping using two sequential high order deformable mirrors, and advanced coronography (PIAACMC). In this paper, we describe the overall system architecture and discuss some characteristics to reach 10-7 contrast at roughly 1 Lambda/D.

Poster Session 2 Tue – AO instruments and pathfinders

Enabling Early High Contrast Observations with Telescope Subapertures

Serabyn, Gene; Mawet, Dimitri
JPL

Optimized high-contrast observational systems are not part of first-light instrumentation suites foreseen for ELTs, but they can be. Here we discuss the use of unobscured off-axis subapertures on large telescopes that can provide early high contrast observational capabilities with planned first generation AO systems. One of these is based on the use of a "well corrected subaperture," in which an off-axis subaperture is reimaged onto the facility deformable mirror in order to provide much finer wavefront correction over the subaperture. Such a system goes hand in hand with a small inner working angle coronagraph, and here we briefly discuss our successful installations of vortex coronagraphs at both the Palomar and Keck Observatories. Finally, the potential use of a sub-aperture nuller, which can access very unique exoplanet science, is discussed.

Poster Session 2 Tue – AO instruments and pathfinders

Microwave Kinetic Inductance Detectors for Direct Imaging of Exoplanets on ELTs

Mazin, Benjamin; Meeker, Seth; Walter, Alex; Szypryt, Paul; Strader, Matthew; Bockstiegel, Clint
UCSB

Microwave Kinetic Inductance Detectors (MKIDs) are single photon counting, energy resolving detectors applicable across the UVOIR. For AO applications, MKIDs are especially attractive for their read noise free, high speed, energy resolved photon counting in reasonably large formats. The first MKID instrument, ARCONS, has been taking data on the Palomar 200" for several years, and we have recently published the first papers using ARCONS data. There are currently two UVOIR MKID instruments fully funded and under construction for direct imaging of planets, DARKNESS for the Palomar P1640 coronagraph and MEC for Subaru's SCExAO.

There are significant opportunities available in pairing MKIDs with AO on ELTs, especially for planet detection and characterization. MKIDs can serve as a combined science camera and fast focal plane speckle sensor, allowing rapid feedback to cancel atmospheric speckles. A coronagraph with MKID-based imager could discover and take spectra of planets in the habitable zones of nearby M dwarfs, potentially discovering life by looking at spectral signatures in their atmospheres.

Poster Session 2 Tue – AO instruments and pathfinders

Aligning the LINC-NIRVANA Natural-Guide-Star MCAO system

Marafatto, Luca; Baumeister, Harald; Bertram, Thomas; Berwein, Jurgen; Briegel, Florian; Bizenberger, Peter; Herbst, Tom; Hofferbert, Ralph; Moreno-Ventas, Javier; Kittmann, Frank; Kuerster, Martin; Bergomi, Maria; Dima, Marco; Farinato, Jacopo; Ragazzoni, Roberto; Viotto, Valentina
INAF Padova

LINC-NIRVANA (LN) is the German-Italian high resolution near-infrared imager for the Large Binocular Telesocpe (LBT). LN is an optically complex instrument, consisting of a Multi-Conjugate Adaptive Optics (MCAO) system, a beam combiner and fringe tracker for interferometry, and a near-infrared science camera, for a total of more than 250 indivudual lenses and mirrors. In its ultimate incarnation, LN will achieve ELT-like spatial resolution. Due to the instrument configuration, this outstanding resolution requires the delivery of plane wavefronts, parallel input beams, homotheticity and zero Optical Path Difference. The LN MCAO sub-system consists of 4 Wavefront Sensors (WFSs), two for each arm of the telescope, to sense the turbulence at the ground layer and at 7.1km above the telescope. They operate in a layer oriented, Multiple Field of View mode, using up to 12 Natural Guide Stars

(NGSs) for the ground layer correction and up to 8 NGSs for the high layer correction. In this paper we present the integration and alignment procedure of the MCAO subsystem to the rest of LN. LINC-NIRVANA's very tight requirements lead to a challenging alignment procedure, which has been recently successfully completed in the lab in Heidelberg. LN is currently on its way to the LBT, where it will be re-aligned and finally mounted at the rear, bent focal stations of the telescope.

Poster Session 2 Tue – AO instruments and pathfinders

On-Sky AO Test Bench: Testing Future AO Technologies

Brousseau, Denis; Deschênes, William; Thibault, Simon; Véran, Jean-Pierre; Lavigne, Jean-François
Université Laval

We present an AO system specially designed for the 1.6-m diameter telescope of the Observatoire du Mont-Mégantic (OMM). The system has been mounted and tested at the OMM. It can be used to evaluate, directly on the sky, the performance of a number of next generation adaptive optics related technologies. The AO system is based on a 97-actuator ALPAO DM and a high-speed Optocraft Shack-Hartmann wavefront sensor (SHWFS). A beam splitter is located in front of the SHWFS to relay the wavefront to a second optical port which can accommodate a second wavefront sensor. During the initial observing run, the second wavefront sensor was a pyramidal wavefront sensor developed by INO. The AO control is achieve using the ALPAO Core Engine (ACE) software which can be used for closing the loop using one of the wavefront sensor while monitoring the wavefront with the other one. An Andor EMCCD camera is used to record the AO optimized PSF for performance analysis. In this paper, we present the AO system design and results from tests made in the lab during the opto-mechanical integration. The results from the observing run at the OMM are also presented. The results have demonstrated that this setup can be a highly flexible tool that can allow the direct side-by-side evaluation of new types of wavefront sensors.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Vibration analysis on GeMS tip-tilt data and performance evaluation using an LQG controller

Leboulleux, Lucie; Sivo, Gaetano; Juvenal, Rémy; Kulcsár, Caroline; Garrel, Vincent; Conan, Jean-Marc; Raynaud, Henri-François; Petit, Cyril; Rambold, William; Marin, Eduardo; Montes, Vanessa; Trujillo, Chadwick
Gemini South Observatory

AO systems aim at detecting and correcting for optical distortions induced by atmospheric turbulences. They are also extremely sensitive to extraneous

sources of pertubations such as vibrations, which degrade their performances. A new well defined vibration at 37Hz has been detected in January 2015 and is still currently affecting the Gemini South telescope secondary mirror. We show how its existence limits the performance of the operational systems at Gemini South: The Gemini Planet Imager (GPI) and the Gemini Multi-Conjugated AO system (GeMS). We further focus on how these vibrations are affecting GeMS performance and propose to implement the tip/tilt (TT) control strategy already tested on CANARY and SPHERE. It combines identification of a sum of auto-regressive models of order 2 with a Linear Quadratic Gaussian (LQG) control. LQG is now routinely used for TT and focus control or the Gemini Planet Imager (GPI) and has been successfully tested on all modes on CANARY. We present in this poster the expected gain in performance brought by this LQG TT control strategy on GeMS. The analysis is conducted in "replay mode" using GeMS TT on-sky data. This allows realistic performance assessment before implementation inside the Real-Time Computer (RTC) of GeMS and on-sky tests in November 2015.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Tip-tilt modeling and control for GeMS: a performance comparison of identification techniques

Kulcsar, Caroline; Juvenal, Rémy; Raynaud, Henri-François; Conan, Jean-Marc; Petit, Cyril; Leboulleux, Lucie; Sivo, Gaetano; Garrel, Vincent

Laboratoire Charles Fabry, Institut d'Optique Graduate School

Tip-tilt modeling and control are key issues to obtain the highest angular resolution with current large ground-based telescopes. It allows in particular the modeling of vibratory perturbations, which is of great interest not only for many existing adaptive optics (AO) systems, but also for the upcoming VLTs and ELTs systems. The Natural Guide Star (NGS) wave-front sensor (WFS) of wide-field adaptive optics instrument GeMS, at the Gemini South Observatory telescope, has been found to be quite sensitive to environmental vibrations, affecting the system performance on tip and tilt modes.

High performance control, and in particular Linear Quadratic Gaussian (LQG) control, has proven to efficiently reject vibrations. The design of such model-based control laws relies on a complete stochastic model of the incoming perturbation, generally obtained by a proper identification method on the data. We present here various modeling and identification procedures and apply them to GeMS on-sky tip-tilt data. The identified models are injected in the LQG control, and performance assessment is then obtained in replay mode on a number of data sets. This allows us to discuss the benefits and disadvantages of each modeling and identification technique, and poses the building block for an on-sky demonstration before the end of this year.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Simultaneous SCIDAR and SLODAR turbulence profiling on the same telescope

Butterley, Tim; Osborn, James; Wilson, Richard
Durham University

Scintillation detection and ranging (SCIDAR) and slope detection and ranging (SLODAR) are triangulation techniques for optical turbulence profiling. Both techniques involve fitting turbulence profiles to spatial covariances - pupil intensity covariances in the case of SCIDAR and wavefront slope covariances for SLODAR. The two techniques have different strengths and weakness. In general SCIDAR offers higher vertical resolution and is better suited than SLODAR to measuring the translational velocity of turbulent layers as a function of altitude. The SLODAR technique can often be applied using wavefront sensor data from an existing adaptive optics (AO) system and is more sensitive to outer scale effects than SCIDAR.

We describe a dual SCIDAR-SLODAR instrument that implements both techniques simultaneously on the 2.5-metre Isaac Newton Telescope on La Palma. We explore how a combined analysis of the data from the two methods can be used to compensate for the techniques' invidivual weaknesses. In particular we consider how non-Taylor flow and the outer scale affect the two techniques and how a combined analysis can help to make better-constrained measurements of these parameters.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Observations of the dynamic atmosphere above La Palma using Stereo-SCIDAR

Osborn, James; Butterley, Timothy; Perera, Saavidra; Fohring, Dora; Wilson, Richard
Durham University

Stereo-SCIDAR is a generalised SCIDAR instrument which is used to characterise the atmospheric optical turbulence in terms of Cn2 and wind velocity profile using triangulation with an optical binary star.

Stereo-SCIDAR differs from most other SCIDAR instruments in that, instead of overlapping pupil images on a single detector, the image of each star is recorded on a separate EMCCD. Separating the pupil images in this way leads to several advantages, including better signal to noise ratios, larger useable magnitude difference of the target stars and reliable automated wind velocity measurements. The data is analysed and made available to observatory systems in real-time.

Here we review the Stereo-SCIDAR technique and present recent results from the instrument on the Isaac Newton Telescope, La Palma.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Scintillation considerations for photometry on the Extremely Large Telescopes

Osborn, James; Fohring, Dora; Dhillon, Vik; Wilson, Richard
Durham University

Transit photometry is a powerful technique for extrasolar planet detection and characterisation. By combining photometry with low-resolution spectroscopy of exoplanet transits it is possible derive information about the temperature distribution, dynamics and composition of the exoplanet's atmosphere. Scintillation noise due to the Earth's turbulent atmosphere can be a dominant noise source in high-precision astronomical photometry when observing bright targets from the ground. Accurate knowledge of scintillation noise is important to enable performance assessment, calibration and optimisation of photometric instrumentation. It is also useful when fitting models to photometric data, for example, extrasolar planet eclipse light curves, and to help develop scintillation correction concepts. The expected scintillation noise is dependent on the instantaneous properties of the atmosphere, and aperture size and shape. Here we derive expressions for scintillation noise on large and extremely large telescopes with segmented and irregular pupils. We show that the ratio of the telescope aperture and outer scale is a significant factor in scintillation noise, making Extremely Large Telescopes favourable for photometric observations. We also describe a scintillation correction technique using tomographic Adaptive Optics systems. This technique, in combination with the large apertures of ELTs makes them an ideal facility for very high-precision photometry, enhancing sensitivity for the detection and characterisation of extrasolar planets.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Progress on measurement of vibration source amplitudes for validation of TMT AO performance vibration budget

Thompson, Hugh; MacMartin, Douglas
TMT

TMT has developed an AO image quality budget. A key item in this budget is an allocation of AO-corrected wavefront error to vibration (both image jitter due to relative motion of main optical elements and the effects of dynamic motion of individual primary mirror segments). This system allocation has been further subdivided into contributions from individual vibration sources at various locations in the TMT observatory both on and off the telescope. This vibration budget was allocated based on the results of finite element modelling of the system and guesses about the relative source strength of

different vibrating equipment. Since that initial allocation, we have measured source amplitudes for a number of potential sources of vibration that may be part installed at the TMT observatory. We report these results evaluating them against the specific frequency filter used in the TMT vibration budget. These results help us to determine both the suitability of the equipment for TMT and the feasibility of our current vibration budget allocations.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Implementation of SLODAR atmospheric turbulence profiling to the ARGOS system

Mazzoni, Tommaso; Busoni, Lorenzo; Esposito, Simone
INAF

ARGOS is the Ground Layer Adaptive Optics system of the Large Binocular Telescope, it uses three Laser Guide Stars, generated by Rayleigh backscattered light of pulsed lasers. Three Shack-Hartmann WFS measure the wavefront distortion in the Ground Layer. The SLOpe Detection And Ranging (SLODAR) is a method used to measure the turbulence profiles. Cross correlation of wavefronts gradient from multiple stars is used to estimate the relative strengths of turbulent layers at different altitudes. We present here the firsts results on sky of the SLODAR profile on ARGOS and the comparison with the preliminary study based on an end-to-end simulator of the system.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

The Self-Coherent Camera Phasing Sensor: a new tool for co-phasing segments for ELTs

Janin-Potiron, Pierre; Martinez, Patrice; Baudoz, Pierre; Carbillet, Marcel
Laboratoire Lagrange

We propose a new focal plane co-phasing sensor directly exploiting the scientific image to retrieve simultaneously segment piston and tip/tilt misalignments. The Self-Coherent Camera Phasing Sensor (SCC-PS) adequately combines the SCC properties to segmented telescopes with adapted segment misalignment estimators and image processing. An overview of the system architecture and a thorough performance and sensitivity analysis, as well as close-loop efficiency, are presented for both space and ground-based applications. We show that the SCC-PS is a serious candidate for segment co-phasing at the telescope level or alternatively at the scientific instrument level.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Optimizing use of multiple stars for near-infrared tip-tilt compensation at the W. M. Keck Observatory

Samulski, Camille; Rampy, Rachel; Femenia, Bruno; Wizinowich, Peter
W.M. Keck Observatory

The implementation of a near-infrared tip-tilt sensor (NIRTTS) in the Keck I adaptive optics (AO) system is the first of its kind, and represents a substantial step forward in AO technology. Enhanced-TRICK is a project built off this implementation, which will further improve performance and versatility. Currently the system is capable of using a single star for measuring image motion, but in the off-axis case this causes elongation in the science image due to tilt anisoplanatism. The NIRTTS has been designed with the capability of using up to three stars from around the field to correct for elongation. In order for the science object correction to be optimized, the measurements from each star must be weighted based on magnitude and separation from the science object. When weighted optimally the tip-tilt error at the science object will be a minimum. The process for assigning weights is described, and results of the first on-sky experiments using multiple tip-tilt stars are presented.

Poster Session 2 Tue – Atmospheric turbulence and other AO disturbances

Point spread function determination for Keck adaptive optics

Ragland, Sam; Jolissaint, Laurent; Wizinowich, Peter
W.M. Keck Observatory

One of the primary scientific limitations of adaptive optics (AO) has been the incomplete knowledge of the point spread function (PSF), which has made it difficult to use AO for accurate photometry and astrometry in both crowded and sparse fields, for extracting intrinsic morphologies and spatially resolved kinematics, and for detecting faint sources in the presence of brighter sources. To address this we initiated a program to determine and demonstrate PSF determination for science observations obtained with Keck AO. This paper aims to give a broad view of the progress achieved in implementing this capability for Keck AO science observations as the project nears completion.

The concept and the implementation are briefly described. The design and development of prototype operational tools for automated PSF reconstruction is presented along with the latest on-sky results using the NIRC2 science instrument. On-sky performance of the technique is discussed by comparing the reconstructed PSFs to the NIRC2 PSFs.

The statistics on seeing conditions and telescope/AO performance during the past 15 months are also presented along with their impact on contributions

from the individual PSF reconstruction error terms. The statistical results are discussed in the context of AO science with the current and future optical telescopes and instruments. The PSF algorithm development for this program is presented in a separate paper.

Poster Session 2 Tue – Current designs for ELT AO systems

New AO strategies for an extremely large telescope dedicated to extremely high contrast: The Colossus Project

Moretto, Gil; Langlois, Maud; Tallon, Michel; Thiebaut, Eric; Kuhn, Jeff R.; Berdyugina, Svetlana
CRAL/CNRS

The colossus project is an extremely large telescope with a nearly filled-aperture composed of sixty very large circular segments with the capability of detecting life signatures. In the frame of this project, we investigate the possibility of performing extreme adaptive optics correction quasi independently for each of the segments prior to cophasing the segments. We present the results of a detailed numerical analysis of this multi-segmented extreme adaptive optics system. The expected performances of such system are presented in this paper including possible trade-offs.

Poster Session 2 Tue – Current designs for ELT AO systems

Implementation of SCAO for ELT-CAM / MICADO-MAORY

Clénet, Yann; Esposito, Simone; Buey, Tristan; Riccardi, Armando; Rousset, Gérard; Lombini, Matteo; Cohen, Mathieu; Spano, Paolo; Gendron, Eric; Diolaiti, Emiliano; Davies, Richard
LESIA

ELT-CAM is the E-ELT first light instrument that associates MICADO, the near-infrared imager, and MAORY, its multi-conjugate adaptive optics (MCAO) module. ELT-CAM will also come with a single conjugate adaptive optics (SCAO) capability motivated by scientific programs for which SCAO provides the best AO performance (e.g. exoplanets, solar system science, bright AGNs, etc). This SCAO capability will be developed inside MICADO through a dedicated SCAO module with its natural guide star (NGS) wavefront sensor (WFS), allowing MICADO to work in SCAO stand alone mode without MAORY, and inside MAORY with the same dedicated NGS WFS. MICADO and MAORY consortia are working together on the development of this SCAO capability in order to perform a WFS trade-off study between Shack Hartmann and Pyramid, to optimize the design of the NGS WFS as well as the interfaces between the two instruments. We present here the current status of the work done by the two consortia on the implementation of this SCAO capability for MICADO and MAORY.

Poster Session 2 Tue – Current designs for ELT AO systems

Optical design of the Post Focal Relay of MAORY

Lombini, Matteo; Diolaiti, Emiliano; De Rosa, Adriano
INAF - Osservatorio Astronomico di Bologna

The Multi Conjugate Adaptive Optics Relay (MAORY) for the European Extremely Large Telescope shall re-image the telescope focal plane to the client instruments. By means of natural and artificial (laser) reference sources for wavefront sensing, and of deformable mirrors for wavefront correction, MAORY shall be able to compensate the wavefront disturbances affecting the scientific observations, achieving high Strehl ratio and high sky coverage. MAORY is planned to be located on the straight-through port of the telescope Nasmyth platform and to deliver the same optical interfaces as the telescope to the client instruments. We show the latest version of the optical design that matches the current requests and its optical performance. The laser guide stars channel, separated from the science path by means of a dichroic beam-splitter, is also presented.

Poster Session 2 Tue – Current designs for ELT AO systems

Flowdown of the TMT astrometry error budget(s) to the IRIS design

Schoeck, Matthias; Ellerbroek, Brent; Andersen, David; Rogers, John
Thirty Meter Telescope

TMT has defined the accuracy to be achieved for both absolute and differential astrometry in its top-level requirements documents. Because of the complexities of several different types of astrometric observations, these requirements cannot be used to directly specify system design parameters. The TMT astrometry working group therefore developed detailed astrometry error budgets for a variety of science cases. These error budgets demonstrate in great detail how astrometric errors propagate through the calibration, observing and data reduction processes, and need to be condensed into sets of specific requirements that can be used by each subsystem team for design purposes. In this paper, we show how this flowdown from error budgets to design requirements is achieved for the case of TMT's first-light Infrared Imaging Spectrometer (IRIS) instrument. We describe the process in general, provide examples of how it is executed and list the most significant consequences for the IRIS design.

Poster Session 2 Tue – Current designs for ELT AO systems

Preliminary design of the MICADO calibration unit

Rodeghiero, Gabriele; Pott, Jörg-Uwe; Müller, Friedrich
MPIA

MICADO is the Multi-AO Imaging Camera for Deep Observations, which aims to be the first light instrument of E-ELT. Thanks to its robust design with fixed mirrors and a cryogenic environment, MICADO will provide unprecedented astrometric capabilities and image stability in the range 0.8-2.5 μm. The operation of the instrument coupled with a SCAO unit will provide diffraction limited images over a field of view of 27", that will enlarge to 53" after the integration of the MAORY module. The poster will present the first concepts for the MICADO calibration unit, currently under development at MPIA. This subsystem will host a special internal calibration mask to measure and compensate instrument distortions, discontinuities between the detectors and telescope instabilities, leading the instrument to deliver an astrometric accuracy in the order of tens microarcsec over the instrument field of view.

Poster Session 2 Tue – Current designs for ELT AO systems

Laser-only AO, readout noise studies and AO verification and integration for ELTs

Basden, Alastair; Morris, Tim; Myers, Richard; Dipper, Nigel; Gendron, Eric; Vidal, Fabrice; Sevin, Arnaud; Rousset, Gerard; Gratadour, Damien; Hubert, Zoltan; Wilson, Angus; Morel, Carine
Durham University

We present a concept for visible near-diffraction limited lucky imaging with full-sky laser assisted adaptive optics. Simulation results are given, along with first on-sky measurements taken with the CANARY AO system on the William Herschel Telescope, and extension to ELT scales. We also present a study of readout noise in EMCCD and sCMOS detectors, with findings that are perhaps surprising when compared with naive models of sCMOS noise. We discuss the relative trade-offs of these detectors for ELT-scale AO and lucky imaging. Finally we introduce the concept of real-time simulation, necessary for integration and verification of ELT-scale AO systems, and provide details of the system developed for CANARY. We also discuss novel hardware investigations for AO real-time control systems that have been performed at Durham using many-core processors. We present AO real-time system designs for several proposed E-ELT instruments.

Poster Session 2 Tue – Numerical simulations and modeling

GTCAO LGS performance simulation

Montilla, Iciar; Reyes Garcia-Talavera, Marcos; Bello, Dolores
Instituto de Astrofísica de Canarias

Results of the simulation of the performance of the GTCAO with LGS on axis and off axis

Poster Session 2 Tue – Numerical simulations and modeling

Anti-aliasing static wave-front reconstruction with Shack-Hartmann sensors

Bond, Charlotte; Fusco, Thierry; Correia, Carlos; Véran, Jean-Pierre; Teixeira, Joel
Laboratoire d'Astrophysique de Marseille

The sampling of a wave-front using a Shack-Hartmann sensor, as determined by the lenslet spacing, puts a limit on the maximum spatial frequency we can measure. The finite sampling also impacts our sensitivity to frequencies at the high end of the band due to aliasing: higher spatial frequencies are folded into the detection band. In this paper we explore an after the fact numerical technique to quantify its utility when no optical filters (like a spatial filter) are used.

We present Wiener filters for wave-front reconstruction (resulting in the maximization of the Strehl ratio) targeting high-contrast AO systems. These filters are defined in the spatial-frequency domain thus being computationally efficient with the use of the Fast-Fourier Transform and therefore particularly suited to systems with a high number of degrees of freedom (n log(n), n being the number of degrees of freedom of the system). We further develop formulae for the anti-aliasing (AA) Wiener filter that optimally takes into account high-order wave-front terms folded in-band during the sensing (i.e., discrete sampling) process. We present Monte-Carlo simulation results for residual wave-fronts and propagated noise and compare to standard reconstruction techniques. To cope with finite telescope aperture we've developed and optimized a Gerchberg-Saxton like iterative-algorithm that provides superior performance. Metrics used are Strehl-ratio, raw contrast and post-coronographic contrast.

Poster Session 2 Tue – Numerical simulations and modeling

SCAO in MICADO: latest adaptive optics performance results from GPU-based end-to-end simulations with the COMPASS platform

Clénet, Yann; Gratadour, Damien; Carlotti, Alexis; Ferreira, Florian; Vérinaud, Christophe; Vidal, Fabrice; Gendron, Eric; Rousset, Gérard
LESIA

MICADO, the E-ELT first light imager, will include a natural guide star wavefront sensor for a SCAO correction when functioning in stand-alone mode without MAORY. We present here the latest results of adaptive optics performance simulations of this SCAO correction. These simulations have been performed with COMPASS, a GPU-based adaptive optics end-to-end simulation platform, which allows us to tackle the issue of the large parameter space of end-to-end simulations worsen by the large number of degrees of freedom of the E-ELT case. We present here results accounting for new features recently

included in the COMPASS platform (pyramid wave-front sensor, E-ELT pupil, etc) and pave the way of work for the future developments.

Poster Session 2 Tue – Numerical simulations and modeling

The Giant Magellan Telescope Dynamic Optical Simulation model

Conan, Rod; Bouchez, Antonin; Quiros-Pacheco, Fernando; McLeod, Brian
GMTO

The Giant Magellan Telescope (GMT) is a gregorian 25.5-meter diameter primary mirror (M1) made of 7 8.4-meter diameter circular aspheric segments. The secondary mirror (M2) is a 1/8th down-scale model of M1 made of 7 1-meter diameter segments. Each segments has positionners to adjust its 6 rigid body motions. The figure of M1 segment is controlled with 44 bending modes and M2 segments are deformed using 672 actuators. In the active and adaptive operation modes of the GMT, around a dozen wavefront sensors (WFS) are selectively used to monitor the optical aberrations building-up into the telescope. A dedicated control system feeds back the WFS measurements to the mirrors actuators to deliver image quality optimized for the field of view of each scientific instrument. This paper describes the GMT Dynamic Optical Simulation (DOS) tool. DOS integrates the optical and mechanical model of the telescope together with the control system. DOS is a cloud-based optical propagation softwarepackage with build-in models for both geometric and Fourier optics and a full control algorithm development environment. Details of the modeling of the active and adaptive optics modes of the GMT with DOS are presented.

Poster Session 2 Tue – Numerical simulations and modeling

Wavefront control simulations for the Giant Magellan Telescope

Quiros-Pacheco, Fernando; Conan, Rod; Irarrazaval, Ben; McLeod, Brian; Bouchez, Antonin
GMTO

In this paper we will present some simulation results showing the performance of the Wavefront Control System of the Giant Magellan Telescope. All simulations have been performed using the GMT Dynamic Optical Simulation (DOS) tool, which integrates the optical and mechanical models of the telescope. On one hand, the optical model of the telescope is required to properly simulate field-dependent aberrations that arise in multiple wave-front sensing configurations. On the other hand, the mechanical model of the telescope is required to simulate the dynamical response of the segments of both the primary and the secondary mirrors. Numerical simulations have been performed to validate and optimize the wave-front control algorithms, taking

into account the spatial and temporal coupling between wave-front measurements and corrections performed by different systems (phasing, active optics, adaptive optics) under the presence of external disturbances.

Poster Session 2 Tue – Numerical simulations and modeling

Efficient identification strategies for tomographic AO systems using GPUs

Gendron, Eric; Ferreira, Florian; Gratadour, Damien; Sevin, Arnaud
LESIA - Observatoire de Paris

One of the main scientific drivers for the E-ELT is the study of distant galaxies, and a multi-object spectrograph (MOS) coupled to Multi-object Adaptive Optics (MOAO) is a key combination for this purpose. MOAO is using tomography for driving the adaptive deformable mirrors (DM), and thus requires the turbulence measurements from several wavefront-sensors. On ELTs, the wavefront sensing would make use of up to 6 laser guide stars and up to 5 natural ones (so up to 11 WFS in total). Due to the large telescope diameter, the number of sub-apertures of each WFS across the pupil would be in the range 60-80, possibly larger. The total number of measurements is then in the range 66K 110K. To drive such system, one critical subsystem of the AO real-time controller is the supervisor module. Its role is to feed the real-time box at a regular rate with a tomographic reconstructor matrix, computed from a statistical analysis of the measurements. This process involves the inversion of the WFS measurements dense covariance matrix, the size of which being of the order of 110k x 110k. In order to minimize the impact of measurement noise in this process, a powerful approach called Learn & Apply (L&A), consists in first fitting a model of the measurements covariance matrix on the measured data and then invert this synthetic matrix to produce the tomographic reconstructor. While the inversion itself can be handled efficiently using efficient computing techniques on massively parallel architectures such as GPUs, the fitting process, also highly compute intensive, is difficult to implement on the latter. In this paper, we will present an efficient scheme for this identification process mixing CPU and GPU code providing a significant speedup as compared to a multi-threaded CPU approach. We will also present the results obtained on sky with the Canary MOAO demonstrator, in a 10 WFS configuration, for which this technique helped to reduce the identification time from minutes to seconds while keeping the same level of accuracy. Various possible optimizations of the process as well as the extrapolation of this performance to the E-ELT scale will also be discussed.

Poster Session 2 Tue – Numerical simulations and modeling

Modeling the pyramidal wavefront sensor in ZEMAX™ by a suitable user defined surface

Antichi, Jacopo; Munari, Matteo; Magrin, Demetrio; Riccardi, Armando
INAF OAA

After 20 years of wavefront sensors based on pyramid (PWFS), there are no straightforward ways to model such device in standard sequential ray-tracing software like ZEMAX ™: modeling strategies tend to be oriented to the needs of the single user only and, in general, are unsatisfactory due to lack of flexibility.To overcome this problem, we have exploited the possibility of ZEMAX™ – one of the ray-tracing software mostly in use nowadays – to developa user defined surface (UDS), whose properties are described in a dynamic link library (DLL) written in C language. The pyramid UDS approach greatly improves the versatility during the design and simplifies both quality and tolerance analysis. In order to prove the potentiality of our UDS-DLL surface, referred as PAM2R, we have reproduced the optical layout of two PWFS systems already installed at LBT: the single-conjugate system FLAO, and the ground-layer system GLAO-WS of LINC-NIRVANA. Moreover we have tested PAM2R on the preliminary design of the GMT AO PWFS. In this proceeding we will highlight the main characteristics of the PAM2R surface, showing various results we obtained on the above case studies with the aim to establish a common design playground for the PWFS in the AO community.

Poster Session 2 Tue – Numerical simulations and modeling

Performance evaluation of mid-IR vortex coronagraphs with centrally obscured segmented pupils.

Carlomagno, Brunella; Absil, Olivier; Mawet, Dimitri; Huby, Elsa; Delacroix, Christian; Ruane, Garreth; Surdej, Jean; Habraken, Serge; Forsberg, Pontus; Karlsson, Mikael; Vargas Catalan, Ernesto
Université de Liège

In its original design, the E-ELT/METIS mid-infrared imager and spectrograph incorporates a vortex coronagraph for the detection and characterization of exoplanets, with a required 5-sigma L-band contrast of 3e-5 (goal: 1e-6) at 5 lambda/D (goal: 2 lambda/D), with lambda/D 20 mas at L band. The AGPM (Annular Groove Phase Mask) is a vortex phase mask with impressive characteristics (small inner working angle, high throughput, achromaticity) and theoretically achieves perfect starlight cancellation for a circular pupil. However, a non-circular or obstructed pupil and non-flat input wavefront result in a starlight leakage, which degrades the performance of the vortex coronagraph. In this work, we present end-to-end performance simulations using Fourier optical propagation to determine the starlight rejection obtained with an infrared vortex coronagraph. We first analyse the performance degradation due to the E-ELT pupil architecture (segments, central obstruction, spiders, missing segments), pointing jitter, and adaptive optics residuals. Phase screens are computed with various AO simulation tools. Advanced concepts to improve the performance of the infrared vortex coronagraph are also presented.

Poster Session 2 Tue – Numerical simulations and modeling

Science simulations for E-ELT spectroscopy with HARMONI: implications for adaptive optics performance

Zieleniewski, Simon
University of Oxford

With the first extremely large telescopes planned for the next decade 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 quantitatively estimate the accuracy with which physical parameters can be measured for a specific science case. In this talk I shall present hsim: a dedicated pipeline for simulating observations with the HARMONI integral field spectrograph on the European Extremely Large Telescope. The pipeline takes high spectral and spatial resolution input data-cubes, encoding physical descriptions of astrophysical sources, and generates mock observed data-cubes. It employs a new method of incorporating the strongly wavelength dependent adaptive optics (AO) point spread functions. This simulation pipeline provides a step above exposure time calculators and allows one to predict the feasibility of a given observing programme with HARMONI. I shall present simulations of several science cases and discuss the need to accurately incorporate the AO point spread function, which allows exploration of the implications of varying AO performance on particular science goals. The simulations include a point source sensitivity analysis which quantifies the importance of accurately understanding the point spread function when performing optimal extraction.

Poster Session 2 Tue – Numerical simulations and modeling

A 2-DMs pseudo-analytical simulation approach for MOAO

Morel, Carine; Gendron, Eric; Gratadour, Damien; Sevin, Arnaud; Rousset, Gérard
LESIA, Observatoire de Paris, CNRS, UPMC, Univ. Paris Diderot, 5 place Jules Janssen, F-92190 Meudon

MOSAIC is the future MOAO-assisted multi-object spectrograph of the European ELT. Its MOAO mode is designed with 10 to 20 near-IR science channels, one for each different observed object. In order to maximise the ensquared energy for each target, each channel has its own deformable mirror, coming in addition to the E-ELT deformable mirror. This latter achieves a global ground layer correction of the 6 arcminute field, and operates independently from all the secondary DMs. Each secondary DM uses a tomographic reconstructor optimised for the direction of the target, that comes as a complement to the global E-ELT correction. We had described in previous work a simulation

scheme that allows us to assess the performance of a large MOAO instrument. In this article, we will show how we have modified our previous single DM simulation to the 2-DM case. We also discuss the performance obtained through this simulation versus the number of actuators on the secondary DM.

Poster Session 2 Tue – Science with ELTS relating to AO requirements

Prospects for Measuring Supermassive Black Hole Masses with ELTs

Do, Tuan
UCLA

The next generation of giant-segmented mirror telescopes will enable us to observe galactic nuclei at much higher angular resolution and sensitivity than ever before. These capabilities will introduce a revolutionary shift in our understanding of the origin and evolution of supermassive black holes by enabling more precise black hole mass measurements in a mass range that is unreachable today. We present simulations and predictions of the observations of nuclei that will be made with the Thirty Meter Telescope and the adaptive optics assisted integral- field spectrograph IRIS, which is capable of diffraction-limited spectroscopy from Z band (0.9 μm) to K band (2.2 μm). These simulations, for the first time, use realistic values for the sky, telescope, adaptive optics system, and instrument to determine the expected signal-to-noise ratio of a range of possible targets spanning intermediate mass black holes of ˜10^4 M$\odot$ to the most massive black holes known today of $>10^{10}$ Msun. I will present simulations across a spectrum of black hole masses and galaxy types to show the ability of IRIS and TMT to quantitatively explore the demographics of black holes in the universe. I will discuss how these observations will enable our study of the origin of the MBH - galaxy velocity dispersion and MBH - galaxy luminosity relationships, and the evolution of black holes through cosmic time.

Poster Session 2 Tue – Science with ELTS relating to AO requirements

Multi year astrometry with GSAOI behind GeMS

Service, Maxwell; Lu, Jessica
University of Hawaii

The multi year astrometric accuracy of the Gemini South Adaptive Optics Imager (GSAOI) is critical to many science goals associated with the system. GSAOI data taken behind the Gemini Multi-Conjugate Adaptive Optics System (GeMS) has large optical distortions in the focal plane which must be mitigated for these goals to be achieved. We use a data set of images taken with GSAOI and Hubble Space Telescope across a 1.6 year baseline to measure the astrometric accuracy that can be achieved in a crowded field. The focus is on the difficulty of mitigating the time variable optical distortion in this system, and how this limits the accuracy of our final measurements.

Poster Session 2 Tue – Wavefront sensing

Progress report of the ELT-elongated LGS on-sky experiment with WLGSU and CANARY at WHT

Rousset, Gerard; Myers, Richard; Bonaccini Calia, Domenico; Gratadour, Damien; Morris, Tim; Basden, Alastair; Buey, Tristan; Chemla, Fanny; Gendron, Eric; Lombardi, Gianluca; Osborn, James; Pfrommer, Thomas; Reyes, Marcos; Reeves, Andrew
LESIA, Observatoire de Paris

One of the main challenges of the Na Laser Guide Star (LGS) in Extremely Large Telescope (ELT) Adaptive Optics (AO) is the mitigation of the impacts of the extreme elongation on the wave-front (WF) measurement. Based on the ESO compact and transportable Wendelstein LGS Unit (WLGSU) and the Multi-Object AO demonstrator CANARY installed at the 4.2m WHT in the La Palma Canary Island, we are currently building a Na LGS WF sensing on-sky experiment at the scale of an ELT. The goal is to record well-calibrated atmospheric WF data to be used as references in the analysis of the mitigation strategies of the elongation effects. The launch telescope (LT) is located at a distance of 40m from the WHT primary, allowing us to mimic the spot elongations of an ELT. The Na LGS WF sensor, based on an OCAM camera, is designed in order to well sample the Shack Hartmann (SH) spots and minimize their truncation. It includes focus tracking and real-time jitter compensation. The SH image patterns and WF measurements are recorded at a150Hz rate, in parallel to synchronous natural guide star WF measurements. In addition, the 2.5m INT, positioned at 460m from the LT, is used to monitor the LGS plume with a fast large field camera, synchronized with the LGS WF sensor. Hence, all these tools will provide unique spatial and temporal WF data associated to Na density profiles. They will allow us to analyse the errors in the measurement, depending on the processing scheme and the observing conditions, and to study the trade-offs for the design of the future ELT LGS AO WF sensors. The first on-sky run is scheduled in Summer 2016. A progress report of the project will be given.

Poster Session 2 Tue – Wavefront sensing

A new Slow Focus Sensor for GeMS

Marin, Eduardo; Garrel, Vincent; Sivo, Gaetano; Montes, Vanessa; Trujillo, Chadwick; Rambold, William; Gigoux, Pedro; Moreno, Cristian; Galvez, Ramon; Gausachs, Gaston
Gemini Observatory

The Gemini South 8-meter telescope's Multi Conjugate Adaptive Optics System GeMS is about to enter a new era of science with an entire new upgrade for its Natural Guide Star wave front sensor (NGS2). With NGS2 the limiting magnitude of the natural guide stars used for tip/tilt sensing is expected to increase from its current limit of 15.4 to 17+ in R-band. This will provide a much

greater sky coverage over the current system. NGS2 is a complete replacement of the current Natural Guide Star wave front sensor (NGS). This presents an interesting challenge as the current NGS includes a Slow Focus Sensor (SFS) used to compensate for the sodium layer mean altitude variations. With the new NGS2 setup, this SFS will be removed and a suitable replacement must be found. Within the Gemini environment there exist two facility wave front sensors, Peripheral Wave Front Sensors one and two (PWFS1 and PWFS2), that could act as an SFS. Only one of these (PWFS1) is located optically in front of the GeMS Adaptive Optics (AO) bench (Canopus). We are currently preparing this wave front sensor as the new SFS for GeMS under the NGS2 setup. The results of several nighttime and daytime tests show that PWFS1 will be an adequate SFS for GeMS in the NGS2 setup providing excellent sky coverage without compromising the GeMS Field of View (FoV).

Poster Session 2 Tue – Wavefront sensing

Pointing control and low-order wavefront sensing for the vortex coronagraph

Huby, Elsa; Absil, Olivier; Mawet, Dimitri; Baudoz, Pierre; Serabyn, Eugene
University of Liège

Vortex coronagraphs (VC) offer unprecedented potential for the direct detection and characterization of extrasolar planets, and, as such, are considered to equip several coronagraphs of the next generation high contrast imaging instruments on future 30m class telescopes. The VORTEX project led by the University of Liège aims to develop all aspects of the vector vortex phase masks made of sub-wavelength gratings, also known as AGPM (Annular Groove Phase Mask): (i) design & manufacturing, (ii) in-lab and on-sky performance tests and optimization, (iii) data reduction optimization and analysis. In this talk, we will report on the development of a tip-tilt retrieval technique designed to reduce the inevitable slow de-centering of the beam with respect to the center of the vortex phase mask caused by mechanical drifts. This is currently one of the main limitations of small inner working angle coronagraphs such as VC and has to be addressed in order to enhance on-sky performance. The QACITS technique (Quadrant Analysis of Coronagraphic Images for Tip-tilt Sensing) has been initially introduced for the four-quadrant phase mask. We have derived its theoretical basis for the particular case of vortex phase masks. The method was then validated in the optical laboratory, and very recently on sky using the newly commissioned L-band vortex on Keck/NIRC2. Its principle is based on the fact that the asymmetry in the coronagraphic image shape is directly linked to the amount of tip-tilt affecting the beam incident on the mask, allowing the correction for residual pointing errors that are not sensed by the adaptive optics system. We will show that QACITS can not only streamline the acquisition and improve the centering accuracy of the star on the mask, but also stabilize the pointing and hence the PSF on long sequences. We will conclude by a short review of the various possible ways to implement low-order wavefront sensing in (vortex) coronagraphy.

Poster Session 2 Tue – Wavefront sensing

Development of an extreme adaptive optics testbench using a self-referenced Mach-Zehnder wavefront sensor

Delacroix, Christian; Loupias, Magali; Langlois, Maud; Tallon, Michel; Thiébaut, Eric
Centre de Recherche Astrophysique de Lyon (CRAL)

Extreme adaptive optics (XAO) has severe difficulties meeting the high speed (>1kHz), accuracy and photon efficiency requirements. An innovative high order adaptive optics system using a self-referenced Mach-Zehnder wavefront sensor allows counteracting these limitations. This sensor estimates the wavefront phase by measuring intensity differences between two outputs, with a lambda/4 path length difference, but is limited by its dynamic range. During the past few years, such an XAO system has been studied by our team in the framework of 8-meter class telescopes. In this work, we report on our latest results with the XAO testbed recently installed in our lab, and dedicated to high contrast imaging with 30m-class telescopes (such as the E-ELT or the TMT). A woofer-tweeter architecture is used in order to deliver the required high Strehl ratio (>95%). It consists of a 12x12 deformable mirror and a 512x512 spatial light modulator, characterized using both mono- and polychromatic light. We present our latest simulation and laboratory demonstration results, including components characterization, close loop performance, and sensitivity to calibration errors. This work is carried out in synergy with the validation of fast iterative wavefront reconstruction algorithms, and the optimal treatment of phase ambiguities in order to mitigate the dynamical range limitation of such a wavefront sensor.

Poster Session 3 Thu – AO instruments and pathfinders

NIR Tip-Tilt Guidance and More With the SAPHIRA APD

Atkinson, Dani; Hall, Donald; Baranec, Christoph; Jacobson, Shane; Baker, Ian; Riddle, Reed; Law, Nicholas; Chun, Mark; Goebel, Sean
University of Hawaii at Manoa

An engineering-grade SAPHIRA APD was installed and commissioned as a NIR tip-tilt sensor on the Robo-AO instrument at the Palomar 1.5-m telescope over Summer 2014. Taking advantage of the SAPHIRA's full-frame 100Hz readout rate and sub-electron read noise, Robo-AO gained the benefit of both TT correction and simultaneous H-band imaging. The addition of this control loop reduced RMS target displacement in the x and y dimensions from 0.284" and 0.184" to 0.033" and 0.035" respectively, achieving sub-pixel stability. This configuration was used to investigate targets of interest in the Kepler catalog. The SAPHIRA's unique capabilities make it well-suited to future adaptive optics applications including ELT instruments.

Poster Session 3 Thu – AO instruments and pathfinders

Operation, Reliability and Maintenance of AO with Adaptive Secondaries

Miller, Douglas; Christou, Julian; Brusa, Guido; Rahmer, Gustavo; Lefebvre, Michael
Large Binocular Telescope

The Large Binocular Telescope (LBT) is operating with two permanently mounted adaptive secondary mirrors (ASMs). These mirrors replace what in other large telescopes is a rigid secondary mirror and are designed to provide AO corrected operational modes as well as seeing limited operation. Because the two adaptive secondaries are on all the time, including the day time for calibration, their reliability and ease of operation is very important to LBT. In this paper we discuss some of the failure modes encountered during operation of the LBT adaptive secondaries as well as the support necessary to operate them reliably, in particular for the AO mode operation. Starting from a description of the software diagnostic system we will show how in most cases a failure mode can be detected and receive the necessary corrective action. We will also discuss our experience in terms of reliability of the hardware and required maintenance. Over the course of roughly five years of operation we have had a significant number of repair missions addressing many issues related to both design shortcoming as well as 'accidents'. In particular we had to deal with a 'freezing' accident that caused the thin shell to get stuck to its reference body, a large contamination of the thin gap, several failures of the capacitive sensor internal position system as well as detachment of magnets from the thin shell. We will report the nature and severity of these issues and the various fixes implemented and address the issues that are still pending.

Poster Session 3 Thu – AO instruments and pathfinders

The Robo-AO large surveys and plans for future deployments [CfAO retreat]

Baranec, Christoph; Riddle, Reed; Law, Nicholas
Institute for Astronomy, University of Hawaii

Robo-AO commenced scientific operations in June 2012 at Palomar Observatory and more than 18,000 observations have since been performed at the 0.12" visible-light diffraction limit. We will review results from many of the large surveys, including imaging of every Kepler planet-host candidate and a comprehensive and homogeneous measurement of stellar multiplicity in the solar neighborhood. The Robo-AO system is now being prepared for a 3 year deployment to the 2.1-m telescope at Kitt Peak which will serve a consortium of partners, with 2 months per year made available to the general U.S. astronomical community. New Robo-AO systems are also in various stages of development: a clone by IUCAA for the 2-m IGO telescope in India a natural guide star variant, KAPAO, by Pomona College at the 1-m Table Mountain

telescope in California and second generation Robo-AO systems are planned for the 3-m IRTF and 2.2-m University of Hawaii telescopes on Maunakea. The latter will incorporate an infrared integral-field spectrograph to quickly classify transients, such as supernovae and asteroids, discovered by the Asteroid Terrestrial-impact Last Alert System in Hawaii.

Poster Session 3 Thu – AO instruments and pathfinders

Solar system observations with HARMONI: 3D spectroscopy of rock, ice and gas.

Clarke, Fraser
University of Oxford

Simulations of HARMONI - the E-ELT's first light integral field spectrograph - observations of SS bodies asteroids, moons and atmospheres, & KBOs. Also observations from SWIFT+PALM3K on Palomar, including 'lessons-learnt' from trying to take high resolution data in three dimensions!

Poster Session 3 Thu – AO instruments and pathfinders

Robo-AO KP: A new era in robotic adaptive optics

Riddle, Reed; Baranec, Christoph; Law, Nicholas
California Institute of Technology

Robo-AO is the first and only fully automated adaptive optics laser guide star AO instrument. It was developed as an instrument for 1-3m robotic telescopes, in order to take advantage of their availability to pursue large survey programs and target of opportunity observations that aren't possible with other AO systems. Robo-AO is currently the most efficient AO system in existence, and it can achieve an observation rate of 20+ science targets per hour. In more than three years of operations at Palomar Observatory, it has been quite successful, producing technology that is being adapted by other AO systems and robotic telescope projects, as well as several high impact scientific publications. Now, Robo-AO has been selected by the NSF to take over operation of the Kitt Peak National Observatory 2.1m telescope. This will create the first dedicated AO observatory, and will give Robo-AO KP the opportunity to pursue multiple programs consisting of several thousand targets each during the three years it will be on the telescope. This presentation will discuss the process adapting Robo-AO to the KPNO 2.1m telescope, the plans for integration and initial operations, and the science operations and programs to be pursued. *** Note that this title and abstract are embargoed until the NSF award of Robo-AO is publicly announced (which should be sometime in May). Please check with Dr. Riddle before publicizing this information.

Poster Session 3 Thu – AO instruments and pathfinders

Commissioning the Shane Adaptive optics infraRed Camera-Spectrograph

McGurk, Rosalie
Max Planck Institute for Astronomy

We describe the design and first-light early science performance of the Shane Adaptive optics infraRed Camera- Spectrograph (ShARCS) on Lick Observatory's 3-m Shane telescope.

Poster Session 3 Thu – AO instruments and pathfinders

HARMONI: the E-ELT first light integral field spectrography

Thatte, Niranjan
University of Oxford

As part of the E-ELT's first light suite of instruments, HARMONI will provide the core spectroscopic capability at visible and near-infrared wavelengths. The instrument is complemented by two flavours of adaptive optics - SCAO using bright natural stars, and LTAO using 6 laser beacons and faint natural stars for tip-tilt correction. In addition, HARMONI will also provide coarse spaxel scales for seeing limited operation. An image slicer based integral field spectrograph with large instantaneous wavelength coverage, HARMONI is ideally suited for detailed (spatially resolved) studies of physical (via morphology), chemical (via abundances and line ratios) and kinematic (via line-of-sight velocities) properties of astrophysical sources. With its unique combination of enormous collecting area and unprecedented spatial resolution, spectroscopy with the E-ELT is going to transform our understanding of the physical processes in the Universe. I will present an overview of the capabilities of HARMONI, its top level design, and its key science cases, with an emphasis on adaptive optics aspects - design features and trade-offs to maximise the return from AO assisted integral field spectroscopy.

Poster Session 3 Thu – AO instruments and pathfinders

Development and on-sky experiment of narrow band filter for daytime AO observation using laser guide star in mid-infrared wavelength

Hayano, Yutaka; Chun, Mark; Honda, Mitsuhiko
National Astoronomical Observatory of Japan

Beckers (Proc. of SPIE Vol. 6986, 69860G, 2008) proposed the possibility to use sodium laser guide star for mid-infrared adaptive optics system in the daytime. The idea is quite unique to expand the observable time one or

two hours in the early morning. The key technology to achieve this idea is the extreme narrow band filter tuned at sodium D2 line to reduce the sky background equivalent to the night time sky background.

In this paper, we introduce the prototype fabrication of narrow band filter with multi-layer coating and evaluation observation using adaptive optics system at Subaru Telescope. We found some technical challenges of the prototype filter that the bandwidth was about 1 nm, which is broader than we specified as 0.3nm. Also the peak transmission was degraded from 65% down to 16%. The required reduction of sky background by a narrow band filter was estimated from on-sky observation at Subaru Telescope. The equivalent optical density of filter has to be darker than OD4.

Additionally, we introduce a prototype etalon filter as a narrow band filter, which has been used for LIDAR observation of sodium layer at 90km altitude in daytime.

Poster Session 3 Thu – AO instruments and pathfinders

Adaptive Optics at the Large Binocular Telescope

Christou, Julian; Brusa Zappellini, Guido; Conrad, Albert; Lefebvre, Michael; Miller, Douglas; Rahmer, Gustavo; Zhang, Xianyu
LBTO

The Large Binocular Telescope (LBT) is unique in that it has two permanently mounted adaptive secondary mirrors (ASM) to control the wavefront correction as measured by different wavefront sensors located at different Gregorian focal stations of the telescope. The First Light Adaptive Optics (FLAO) systems are located at the Front Bent Gregorian (FBG) foci and provide correction for the two LUCI NIR imagers/spectrographs the ARGOS wavefront sensors are also accessed via the FBG and provide ground-layer correction for the two LUCIs the two Large Binocular Telescope Interferometer (LBTI) systems are located at the Center Bent Gregorian stations and provide correction for the LBTI Optical Bench including the beam combiner and the Rear Bent Gregorian stations are being prepared for the installation of LINC-NIRVANA. We present an overview of the current status of and future plans for the AO systems and the ASMs.

Poster Session 3 Thu – Data post-processing

Astrometry with Spatially Variable PSFs: Instrumental Field-Depenedent Aberrations in the NIRC2 Instrument on the Keck II Telescope

Sitarski, Breann; Witzel, Gunther; Fitzgerald, Michael; Lu, Jessica; Campbell, Randall; Ghez, Andrea; Do, Tuan; Kassis, Marc; Lyke, Jim; Doppmann, Greg
UCLA

We present a model of field-dependent aberrations arising in the NIRC2 instrument on the W. M. Keck II Telescope. We use high signal-to-noise phase diversity data employing a source in the Nasmyth focal plane to construct a model of the optical path difference as a function of field position across the detector. With a differential wavefront error of up to 190 nm, this effect is one of the main contributors to astrometric and photometric measurement uncertainties. We discuss the contribution of time variability in our phase diversity data as well as the construction of a third-order spline interpolated model constructed for each Zernike coefficient across the field of view of the detector. This interpolated model is absolutely essential for the creation of a continuous model of these instrumental contributions, and we discuss the robustness of the model.

Poster Session 3 Thu – Data post-processing

PSF reconstruction for the MUSE-GalacsiGLAO mode in Python

Silva, Manuel; Fusco, Thierry; Neichel, Benoit; Garcia, Paulo; Ascenso, Joana

SIM / FEUP

The resolution of ground-based telescopes can be dramatically increased by using Adaptive Optics (AO) instruments to correct wavefront distortions introduced by Earth's atmosphere. The use of AO systems is growing at an increasing rate and ESO, in particular, is already preparing the next generation of AO instruments for both the VLT and the E-ELT. Even though the corrected images obtained with these instruments are closer to the ultimate diffraction limit, the correction is not perfect, particularly in the case of a large Field of View. Thus, it is often necessary to use a posteriori image processing techniques in order to improve estimation of astrophysical data. These techniques require accurate knowledge of the system's PSF in an arbitrary position in the Field of View. We present a PSF reconstruction software, written in Python, which estimates the PSF in the particular case of the MUSE/GALACSI instrument. It includes the Field of View location and wavelength dependencies, and takes into account the main sources of error.

Poster Session 3 Thu – Data post-processing

Astrometry with spatially variable PSFs: modeling atmospheric anisoplanatism and instrumental aberrations for NIRC2

Witzel, Gunther; Lu, Jessica R.; Ghez, Andrea; Fitzgerald, Mike; Sitarski, Breann; Campbell, Randall; Do, Tuan

UCLA

The UCLA Galactic Center group presents the results after year three of an ongoing effort to model the spatially variable adaptive optics (AO) point

spread functions (PSFs) for the AO near-infrared camera NIRC2 at the Keck II Telescope. It is the goal of this project to improve astrometry and photometry for stars in the innermost 10" of the Galactic Center, and to thereby dramatically enhance the precision of stellar orbit measurements. The lack of knowledge about the spatial variability of NIRC2 PSFs is the most important limitation to date both due to atmospheric anisoplanatism and field-variable instrumental aberrations. We developed a toolset for modeling field-variable PSFs and efficiently determining astrometry and photometry by PSF-fitting with variable PSFs. We present an overview of our code and astrometric calibration, and characterize the performance of the algorithm with on-sky Galactic Center data.

Poster Session 3 Thu – Data post-processing

Deconvolution of Large Binocular Telescope Interferometer Images of the Jovian satellite Io.

Christou, Julian; Baena-Gallé, Roberto; Betero, Mario; Boccacci, Patricia; Conrad, Albert; Fusco, Thierry; Gładysz, Szymon; Hinz, Philip; Hofmann, Karl-Heinz; La Camera, Andrea; Leisenring, Jarron; Schertl, Dieter; Weigelt, Gerd

LBTO

The Large Binocular Telescope Interferometer, is able to provide unprecedented ground-based IR resolution from the 23m baseline of the two comounted 8.4m apertures, each using AO correction. One object of significant scientific interest is the Jovian satellite Io which has numerous volcanoes scattered across its surface. Their thermal signatures are clearly visible in the L & M bands. Unfortunately, the point spread function provided by the LBTI is dominated by visibility fringes which makes identification of all of the "hot-spots" problematic. However, the LBTI focal plane does not rotate with the sky so that these fringes appear to rotate with reference to the source. This allows for multiple observations of the same field but with a changing PSF. The satellite, however, also rotates as seen from the Earth so that the hot-spots move slowly across the disc from one apparition to the next further complicating the problem. We present the results of the application of different state-of-the-art deconvolution algorithms to these Io data to determine which are better suited to extract the science.

Poster Session 3 Thu – Laser guide star systems

Laser Pointing Camera: a valuable tool for the LGS-AO operations

Centrone, Mauro; Bonaccini Calia, Domenico; Pedichini, Fernando; Cerruto, Antonio; Ricciardi, Andrea; Ambrosino, Filippo

INAF Osservatorio Astronomico di Roma

In this talk we describe the design and functionalities of the Laser pointing Camera, developed for the ESO Adaptive Optics Facility.

The LPC allows to have a fast pointing of the multiple LGS on the AO WFS during the initial acquisition phase of the telescope preset, thus reducing considerably the overheads currently experienced in most LGS-AO systems in operation. By recognizing the field stars as well as the multiple LGS, LPC is insensitive to flexures of the laser launch telescope or of the receiver telescope opto-mechanics.

Moreover, LPC gives regularly the photometry and fwhm of the LGS, as well as the scattering of the uplink beams at the height of 10-15km, thus monitoring the presence and evolution of cirrus clouds.

We will further present the first Commissioning results of the Laser Pointing Camera, obtained at the ESO VLT during the 4LGSF first unit Commissioning, and will discuss its possible extension for the ELT operations.

Poster Session 3 Thu – Laser guide star systems

Long pulse Sodium laser on sky test in 2011 2015

Wei, Kai; Li, Min; Chen, Shanqiu; Bo, Yong; Cheng, Feng; Zuo, Junwei; Bian, Qi; Yao, Ji; Zhou, Luchun; Wei, Lin; Jiang, Changchun; Chen, Donghong; Gao, Yang; Jin, Kai; Dai, Xiaolin; Fu, Hanchu; Xu, Chang; Wang, Zhichao; Xue, Xianghui; Cheng, Xuewu; Qian, Xianmei; Zhou, Yu; Xian, Hao; Peng, Qinjun; Rao, Changhui; Xu, Yanzu; Zhang, Yudong
Institute of Optics and Electronics, Chinese Academy Science

The test for the long pulse Sodium laser is presented, including the laser stability test, on sky for the photon return test, D2b repumping test. The LGS AO system using a long pulse Sodium laser which is mounted on 1.8 meter telescope for LGS AO first light testing is presented. And latest status for an upgraded high power laser (40W), upgraded AO system with 164 elements DM for High Contrast Imaging is described.

Poster Session 3 Thu – Laser guide star systems

Retrieving Tip-tilt information from Tomographic Laser Guide Star Adaptive Optics Systems

Reeves, Andrew; Myers, Richard; Morris, Tim; Osborn, James; Bharmal, Nazim Ali
Centre for Advanced Instrumentation, Durham University

Current Laser Guide Star (LGS) Adaptive Optics (AO) systems disregard all tip-tilt wavefront information received from the LGS Wavefront Sensors (WFS), as it is considered irretrievably entangled with the "up-link" turbulence that the laser encounters as it passes through the atmosphere to form a guide star. Consequently, they must still observe a Natural Guide Star (NGS) in order to correct for tip-tilt aberrations. In this paper a method is

presented to use the tomographic capabilities of centre-launched, multi-LGS AO systems to predict the LGS uplink turbulence and hence allow correction with a reduced requirement on the NGS, or potentially no NGS requirement at all for some scientific applications. Due to the increased separation of the laser beams at higher altitude, the method is more effective for correction of tip-tilt from high altitude turbulence, with performance approaching that of an NGS-only system. The method is less successful for correcting tip-tilt contributions from low altitudes, though potential mitigation of this is considered. We finally discuss the method's potential for ELT scale operation. Due to the large aperture size, and large LGS separation, it is expected that the method would be more effective for larger telescopes.

Poster Session 3 Thu – Laser guide star systems

Progress report on the ESO 4LGSF

Hackenberg, Wolfgang; Bonaccini Calia, Domenico; Guidolin, Ivan; Pfrommer, Thomas; Kern, Lothar; Dupuy, Christophe; Lewis, Steffan; Huber, Stephan; Guzman, Ronald; Comin, Mauro; Popovic, Dan; McLay, Stewart; Holzlöhner, Ronald
ESO

The ESO 4LGSF is part of the Adaptive Optics Facility, which is built for the VLT UT4 telescope, with the aim of transforming UT4 into an adaptive telescope. The AOF and its subsistems are considered a prerunner for the EELT.

In April this year we have integrated, verified and Commissioned at nighttime the first of four LGS units at the UT4.

We report on the prgress of the project, on the industrial laser units tests as well as on the field test results of the LGSU1 Commissioning.

Poster Session 3 Thu – Laser guide star systems

Laser Operations at the Large Binocular Telescope Observatory

Rahmer, Gustavo; Lefebvre, Michael; Christou, Julian
LBTO

ARGOS is the GLAO (Ground-Layer Adaptive Optics) Rayleigh-based LGS facility for the Large Binocular Telescope Observatory (LBTO). It is dedicated for observations with LUCI1 and LUCI2, LBTO's pair of NIR imagers and multi-object spectrographs. The system projects three laser beams from the back of each of the two secondary mirror units, which create two constellations circumscribed on circles of 2 arcmin radius with 120 degree spacing. Each of the six Nd:YAG lasers provides a beam of green (532nm) pulses at a rate of 10kHz with a power of 14W to 18W. We achieved first on-sky propagation on the night of November 5, 2013, and commissioning of the full system

is ongoing. We present an update on laser operations at the observatory, including safety procedures and the required coordination with external agencies (FAA, Space Command, Military Airspace Manager). We also describe our operational procedures and report on our experiences with aircraft spotters. Current plans for safer and more efficient aircraft monitoring and detection are discussed.

Poster Session 3 Thu – System control & algorithms

Distributed Kalman Filter for Large Scale Adaptive Optics

Gilles, Luc
Thirty Meter Telescope

We have developed a computationally efficient recursive adaptive distributed Kalman filter (ADKF) for atmospheric tomography on extremely large telescopes. ADKF incorporates a low-cost adaptive least squares wind profiler operating on a small portion of each estimated phase screen to track temporal dynamics. With this module, ADKF is able to reach the same performance level as the static minimum variance reconstruction (MVR), thereby fully compensating for the loss of performance of the original distributed Kalman filter (DKF) arising from the infinite pupil and uniform measurement noise approximations. ADKF's additional computational cost is negligible with respect to the original DKF algorithm.

Poster Session 3 Thu – System control & algorithms

Durham AO Real-time Controller (DARC) on GPU

Bitenc, Urban; Basden, Alastair; Dipper, Nigel; Myers, Richard
Durham University, CfAI

We present an implementation of Durham AO Real-time Controller (DARC) that can run on one or more GPUs. The pixel data from a camera is retrieved by the CPU, copied to GPU, processed and the actuator commands are copied back to CPU. We ensure that copying pixel data from CPU to GPU runs to a large extent in parallel to processing data on GPU. The data from one wavefront sensor can be processed by one or more GPUs. For a source of pixel data we use a real camera and multiplex its output to emulate several wave-front sensors. We demonstrate that the GPU architecture can successfully be used on ELTs.

Poster Session 3 Thu – System control & algorithms

An efficient Reconstruction Method for Ground Layer Adaptive Optics with mixed Natural and Laser Guide Stars

Wagner, Roland
RICAM Linz

As the image quality of modern ground based telescopes like the planned European Extremely Large Telescope (E-ELT) is degraded by effects of atmospheric turbulence, they depend heavily on Adaptive Optics (AO) systems. Using measurements of incoming wavefronts from guide stars, AO systems reconstruct the turbulence above the telescope and derive the shape of deformable mirror(s) (DM). Most types of AO systems rely on measurements from artificially created laser guide stars (LGS) as the sky coverage with bright stars is low. Unfortunately, measurements from LGS suffer from additional effects, e.g., spot elongation, which affect the reconstruction of the atmosphere or the shape of the DM. We present a new reconstruction method for Ground Layer Adaptive Optics (GLAO), based on the Bayes approach. In GLAO, several guide stars, each associated to a wavefront sensor, and a single mirror are used for the correction of the turbulence in the layer closest to the ground, where usually most of the atmospheric turbulence is located. Such a system uses a combination of natural and laser guide stars. As spot elongation is a well-documented effect when observing an LGS, one can model it mathematically in the reconstruction approach. In the Bayes approach it is natural to model the spot elongation as a specific noise distribution. Contrary to the standard approach, including the noise distribution of the spot elongation directly into the reconstruction of the atmosphere, e.g., by the minimization of an appropriate Tikhonov functional, and thus solving a large coupled system of linear equations, we aim for a compensation of spot elongation in a separate preprocessing step. Together with a cumulative reconstructor (CuReD), this results in a new linear and fast GLAO reconstructor.

Poster Session 3 Thu – System control & algorithms

LMI based anti-windup compensator design of tip-tilt mirror.

Folcher, Jean-Pierre
Laboratoire Lagrange

This paper adresses the application of LMI-based approach for the control of tip-tilt modes. We focused our attention on saturation phenomena which can occur in a strong turbulence context and in the presence of structural vibration of the telescope. This phenomena can degrade the performance or even destabilize the feedback system that is denoted the “windup” effects. We propose an anti-windup two-step approach which guarantees stability and levels of performance. A controller is first designed to work well in the absense of input saturations. Then, it is modified by an anti-windup block which would modify the control signal when saturations are present. The advantages of the proposed approach are shown through numerical experiments.

Poster Session 3 Thu – Wavefront correctors

Thin shell manufacturing for current and next generations of astronomical telescopes

Ruch, Eric
Reosc

Glassy thin shells are key components for the development of adaptive optics and are part of innovative projects such as the E-ELT. However, manufacturing thin shells is a real challenge. Indeed, a classical mirror has an 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 two thin shells for the 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.

Tow VLT DSM thin shells have been delivered. This convex aspheric shell presented significant challenges during its development and manufacturing. The lessons learned during the manufacturing of the shells will be presented and the final performances will be reported.

Poster Session 3 Thu – Wavefront correctors

An Approach to Fabrication of Adaptive Secondaries for Extremely Large Telescopes

Cavaco, Jeffrey; Bruno, Terry
Northrop Grumman/Xinetics

For more than two decades, Northrop Grumman Xinetics has been the principal supplier of small deformable mirrors that enable adaptive optical (AO) systems for the ground-based astronomical telescope community. With today's drive toward extremely large aperture systems, and the desire of telescope designers to include adaptive optics in the main optical path of the telescope, Xinetics has recognized the need for large active mirrors with the requisite bandwidth and actuator stoke. Presented in this paper is the proposed use of Northrop Grumman Xinetics' large, ultra-lightweight Silicon Carbide substrates with surface parallel actuation of sufficient spatial density and bandwidth to meet the requirements of large adaptive secondary mirrors, while reducing complexity and cost.

Poster Session 3 Thu – Wavefront correctors

Optical calibration of the M4 prototype toward the final unit

Briguglio, Runa; Pariani, Giorgio; Xompero, Marco; Riccardi, Armando; Andrighettoni, Mario; Tintori, Matteo; Biasi, Roberto; Gallieni, Daniele
INAF

The M4DP is the demonstration prototype of the E-ELT adaptive mirror M4. The optical calibration and test of the M4DP, held in INAF laboratories during February and March 2015, has been a lesson learned for the forthcoming optical verification of the 5000 actuators, 6 segments final unit. The test procedure was tailored to fit the peculiarities of such 2 segments, 222 actuators prototype. Key elements are the simultaneous segments control and the measurement and correction of the rigid modes over the segmented pupil convection noise affecting the phasing was also investigated. In this paper we will report the results of the optical test and the specific solutions implemented for the phasing control and performance verification.

Poster Session 3 Thu – Wavefront correctors

Recent developments on piezo-stack deformable mirrors for ELTs

Pages, Hubert
CILAS

Recent developments on piezo-stack deformable mirrors for ELTs

Poster Session 3 Thu – Wavefront correctors

E-ELT M4 Unit updated design and prototype results

Biasi, Roberto; Gallieni, Daniele; Briguglio, Runa; Vernet, Elise; Andrighettoni, Mario; Angerer, Gerald; Pescoller, Dietrich; Manetti, Mauro; Tintori, Matteo; Mantegazza, Marco; Lazzarini, Paolo; Fumi, Pierluigi; Anaclerio, Vincenzo; Xompero, Marco; Pariani, Giorgio; Riccardi, Armando; Cayrel, Marc; Dierickx, Philippe; Hubin, Norbert; Kornweibel, Nick; Pettazzi, Lorenzo
Microgate

We present the current design of the E-ELT M4 deformable mirror consolidated at the conclusion of the Preliminary Design activity. The most prominent features of this unit are the SiC Reference Body now mounted to the positioner by a whiffle-tree and cell structure, actuators bricks, capacitive sensors layout and new cooling concept. All this allowed achieving the challenging stability requirements demanded to the M4U, as proved by analysis

and test results measured on the Demonstration Prototype, which has been updated to implement the current design. The final design and construction contract is now on-going: Final Design Review is planned on mid 2017 and delivery to site by late 2022.

Poster Session 3 Thu – Wavefront sensing

The SCAO and Low-Order WFS module of E-ELT MAORY

Spano', Paolo; Agapito, Guido; Antichi, Jacopo; Briguglio, Runa; Busoni, Lorenzo; Carbonaro, Luca; Di Rico, Gianluca; Giordano, Christophe; Riccardi, Armando; Esposito, Simone; Diolaiti, Emiliano
INAF Osservatorio Astrofisico di Arcetri

We present a status update of the NGS module designs for SCAO and Low-Order WFSs for the E-ELT MAORY instrument. Different options have been investigated, including Shack-Hartmann and Pyramid WFSs, working at visible and near-infrared wavelengths. The optical and mechanical designs match the MAORY or the E-ELT focal planes to cope with different integration scenarios. A performance comparison is given, as one of the preliminary trade-off of the current Preliminary Design phase.

Author Index