ADAPTIVE OPTICS: FROM CONCEPTS TO THE LATEST ADVANCES AND ITS APPLICATION TO EXTREMELY LARGE TELESCOPES (OP-002-ELT)

Course Overview

The image quality of astronomical telescopes is severely limited by atmospheric turbulence. However, Adaptive Optics solves this problem by measuring and correcting image aberrations in real time. This has been applied in all major observatories and will be an absolute necessity for future Extremely Large Telescopes including the European E-ELT. This course explains Adaptive Optics (AO) systems from the basic concepts to the latest advances and provides the background necessary to understand future AO systems for ELTs.

Summary of contents

Module 1: Introduction to Adaptive Optics

This module is concerned with the effects of turbulence on light passing through it and how these effects may be corrected by Adaptive Optics. In particular, it will cover the spatial and temporal statistics of aberrations introduced by atmospheric turbulence in lasers and stellar light. The concept of Adaptive Optics is introduced together with a summary of its history and an overview of current systems.

Module 2: Adaptive Optics Subsystems and components

This module covers the subsystems and components of an adaptive optics system in detail. Alternatives for the wavefront sensor, deformable mirror and opto-mechanical components are analysed. Control algorithms are also presented, and their optimization according to the operating conditions (turbulence statistics, signal to noise ratio in the wavefront sensor etc.)

Module 3: Advances and perspectives for Adaptive Optics

This module considers the latest advances in Adaptive Optics in some detail, as well as the areas of active research and development. The challenge of adaptive optics for the ELTs which are being designed and constructed are considered as well as the different solutions proposed.

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Module 1: Introduction to Adaptive Optics

Module 1.1. Introduction

- The importance of spatial resolution, especially for astronomy
- Limitations imposed by the Earth's atmosphere. Measures of spatial resolution (full-width at half maximum, enclosed energy) and concentration of energy (Strehl ratio)
- The concept of Adaptive Optics (AO)
- Summary of the history of AO
- Summary of current systems

Module 1.2. Atmospheric Turbulence

- The Kolmogorov theory of turbulence. Vertical structure of turbulence (turbulence due to the telescope dome, surface layer and tropopause)
- Effect of the propagation of wavefronts through a thin layer of turbulence, and its propagation to the ground. The optical transfer function (OTF) and the Fried parameter. Short and long exposures and how they depend on the ratio of telescope diameter to the Fried parameter Stellar scintillation and how it depends on the height of the turbulent layers
- Decomposition of aberrations into Zernike and Karhonen-Loeve modes. The Noll coefficients
- The Taylor hypothesis and temporal statistics of turbulence. Power spectra of Zernike modes
- Image structure as a function of the degree of correction

Module 2: Adaptive Optics Subsystems and components

Module 2.1. Wavefront Sensors

- The Shack-Hartmann sensor. Theory of operation, signal to noise ratio of the measure. Practical realization
- The Curvature sensor
- The Pyramid sensor
- The Point Diffraction Interferometer (PDI)
- Estimating aberrations from the image – Phase Diversity

Module 2.2. The Deformable Mirror

- The most common mirrors, their operation and characteristics (range, hysteresis and dynamic response)
    - Bimorph, unimorph, Piezoelectric. Membrane. Micro-mirrors
    - The actuator influence functions, correction modes of the mirrors
    - Deformable telescope mirrors (secondary and tertiary mirrors etc.)

Module 2.3. The Control System

- Algorithms for phase estimation
    - Least-squares, use of Singular Value Decomposition (SVD)
    - Maximum Likelihood (ML), and ´Maximum a Priori´(MAP) estimators
- Dynamic analysis of an adaptive optics system
- Modal Control, optimization. Kalman filter
- Control Hardware. Processing speed and data flow

Module 2.4. Optics and opto-mechanics

- Design requirements for an AO system
- Design of a system based on off-axis parabolas; first-order design and aberrations
- Opto-mechanics of the elements of an AO system
- Correction of atmospheric dispersion, Risley prisms and alternatives

Module 2.5. The error Budget of an AO system

- Analysis of the sources of error of an AO system
- Numerical simulation of the system

Module 3: Advances and perspectives for Adaptive Optics

Module 3.1. Laser guide stars

- Sky coverage limitation with natural guide stars
- Rayleigh and Sodium Laser guide stars
- Limitations, tip-tilt in determination, focal anisoplanatism, elongation of the wavefront sensor image due to the sodium layer thickness, the ‘fratricide’ effect, sporadic layers and changes in the mean sodium layer height
- Laser Technology applicable to sodium and Rayleigh guide stars
- Laser beam transport

Module 3.2. The new AO systems

- Multi-conjugate adaptive optics (´MCAO´)
- Ground layer adaptive optics (`GLAO´). Improving the encircled energy with one deformable mirror
- Multi-object OA (´MOAO´). An AO system for each object of interest in the field
- Extreme AO (´XAO´)
- SPHERE and GPI exoplanet hunters

Module 3.3. Adaptive Optics for ELTs

- Review of the ELTs being developed
- The challenges of AO for ELTs
- Co-phasing of segmented mirrors
- Current designs of AO for ELTs

Module 3.4. The European ELT (E-ELT)

- Optical Design of the E-ELT
- The E-ELT Adaptive Optics system
- AO systems for the E-ELT instruments