V Workshop Nazionale ADONI

Rome, 21–24 april 2026

Book of Abstracts

Contents

SPECULA: the Italian effort to advance end-to-end simulations in Adaptive Optics

21 Apr 14:00

author: Fabio Rossi

co-authors: Guido Agapito, Alfio Timothy Puglisi

Numerical end-to-end simulation is a fundamental tool in the design and optimization of complex Adaptive Optics (AO) systems. In this contribution, we present the latest developments of SPECULA (Scalable Parallel Execution of Computations Upscaling Large Adaptive optics simulations), the Python-based successor to the PASSATA framework. Developed by the AO group at the INAF-Osservatorio Astrofisico di Arcetri, SPECULA represents a paradigm shift toward modularity and high-performance computing (HPC). We detail the core architecture of the library, which leverages GPU acceleration and distributed computation to meet the heavy demands of Extremely Large Telescope (ELT) scale simulations. A recent development is the introduction of a dedicated Design GUI, which eases the construction of complex simulation networks, alongside an increasingly vast library of processing objects—including advanced wavefront sensors, Fresnel optics propagation, and multi-layer atmospheric models. The adoption of SPECULA is now a key part of the simulation and analysis efforts for major projects, including the MATTO and REVOLT facilities and the ESO ELT systems and instruments, MORFEO, ANDES, and HARMONI. Furthermore, we explore the use of SPECULA as a fast and high-fidelity data generator for training neural networks. By producing large, accurately labeled synthetic datasets, SPECULA is enabling new AI-driven solutions to traditional AO challenges, such as predictive control and non-common path aberration (NCPA) correction. We conclude by discussing the roadmap for SPECULA as it becomes a standard tool for the Italian and international AO communities.

OPTICALIB: A Python Framework for Adaptive Optics Experimentation

21 Apr 14:30

author: Pietro Ferraiuolo

co-authors: Runa Antonio Briguglio Pellegrino, Marco Xompero

Did you ever set up a new laboratory experiment, to then lose the following days, if not weeks, trying to interface the hardware with your software?

We present the solution: opticalib, an open-source Python software library developed within the Adaptive Optics Group at INAF - OAA, designed to streamline laboratory control, calibration, and data workflows for adaptive optics systems. opticalib provides a high-level interface to common laboratory hardware — including interferometers and deformable mirrors — along with a suite of robust routines for deformable mirror characterization, influence function acquisition, and related calibration tasks. Originally extrapolated from control and calibration code for both the European-Extremely Large Telescope (ELT) M4 adaptive mirror and its Optical Test Tower (OTT), the package emphasizes modularity, reproducibility, and

ease of integration with experimental setups, reducing entry barriers for AO experimentation and development. We discuss its architecture, core functionality, typical use-cases, and roadmap for future extensions.

---

21 Apr
15:00

AI Optimization for Sensorless Adaptive Optics

authors: Ivan Agostinelli, Mauro Centrone, Marco Faccini

Adaptive optics (AO) systems aim to compensate for atmospheric turbulence to achieve near diffraction-limited imaging from ground-based telescopes. Traditional AO approaches rely on wavefront sensors and model-based reconstructors, which may be sensitive to calibration errors, noise, and system non-linearities. We present ZARA, a sensorless adaptive optics optimization algorithm based on a genetic metaheuristic. The method explores the space of possible wavefront corrections by evolving populations of candidate solutions represented through Zernike modal coefficients applied to a deformable mirror. Each solution is evaluated directly from focal-plane images using a Fourier-based image-quality metric. Simulations performed show that ZARA can effectively improve image quality under turbulent conditions.

---

21 Apr
16:00

Optical Turbulence Forecast: challenges for the next-generation ground-based astronomy and for the free-space optical communication (FSOC)

author: Elena Masciadri

co-authors: Marlene De Sepibus, Fernando Pedichini, Armando Riccardi, Alessio Turchi, Camilo German Weinberger Cerro, Luca carbonaro

INAF-OAA is deeply involved since a few decades in R&D on the optical turbulence (OT) forecast applied to the ground-based astronomy mainly supported by the AO. While in the first decade of this century the main efforts in this area were focused in proving the ability on reconstructing the CN2 principally with atmospheric non-hydrostatic mesoscale models suitably equipped for the OT, in the last years the open questions are mainly focused on the improvement of the accuracy of these predictions and on the ability in implementing operational forecast systems to support the science operations of new generation telescopes. INAF-OAA is at the forefront of this research and it has been one of the main contributors to the progress in this area at international level. We are leading at present two operative forecast systems of the OT at long (next night) and short time (1h-2h) scales above two among the top-class telescopes in the visible and infrared range (ALTA at LBT and FATE at VLT). These are, at our knowledge, the first tools that can achieve the level of accuracy of the order of 0.08”- 0.1” in RMSE with observations (depending on the typology of forecasts). The experience that we are building in these years on two relevant but at the same time very different contexts (VLT and LBT) are certainly useful to pave the roadmap towards an application to the ELTs and the facilities beyond ELTs.

At the same time the forecast of the optical turbulence will play a crucial role in the coming years in the field of the free-space optical communication (FSOC) that is living an exciting boost in the last years and on which rely ambitious objectives in a wide spectrum of fields such as the space situational awareness, telecommunication, navigation, GPS, Earth observations, climate change up to quantum communication.

I will present the state of the art (achievements) and the perspectives (where we are going on). Our goals aim to improve forecast performances as well as technological infrastructures. The most performant methods of OT forecasts are at present the hybrid systems that imply the simultaneous use of non-hydrostatic mesoscale atmospheric models forecasts and real-time measurements. Such a combination can be done thanks to statistical methods such the autoregression approach, machine learning (ML) and neural networks (NN). For this reason, we are investing energies in the development of light instrumentation for the continuous monitoring of the optical turbulence (integrated values and vertical profiles) that can suitably feed the hybrid approaches.

Neural networks applied to forecasting the astroclimatic parameters in an operational context

21 Apr
16:30

authors: Marlene Callisto De Sepibus, Elena Masciadri, Steffen Mieske, Angel Otarola, Sam Ragland, Alessio Turchi, Christian Veillet, Camilo German Weinberger Cerro

The forecasting of optical turbulence is a crucial goal for astronomical ground-based observations for science operational optimization. Current research in this area identified autoregressive (AR) models as the best performers so far, achieving an RMSE of about 0.1" for seeing forecasts on a time scale of 1h (Masciadri et al. 2020 at LBT, Masciadri et al. 2023 at VLT) however neural networks (NN) remain extremely appealing as they are very flexible and they can be applied in contexts where the AR can not be used. Indeed, NN does not necessarily imply analytical expressions between observations-to-observations or observations-to-models as is the case of the AR of the references above. It is therefore interesting to investigate characteristics of such an approach particularly in a forecasting operational context. We extend here our analysis to further algorithms beyond Random Forest (RF) (Turchi, et al. 2022, Milli et al. 2019) specifically developed for time series therefore for the forecast context. Our goals are: (1) to identify the best performances achievable with neural networks, (2) which are the suitable sample of data necessary to perform a training, how to optimize them in an operational configuration, (3) how and if to modify the training all along the years to retrieve the best performances in an operational context, (4) if and how we can provide useful forecasts on time scales in between the short ones (1h or 2h) and long ones (1 or more days), (5) to investigate if and how the lack of observations of astroclimatic parameters during the day impacts on the forecast accuracy. We focus our attention on the most relevant astroclimatic parameters and we tackle two typology of forecasts: the forecast of the temporal evolution of parameters on a time scale of 1h and the forecast of the average on 1h of the parameters. This study is carried out within the framework of the FATE and ALTA projects, applied respectively to the VLT and LBT.

---

22 Apr
09:30

Towards First Light for MICADO: the PSF Reconstruction Software

author: Andrea Grazian

The MICADO instrument is designed to provide diffraction-limited, Adaptive Optics (AO)-assisted Near-Infrared (NIR) imaging and spectroscopy for the ESO Extremely Large Telescope (ELT). A key element of MICADO is the Point Spread Function Reconstruction (PSF-R) Software service. This tool is designed to perform blind reconstruction of the PSF for all science observations solely from AO telemetry data in post-processing, without requiring any information from the scientific data in the focal plane. It will work with both the Single Conjugate (SCAO) and Multi-Conjugate Adaptive Optics (MCAO) observing modes of MICADO. The SCAO PSF-R Pipeline is currently being completed and has run flawlessly using COMPASS simulated data under ESO's latest EDPS pipeline framework. The same software has also been applied to analyze ERIS-VLT AO-telemetry data from a bright three-star asterism. This validation demonstrates that the PSF-R software achieves percent-level accuracy in metrics such as Strehl Ratio, Full Width at Half Maximum (FWHM), Encircled Energy, and half-light radius for the on-axis star. For the off-axis stars, the results match within 5-20% at a distance of half isoplanatic angle. Furthermore, initial scientific simulations on extra-galactic objects confirm that the PSF-R software can accurately characterize MICADO's PSFs, meeting the high accuracy required for cutting-edge scientific analysis. This successful validation firmly places the PSF-R software on a trajectory for a highly productive first light of MICADO and regular ELT operations in the near future.

---

22 Apr
10:00

The SHARK-VIS experience in post-AO high-resolution and high-contrast imaging in visible band as a sandbox for playing with WFS telemetry and deconvolution

author: Gianluca Li Causi

The high-contrast imager SHARK-VIS, working in the visible wavelengths downstream the SOUL adaptive optics at the LBT, has recently obtained quasi-diffraction limited images of spectroscopic binaries, main belt asteroids, and the jovian moons Io and Europa, achieving a spatial resolution far beyond existing results from ground telescopes. In this talk we describe the techniques that we adopted, and present some initial experiments with recording WFS telemetry and reconstructing PSF, with the final aim to got true diffraction limit for Solar System bodies and photon limit for star subtraction in high-contrast imaging of exoplanets and their formation disks.

EKARUS: A new Adaptive Optics R&D Platform at the Asiago Observatory

22 Apr
10:30

authors: Davide Greggio, Taïssir Heritier

EKARUS is a project led by LAM/ONERA and INAF, in collaboration with Durham University, UNIGE and IPAG to gather resources and provide an ambitious state-of-the-art AO platform with guaranteed on-sky access and a modular design to test and validate innovative AO R&D concepts at the ASIAGO Observatory. EKARUS will inherit from the PAPYRUS platform, scheduled to be decommissioned early 2026 due to the renovation of the OHP Telescope 152 [Petit et al 2025]. The availability of most of the key-elements (RTC, DM, Pyramid, fast WFS Detectors) as well as the experience acquired on the PAPYRUS bench allows us to target an aggressive first light for the EKARUS platform currently scheduled for September 2026.

EKARUS will provide a SCAO system targeting high level of AO correction through a two-stages AO system scheme. The ambition of EKARUS is to provide a first stage operating in the visible (600-950 nm) and a second stage operating in the near infrared (1000-1600nm) with multiple visitor ports to welcome new concepts to be tested on-sky. In addition, an internal perturbation units will be developed to operate the system during day-time and simulate night time operation and phasing error scenarios. The AO system will be used to test innovative instrumentation concepts such as visible and near IR fiber-fed instruments (VIPA and RISTRETTO) as well as new detection concepts (Microwave Kinetic Inductance Detectors and Event-Based Cameras). This communication will present the current status of the project as well as the expected AO performance of EKARUS.

Ideas for transmissive wavefront corrector developments for enhancing wide field adaptive optics

22 Apr
11:30

authors: Armando Riccardi, Simone Esposito, Ciro Del Vecchio, Tommaso Lapucci, Carmelo Arcidiacono, Davide Giughello

Managing the large fields of view required by Multi-Conjugate Adaptive Optics (MCAO) systems presents a significant challenge for traditional reflective wavefront correctors.

Currently, these correctors must be conjugated to specific atmospheric turbulent layers, often leading to complex optical layouts. Especially in the context of Extremely Large Telescopes (ELTs), the Lagrange Invariant necessitates large-scale optics to handle reflections from a cascade of correctors. This increases system dimensions and costs, ultimately limiting the number of correcting layers and, consequently, the size of the corrected field or the performance for a given field. The introduction of transmissive wavefront correctors (TWC) would provide a major simplification, allowing for the direct stacking of devices along the same optical beam. The current market of TWC technologies is extremely limited after excluding monochromatic or polarization driven devices. Moreover, existing devices lack the necessary number of correction modes (currently < 40) or the rapid dynamic response required for astronomical AO applications (currently 100ms settling time) with clear apertures of the order of few centimeters.

After a brief review of the current technology, we present our ideas for a development, in the framework of ADONI, of TWC devices in the direction of the astronomical AO needs.

---

22 Apr
12:00

AIO: Adaptive Intelligent Optics

author: Massimo Brescia

Adaptive optics is now an essential tool for achieving diffraction-limited resolution on ground-based telescopes in the 8–40 m class. However, the drastic increase in the number of actuators, correction frequencies and computational volume places severe limits on classical AO systems based on Least-Squares/Minimum-Variance reconstruction and linear control. We present the state-of-the-art of Artificial Intelligence (Machine Learning and Deep Learning) solutions applied to the entire AO chain: from wavefront sensing to wavefront reconstruction and predictive control, up to end-to-end and sensorless approaches that directly optimize the scientific image without explicit sensors. We will outline the open challenges (interpretability, real-time training, edge-AI) and the concrete opportunities for the ADONI community to develop Italian open-source frameworks and actively contribute to the development of next-generation AI.

---

22 Apr
12:30

Stack of deformable lenses for multi-conjugate adaptive optics

author: Stefano Bonora

Long-range imaging and Free-Space Optical (FSO) communications are severely degraded by atmospheric turbulence, which induces complex phase aberrations. While Multi-Conjugate Adaptive Optics (MCAO) using dual Deformable Mirrors (DMs) has traditionally addressed wide Field-of-View (FOV) corrections, its implementation is often limited by significant optical footprints and alignment complexity. This study investigates an innovative MCAO architecture based on a stack of transmissive Adaptive Lenses (AL). By replacing bulky reflective components with a refractive, in-line configuration. We present the system design and preliminary experimental results, demonstrating that AL-based MCAO provides a robust, compact, and 'plug-and-play' solution for high-bandwidth optical links in turbulent environments.

ORCAS a new space orbiting guide star

22 Apr
14:30

author: Gianluca Di Rico

Recent adaptive optics systems have greatly improved the sensing and correction of atmospheric turbulence in large ground-based telescopes, nevertheless, yet important constraints continue to limit its full effectiveness. Although recent progress in LGS and NGS wavefront sensing is expected to mitigate the issue of sky coverage, achieving the full performance of current 8-10 meter facilities and future Extremely Large Telescopes remains an open challenge. A promising path is offered by Satellite Guide Stars, an idea introduced in the 1990s that has now become technically feasible with existing technologies. Within this framework, NASA's ORCAS mission aims to deploy the first SGS with a brightness of magnitude 0, enabling diffraction-limited observations from the infrared to the visible band over potentially the entire sky. Such a capability would have a major impact on a wide range of astrophysical investigations, including studies of Active Galactic Nuclei, Dark Matter, flux calibration, the high-redshift Universe, exoplanets, and the Solar System, while also maximizing the value of current instruments and strengthening the scientific potential of future observatories. We outline the ORCAS mission and its main technical goals, with the aim of fostering discussion on the potential role of INAF and on the new opportunities that such a collaboration could open, in view of its involvement in the development of major current and next-generation adaptive optics facilities.

Convolutional neural network for the PSF subtraction in high contrast imaging

23 Apr
09:30

authors: Benedetta Di Francesco, Gianluca Di Rico, Fernando Pedichini, Elisa Portaluri, Simone Sacquegna

Thanks to Adaptive Optics systems, ground-based telescopes in the 8m class have been successful in detecting exoplanets through direct imaging, starting with the infrared bands, and recently also in the visible, with the Hα observations of PDS 70 b,c and WISPIT 2 b protoplanets. One of the hardest parts of exoplanet detection is the data post-processing, in particular distinguishing the planet signal from the speckle noise of the parent star in which it is embedded (by reconstructing and removing the PSF of the star from the image); the planet is indeed often 10^5 or more times fainter than the star. Typical algorithms such as ADI - PCA rely on the statistical analysis of the data sequence. In this work, we are proposing the use of a trained neural network as a robust estimator of the parent star PSF, using precise simulations of telescope observations in which the PSF is generated through a complete physical optics system, generating pairs of ideal and corrupted images of the field.

---

23 Apr
10:00

EKARUS at Asiago Observatory: Design and Implementation of the Instrument Control Software

author: Elia Costa

co-authors: Angelie Alagao, Andrea Balestra, Alessandro Ballone, Andrea Baruffolo, Benedetta Di Francesco, Daphne Diretto, Davide Greggio, Cédric Taïssir HERITIER-SALAMA, Salvatore Lampitelli, Alessandro Lorenzetto, Bernardo Salasnich

The EKARUS project, building on the technologies and experience gained from the PAPYRUS bench, is an international collaboration between LAM, ONERA, INAF, Durham University, and IPAG. The adaptive optics (AO) instrument will be installed at the Copernico Telescope at the Asiago Observatory and is primarily intended as a testbed for AO technologies. This paper presents the design, architecture, and implementation of the EKARUS Instrument Control Software (ICS). The ICS is built on the Python-based PLICO framework, chosen for its native support for distributed systems and for its clear separation between high-level sequencing logic and low-level hardware interface. The software architecture adopts a fully service-oriented model, leveraging the ZeroMQ (ZMQ) messaging library to establish robust communication. The system comprises multiple specialized, independently server components - including Motor Servers, Scientific Camera servers and the Data Archiver - all operating autonomously and communicating with a central "Sequencer-like" control component. A key design principle is strict hardware abstraction: replacing any physical device (e.g., motors or cameras) requires modifying only the corresponding server module, leaving the Sequencer and the rest of the system untouched. This approach provides substantial flexibility for an R&D test bench, enabling rapid hardware swap-out, short integration cycles, and high testability. The resulting EKARUS ICS provides a highly modular, scalable, and maintainable solution. It ensures data integrity via a segregated database layer (DB Manager). While the ICS provides open-loop control, its design is optimized for efficient support of the EKARUS AO bench infrastructure and seamless communication with the Real-Time Controller (RTC) system and the Telescope Control System (TCS).

---

23 Apr
10:30

The New Ingot WFS Optical Test Bench

author: Tania Sofia Gomes Machado

co-authors: Elisa Portaluri, Davide Greggio, Kalyan Radhakrishnan, Simone Di Filippo, Alessandro Ballone, Federico Battaini, Oleksandra Rebrysh, Maria Bergomi, Marco Dima, Carmelo Arcidiacono, Luca Marafatto, Jacopo Farinato, Demetrio Magrin, Valentina Viotto, Roberto Ragazzoni, Davide Giughello, Dhiraj Gupta, Andrea Bianco, Michele Frangiamore, Gianluca Di Rico, Mauro Centrone, Marco Faccini, Ivan Agostinelli

The Ingot Wavefront Sensor (I-WFS) is currently being tested and characterised at the INAF-Osservatorio Astronomico di Padova laboratory. This new technology for Adaptive Optics (AO) systems is designed to mitigate issues related to the Sodium Laser Guide Star (Na-LGS) wavefront sensing in the context of Extremely Large Telescopes (ELTs). The I-WFS design is tailored to the unique

three-dimensional geometry of the Na-LGS, an approach different to that of classical WFSs which are optimised for point-sources like the natural guide stars. The I-WFS project over the years has been divided into several work packages, including E2E simulations, laboratory testing and on-sky demonstration planning. We present an update on the current status of the project regarding laboratory testing and point out future plans of the project. Particularly, the optical test bench is undergoing exciting modifications: the new optical design closely resembles the MORFEO LGS module and the ELT laser launcher configuration. It allows to simulate LGS elongations of maximum ∼20 arcseconds, LGS altitude of 92 km and maximum width of 18 km, with the possibility to simulate different sodium density profiles. We also detail the new features of the test bench, mainly the new LGS source replication, the DM, the RTC and the Ingot prototype.

NirvanaVIS: AO-Assisted Wide Field Speckle Imaging at LBT

23 Apr
11:30

author: Remon Sjoerd Van Gaalen

NirvanaVIS, the visible imager upgrade to the LINC-NIRVANA@LBT instrument, will use the on-sky proven wide-field ground-layer correction with speckle imaging to approach the LBT's single-eye diffraction limited resolution.

The combination of an 8m telescope, a fast and low-noise sCMOS detector, and the use of an AO-system is unique in the field of speckle imaging, pushing the limits of this technique. This instrument is currently going through the AIV phase in the laboratories of INAF-OAPD and expected to start commissioning at the end of 2026.

In this talk, the capabilities of this instrument will be presented along with the current state of the AIV.

Speckle Reconstruction Techniques for High-Resolution Visible Imaging

23 Apr
12:00

author: Carmelo Arcidiacono

Speckle imaging remains a powerful approach for achieving diffraction-limited resolution at visible wavelengths from the ground, particularly when adaptive-optics correction is limited or unavailable. This review summarizes the main reconstruction techniques developed for short-exposure imaging, including power-spectrum methods, Knox–Thompson phase retrieval, bispectrum analysis, speckle masking, and speckle holography. Particular emphasis is placed on their relative performance in terms of phase recovery, photon efficiency, and robustness in realistic observing conditions. The talk will also discuss recent developments in the photon-limited regime and the growing interest in combining speckle reconstruction with partial adaptive-optics correction, such as ground-layer AO, to improve sensitivity and image quality.

---

23 Apr 12:30

Final optical design of the adaptive optics module of MAVIS

author: Oleksandra Rebrysh

MAVIS (MCAO-Assisted Visible Imager and Spectrograph) is a next-generation instrument being developed for the Very Large Telescope (VLT). Designed to deliver high-resolution imaging and spectroscopy in the visible wavelength range, MAVIS represents a major technological step forward, as it will be the first multi-conjugate adaptive optics (MCAO) system operating in this spectral range. To achieve the goals, MAVIS requires a highly optimized adaptive optics system.

We present the final optical design of the adaptive optics module (AOM) of MAVIS, along with the corresponding optical analyses. The AOM consists of three optomechanical modules – the post-focal relay optics, the Natural Guide star (NGS) and the Laser Guide Star (LGS) wavefront sensor (WFS) modules – as well as the Real Time Control (RTC) system. The system provides means to use up to three NGSs for low-order aberration measurements and eight LGSs for sensing higher modes. Wavefront correction is performed using the Deformable Secondary mirror (DSM) of the AOF and two post-focal deformable mirrors conjugated at altitudes of 6 km and 13.5 km, allowing for wide-field turbulence compensation. The AOM is expected to deliver a 30x30 arcsec field of view to the scientific instruments. The optical design presented here is the outcome of extensive trade-off studies aimed at balancing the feasibility and maximizing the performance of the instrument.

---

23 Apr 14:30

Prototyping activities of the MORFEO Soft Real-Time Computer

author: Chiara Di Prospero

co-authors: Andrea Baruffolo, Giulio Capasso, Salvatore Lampitelli, Alfio Timothy Puglisi, Salvatore Savarese

MORFEO (Multi-conjugate adaptive Optics Relay For ELT Observations) is the post-focal adaptive optics module of the ESO Extremely Large Telescope (ELT) and it provides MCAO correction for MICADO and HARMONI instruments.

MORFEO provides a high and uniform image quality across a 1-arcmin wide FoV via two post-focal deformable mirrors, the ELT's adaptive mirrors M4 and M5 and via wavefront sensing of 6 Laser Guide Stars (LGS) and up to 3 Natural Guide Stars (NGS). The latter are sensed respectively by low-order infrared (LO) and visible (REF) wavefront sensors.

The AO corrections are computed by the MORFEO Real-Time Computer (RTC), which comprises two subsystems: Hard (HRTC) and Soft (SRTC) Real-Time Computer. While the HRTC implements the core AO control loops (via a pseudo open loop strategy), the SRTC is in charge of the whole RTC monitoring, coordination and optimization. Additionally, the SRTC is entrusted with data recording for scientific and engineering purposes, AO performance parameters estimation and computation of the ELT M4 segment phases.

This paper focuses on the prototyping activities carried out in order to design the SRTC according to the functionalities listed above and to the stringent timing requirements, within the constraints imposed by the ESO standards, both in hardware and software (ESO RTC toolkit framework - rtctk). In particular, prototypes were developed to investigate three main scenarios:

- The SRTC system's ability to sustain high throughput and low latency network traffic
- Optimal allocation of SRTC tasks' resources to properly distribute the computational load
- Customization of ESO rtctk components in order to meet instrument's specific functionalities, such as the handling of the LO and REF multi-rate telemetry

Results of these prototypes are presented, as well as future prototyping activities envisioned as the ESO rtctk framework continues to evolve.

Static adaptive correction to compensate for non-axisymmetric wavefront distortions in next-generation gravitational wave detectors

23 Apr
15:00

authors: Lorenzo Aiello, Elisabetta Cesarini, Maria Cifaldi, Luciano Antonio Corubolo, Viviana Fafone, Matteo Ianni, Matteo Lorenzini, Diana Lumaca, Yury Minenkov, Ilaria Nardecchia, Alessio Rocchi

In gravitational wave detectors, optical aberrations arise mainly from laser absorption in coatings and production process defects in the optics along the laser path. If left uncorrected, these optical path distortions drive the interferometer away from its optimal working point, compromising stability and sensitivity. Future generations of gravitational wave detectors, such as Einstein Telescope–High Frequency, will operate with unprecedented circulating optical power, further amplifying the aberration budget.

The adaptive correction of optical path distortions in transmission is obtained by illuminating on–path dedicated optics with a shaped CO_2 beam, whose wavelength is locally fully absorbed to produce a corrective thermal lens for the main beam of the interferometer. Assuming the axisymmetric component is compensated by the thermal and CO_2 actuators as in Advanced Virgo, the non–axisymmetric wavefront distortions still need to be mitigated.

Deformable Mirrors (DMs) are investigated as a flexible solution for mitigating such defects: by shaping the CO_2 beam phase upon reflection, DMs can project the required asymmetric intensity pattern on the lensing optics. The static and adaptive nature of this correction avoids introducing frequency–dependent noise in the detector band. The needed phase correction is computed using a Modified Gerchberg–Saxton algorithm. We describe the simulations developed to model the projection strategy and the experimental validation of the target intensity pattern reproduction.

---

23 Apr
15:30

AdaSTRA: Adaptive optics for Space Telescopes

authors: Chiara Scandaglia, Runa Briguglio, Matteo Menessini, Marco Xompero, Alberto Riva

Scientific cases of interest for future-generation space telescopes, such as the characterization of extrasolar planets and large-scale cosmological structures, result in particularly challenging requirements such as high resolution, very high contrast and ultra-stability of the wavefront, which in turn must be matched with an effective mitigation of the risks and costs related to the particular environment in which the telescope operates. In this context, the integration of active optics techniques may address these needs, through the active control of the wavefront and the capacity to implement corrections directly on the primary mirror, where the light is collected. The use of special contactless actuators on the DM (e.g. voice-coil) would also provide decoupling between the mirror and its reference body, with consequent rejection of vibrations and reduction of tolerances and weights due to the opportunity of adopting lighter materials. The employment of deformable mirrors also combines well with coronagraphic techniques to acquire high-contrast images, which are essential for the direct observation of exoplanets.

The present contribution aims to provide a tool to simulate the effects of the orbital environment on a space telescope equipped with a segmented deformable primary mirror and its actuating system, based on voice coil actuators and capacitive sensors: the peculiarity of this contactless technology lies in the independence of the mirror influence functions from the actual local shape of the support. The system is represented by an integrated model with parametrizable features, including the number and the arrangement of the mirror segments and actuators. The simulator will perform coupled thermo-mechanical analyses taking into account the thermal loads on the mirror as the orbit and configuration of the telescope change, and will return the deformations and displacements of the support and their propagation to the optical surface, with the dual objective of calculating the wavefront correction at the focal plane and thus estimating the mirror performance, in terms of fitting error, in the presence of global thermo-elastic aberrations.

This tool is meant to deliver a first qualitative and quantitative evaluation of the mechanical behaviour, as well as its consequences on the performance and hence on the expected scientific return, of a telescope with an active contactless mirror cast in the space context. Furthermore, it can work as an asset for a preliminary study of the mission costs thanks to the possibility of comparing the effects of different orbit profiles and therefore conducting an appropriate trade-off analysis. At last, the simulation tool might be leveraged to assess in simulation high contrast techniques using a high order deformable mirror, through integration with suitable software packages for high resolution analysis.

Current challenges in Adaptive Optics at Bertin Alpao

23 Apr
16:00

author: Armin Schimpf

The technical and organizational challenges faced by Bertin Alpao today are increasingly shaped by the requirements of Free Space Optical Communication, astronomical instrumentation, and demanding industrial applications. We present related developments in wavefront correction, sensing, and control, and discuss the strategies implemented by Bertin Alpao to support production scale-up and industrial transformation.

SHARP: a next-generation near-IR spectrograph conceived for the ESO-ELT

24 Apr
09:30

author: Paolo Saracco

The next decade of observational astronomy will be defined by the transition from the pioneering discoveries of the James Webb Space Telescope (JWST) to the unprecedented resolving power of the Extremely Large Telescope (ELT). While JWST/NIRSpec is revolutionizing our understanding and opening new horizons through unexpected findings, it is also highlighting the need to go beyond its current limits to address emerging questions.

SHARP is a next-generation near-IR (0.95–2.45 μm) spectrograph designed to fully exploit the collecting area and angular resolution of the ELT through the Multi-Conjugate Adaptive Optics (MCAO) module MORFEO. By achieving an angular resolution ($\sim$0.03") more than three times better than JWST/NIRSpec (0.1"), SHARP will resolve sub-pc scales even beyond the Local Group, and sub-galactic structures down to the scale of Giant Molecular Clouds (GMCs; $\sim$150-200 pc) up to the early Universe.

Its dual-mode architecture, featuring NEXUS for multi-object spectroscopy and VESPER for multi-integral field spectroscopy, will enable the detailed mapping of these fundamental building blocks even in the earliest galaxies. This presentation will provide an overview of the multi-mode spectrograph SHARP and its technical features, along with an update on its design and overall project status.

---

24 Apr
10:00

Design and early implementation of the MCAO MATTO bench

author: Alessandro Ballone

co-authors: Valentina Viotto, Luca Marafatto, Davide Greggio, Oleksandra Rebrysh, Lorenzo Merli, Carmelo Arcidiacono, Andrea Baruffolo, Maria Bergomi, Elena Carolo, Simonetta Chinellato, Simone Di Filippo, Marco Dima, Jacopo Farinato, Demetrio Magrin, Kalyan Radhakrishnan, Gabriele Umbriaco, Daniele Vassallo, David Barr, Cetre Sylvain, Roberto Ragazzoni

In this contribution, we will present the design and the very first implementation of the Multi-conjugate Adaptive Techniques Test Optics (MATTO) bench at the Astronomical Observatory of Padova. Conceived in the framework of the INAF STILES (Strengthening the Italian leadership in ELT and SKA) PNRR program, MATTO will serve the ADONI and international AO community as a multi-purpose wide-field AO test facility, aimed at simulating existing or future MCAO systems configurations with test or validation purposes. The modularity of MATTO's opto-mechanical design allows to explore a wide range of WFS and source combinations. A reference source module simulates the atmospheric behavior on a maximum of 3 natural and 3 laser guide stars that can be configured independently and injected through dedicated deformable mirrors (DMs) or Spatial Light Modulators (SLMs). The atmospheric turbulence can be alternatively injected in the telescope simulator module, via lithographically-printed phase screens. In the MCAO correction module, three DMs (almost 1500 actuators in total) can be conjugated at various heights, to mimic a wide number of optical configurations. The sensing module will allow to replicate the main properties of different types of pupil or focal plane WFSs, through simulated (via SLMs) or physical phase masks. The DAO4MATTO control system, based on the flexible DAO RTC toolkit, will provide MCAO loop control, reinforcing the overall modular approach and adapting to any possible experimental setup.

---

24 Apr
10:30

The ADONI-ET Optical Test Bench experiment. Part of a feasibility study for closed-loop adaptive thermal compensation in gravitational wave detectors

authors: Simone Lombardi, Armando Riccardi

co-authors: Luca Carbonaro, Ciro Del Vecchio, Simone Esposito, Tommaso Lapucci, Alfio Timothy Puglisi

Within the international effort toward the realization of third generation ground based Gravitational Wave Detectors (GWD), Italy founds the PNRR project ETIC (Einstein Telescope Italy Contribution), which is developing facilities addressing a wide range of technological challenges. While the Italian Einstein Telescope (ET) instrument scientists are primarily affiliated with INFN, INAF is responsible for the ADONI-ET Optical Laboratory (Adaptive Optics National Laboratory of INAF for the Einstein Telescope), with the aim of transferring technology and expertise to the Thermal Compensation Systems (TCS) already in use in VIRGO and LIGO.

In fact, while the current working TCS only allows correction of the probe beam radius of curvature (ROC), the use of a Deformable Mirror (DM) to shape the intensity pattern of the compensating beam could enable the correction of higher-order aberrations, with the ultimate goal of an adaptive closed-loop system. The ADONI-ET optical bench enables, for the first time, the measurement of the actual optical path difference (OPD) amplitude and spatial pattern induced in a glass test piece (GTP) by shaping the intensity of a 1W laser power source (IR@1064 nm) with a DM. The experimental setup also allows the induced OPD to be monitored in real time using an interferometer. In the final year of my PhD, significant progress was achieved both from a theoretical perspective and in the final implementation of the optical system, highlighting several technical aspects that proved crucial to the project.

Petaling on the ELT: mitigation strategy for MORFEO

24 Apr
11:30

authors: Cédric Antoine Adrien Gabriel Plantet, G. Agapito, L. Busoni, G. Carlà, M. Bonaglia, G. Pariani, A. Puglisi

The Extremely Large Telescope (ELT) relies on the segmented M4 deformable mirror to maintain high-resolution adaptive optics (AO) performance. However, these segments are prone to petaling: discontinuities in the wavefront translate into differential pistons between the segments, or "petals". These errors, for example induced by thermal gradients in low wind conditions (the "Low Wind Effect"), are catastrophic for image quality. To mitigate this, MORFEO (formerly MAORY) integrates a dedicated sensing path into its full-aperture infrared wavefront sensor. This implementation uses a specific optical setup to generate a defocused image within a narrow spectral band on the same detector as the image used to sense tip/tilt. By applying the Linearized Focal-plane Technique (LIFT) to this defocused spot, the system can reconstruct low-order phase aberrations and the petal modes directly from focal-plane data. A significant hurdle in LIFT implementation is its capture range limited by the sensing wavelength, which can lead to phase-wrapping ambiguities. To resolve this, this work proposes a multi-band configuration that utilizes different wavelengths across MORFEO's two full-aperture sensors, effectively extending the dynamic range of the phasing measurements. In this contribution, we provide a detailed analysis of the design, simulation-based performance metrics, and the current roadmap for experimental validation.

The potentiality of refractive wavefront correctors

24 Apr
12:00

author: Roberto Ragazzoni

Author Index