Atmospheric turbulence, image formation, introduction to adaptive optics

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Objectives

Atmospheric optics part: Main goal is to provide knowledge and skills in atmospheric optics, including the understanding of its fundamental laws and the measurement of its main parameters.

Image formation part: Students will become able to understand the physics of image formation through atmospheric turbulence, numerically modelize the subsequent physical phenomena involved (turbulence, image formation, detection noises). They will also learn the basics of adaptive optics and study one of its main errors: anisoplanatism.

Evaluation

Examination will be based on two reports, one about the data processing and analysis of atmospheric turbulence measurements with dedicated instruments, and the other one about the numerical modeling and analysis of simulations concerning image formation through atmospheric turbulence and anisoplanatic error. Each report represents 50% of the final mark.

Main progression steps

Atmospheric optics part:

- First period: 6 lectures lectures to acquire theoretical background on atmospheric turbulence and its origin, light propagation through turbulence, optical turbulence modelling & characterization, turbulence impacts on HAR techniques and site selection and testing,
- First period: On-sky observations with the Calern Atmospheric Turbulence Station (CATS).
- Second period: support and supervision of data processing, analysis and extraction of results on the atmospheric turbulence characterization by means of CATS instruments

Image formation part:

- First period: 6 lectures on image formation through turbulence, punctuated by various preliminary computations and the detailed numerical modelling of each basic physical phenomenon,
- First period: Physical modelling and detailed numerical simulations with CAOS and application to a study on anisoplanatic error.
- Second period: Support and supervision of the numerical simulations and analysis of the results of simulations in the framework of the anisoplanatic error study.

Bibliography & Resources

The lectures on image formation through turbulence and introduction to adaptive optics (see other references therein).

Contents

Atmospheric Optics

by Aziz Ziad

1. Introduction to atmospheric turbulence and its impact on astronomical observations
   - Observations in Astronomy, Loss of resolution
   - Atmospheric turbulent layers (wavefront random deformations)
   - Impacts of turbulence on High Angular Resolution (HAR) techniques
2. The atmospheric turbulence: Statistical properties, Dynamic and Optical Turbulence:
   - Laminar and turbulent flows
   - Characteristics of turbulent flows
   - Origin of the turbulence
   - The Kolmogorov's theory: Energy cascade
   - Dynamic turbulence
   - Temperature fluctuations
   - Refractive index fluctuations : Optical turbulence
   - Turbulence localizing
3. Light propagation through the atmosphere: Phase structure function, turbulence models, scintillation & Angle-of-arrival fluctuations:
   - Light propagation through one turbulent layer
   - Case of multiple layers (illustration with two layers)
   - Structure function of phase fluctuations (Kolmogorov's law)
   - Spectral density of phase fluctuations

- Other models describing turbulence (von Karman, Greenwood-Tarazano)
- Long exposure images
- Point spread function and optical transfer function of telescope & atmosphere
- Wavefront coherence (spatial, temporal, angular, chromatic)
- Wavefront coherence parameters

4. Site-testing instruments:
   - Site selection
   - Atmospheric turbulence characterizattion
   - Turbulence profilers : Scidar, radio-sonding balloons, MASS, SLODAR, MOSP, PBL.
   - Turbulence monitors : DIMM, GSM, Scintillometer.
   - Atmospheric turbulence and High Angular Resolution (HAR) techniques

Image formation through atmospheric turbulence and introduction to adaptive optics

by MARCEL CARBILLET

1. High-angular resolution imaging in astronomy
2. Atmospheric turbulence
   - Images & turbulence
   - Numerical modelling of perturbed wavefronts using IDL
   - Seeing and full-width and half-maximum
   - Influence of the Fried parameter, the wavelength and the outerscale
3. Formation of the resulting image
   - Detection noises
   - Detailed numerical modelling
4. Introduction to speckle interferometry
   - Basic principle
   - Numerical experiments
5. Adaptive optics (AO)
   - Introduction to AO
   - AO error budget & post-AO point-spread function morphology
6. Anisoplanatic error study
   - Introduction
   - Numerical modelling using the Code for AO Systems (CAOS)
7. Useful metrics for the analysis of post-AO data