OPTICAL FIBRES IN ASTRONOMY (OP-006)

Course Overview

The course, based on practical experience and containing several examples of real instruments, is focused on the application of optical fibres in Astronomy. Starting from the basic principles of light propagation inside the optical fibres, the course reviews the diverse materials used for different spectral ranges from UV to medium IR. Then, it describes the main parameters used to specify and characterize a fibre-fed astronomical instrument (focal ratio degradation, modal noise, scrambling, etc.), that have a direct impact in the final instrument performance, as well as the lab set-ups required to measure them. Next, the course explains the requirements needed by the fibre links that connect the focal plane to the slit of a fibre-fed instrument, from the practical point of view of the microlens - fibre gluing process. A description of the different Multi Object Spectroscopy (MOS) positioners technologies used in the arrangement of fibres at the telescope focal plane will follow. The manufacturing process (manufacturers, quality reports, delivery time…) and practical aspects of packaging, shipping and integration on site will be then summarized, to finish with an overview of the software tools used in fibre-fed instruments.

Summary of contents

Module 1: Introduction to optical waveguides

This module begins with a historical review of optical waveguides, introducing the concept of optical fibre and describing the anatomy of a fibre and all its parts. The light propagation through the fibres is then described from two perspectives: first, from the Geometrical Optics point of view, i.e. treating the light beams as rays, applying the Snell's law of refraction and the process of Total Internal Reflection, introducing the concept of numerical aperture and the importance of meridian and skew rays. And secondly, from the Physical Optics point of view, that treats the light beams as electromagnetic waves to explain phenomena such as the electromagnetic modes propagation. The module continues with a description of single and multi-mode fibres and finishes with the concept of step and graded index.

Module 2: Optical fibres main parameters and lab set-ups for their measurement

The aim of this module is to learn the kind of parameters that are important to be measured and characterized in an astronomical instrument and their impact in the final efficiency and performance of the instrument. The parameters covered will be the attenuation and transmission of optical fibres, the focal ratio degradation (FRD) and its impact on the final transmission of the instrument. Also, those parameters that place restrictions on the instruments dedicated to exoplanet finding, such as scrambling and modal noise. Then, a detailed description of the lab set-ups necessary for their measurement will be done, to finalize with a brief review of filtering and interferometry with optical fibres.

Module 3: Optical fibres and spectral interval

In this module we will detail what kind of optical fibres, materials and elements are used for propagating the light through an optical fibre depending on the astronomical spectral range, from ultraviolet (UV) to the medium infrared (MIR).

Module 4: New waveguides and Technologies

In this module we review the current technologies applied for guiding light within a fibre and their use in Astronomy. Concepts such as tapered fibres, photonic-crystal fibres and their allowed and forbidden gaps of energy will be introduced, followed by Bragg grating fibres and their properties for filtering signals; then, the module will continue by explaining the novel photonic lanterns technology that allow changing from single to multi-mode fibres and vice versa, to finish with active fibres, doped with rare earth elements of the periodic table.

Module 5: Fibre links in Astronomy

The use of optical fibres in Astronomy set a milestone in the astronomical instrumentation development. Amongst other things, in the way that instruments were built, since they have allowed, for instance, to decouple the instruments form the telescope tube structure, thus helping to reduce the weight of the telescope and, as a consequence, minimize the impact of flexures; by connecting the instruments to the telescope through optical fibre bundles, bigger and more complex instruments can be built. Moreover, the fibres enable us to adapt the instruments to higher mechanical and thermal stability environments, that is crucial to reach the required accuracy in high resolution spectrographs. Last but not least, the fibres make it possible to keep the slit width (since the telescope pupil is imaged directly on the fibre core) and therefore the spectral resolution as well.

However, the success of a fibre-fed instrument is not conceivable and reached without a good fibre link. In this module, we introduce the importance of the fibre link´s use, together with the requirements needed to specify them, the use of microlenses and how to minimize the impact of the focal ratio degradation (FRD). The module describes how a microlens is glued to the fibre, what type of connectors, optical bonds and epoxy are optimal, as well as the set-up needed. The module follows with a brief introduction to the concept of integral field units (IFU), detailing the different fibre-fed IFU types. Finally, at the other end of the fibre link is the pseudo-slit: the different solutions to align the fibres in the spectrograph entrance slit will be surveyed, with real examples in different astronomical instruments.

Module 6: Multi Object Spectroscopy. Fibre positioning technologies

In this module, the concept of multi object spectroscopy is introduced to look into the different technologies used for positioning the fibres at the telescope focal plane, thus enabling simultaneous observation of several astronomical objects. Each technology shows advantages and disadvantages that have to be taken into account for observing a denser or lower dense object field.

Module 7: Manufacturing process

In this module, the manufacturing process is summarized, covering from the specifications and requirements of the fibre link various subsystems and components, to the fibre and microlens manufacturers, the recommended quality reports, the delivery time and its impact on the management plan for the final development and integration of the instrument at the telescope.

Module 8: Integration and tests at the telescope

This module is focused on the process from the lab to the telescope: packaging, tests and shipping of the fibre bundles, interfaces with the telescope and the steps to be followed for integrating the fibres at the telescope. Also, the tests to be carried out with the fibre-fed instruments at the telescope will be detailed, together with the sky characterization of the instrument.

Module 9: Software and Tools in a fibre-fed instrument

This module describes the necessary software tools for the success of a fibre-fed instrument: fibre spectra data reduction (simulators during development, calibration and its application to the reduction steps), the importance of data cube visualization software (MOS or IFU data cube reconstruction in real time) and the need of a positioners configuration and arrangement tool for observing a certain field of objects in the sky.

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Module 1: Introduction to optical waveguides

Module 1.1. Introduction

Module 1.2. Anatomy of a fibre

Module 1.3. Propagation of light through an optical fibre

- Geometrical Optics
  - Snell's Law
  - Total Internal Reflection
  - Numerical Aperture
  - Meridian and skew rays
- Physical Optics
  - Electromagnetic waves
  - Wavefronts
  - Electromagnetic modes

Module 1.4. Single mode fibres. Step index

Module 1.5. Multimode fibres. Step and graded index

Module 2: Optical fibres main parameters and lab set-ups for their measurement

Module 2.1. Attenuation

Module 2.2. Transmission

- Set-up for transmission measurement

Module 2.3. Focal Ratio Degradation (FRD)

- FRD vs. length, core size and bend
- FRD in step and graded index fibres
- FRD in fibres with different core geometries
- FRD origin:
  - Micro-bending
  - End terminations: polishing and cleaving
- Set-up for FRD measurement

Module 2.4. Modal Noise

- SNR limits
- Dynamic diffusers
- Shakers
- Set-up for modal noise measurement

Module 2.5. Polarization

Module 2.6. Scrambling

- Scrambling gain
- Optical lens Scramblers
- Light pipes
- Beam distributors
- Beam homogenizer
  - Pupil homogenizer
  - Object homogenizer
- Mechanical Scramblers:
  - Squeezers
  - Vibrators
- Scrambling in fibres with different core geometries

Module 2.7. Filtering. Interferometry

- Beam Combiners:
  - X-coupler
  - Y-coupler
- Pupil masking
- Nulling Interferometry

Module 3: Optical fibres in astronomy depending on the spectral range

Module 3.1. Fibres for ultraviolet (UV)

Module 3.2. Fibres for visible and near infrared (VIS/NIR)

- Fused Silica.
- ZBLAN and fluoride fibres

Module 3.3. Fibres for mid infrared (MIR)

- Chalcogenide fibres
- Silver halide fibres
- Photonic fibres

Module 4: New waveguides and technologies

Module 4.1. Tapered fibres

Module 4.2. Photonic crystal fibres: Solid and hollow core

Module 4.3. Photonic lanterns

Module 4.4. Fibres Bragg grating

Module 4.5. Active fibres

Module 5: Fibre links in Astronomy

Module 5.1. Fibre link definition

Module 5.2. F-number requirements

Module 5.3. Impact on FRD

Module 5.4. Matching fibre NA

Module 5.5. Fibre Connectors

- Ferrule types
- Ferrule sizes
- Fibre fusion splicing

Module 5.6. Integral Field Units (IFUS)

- IFU with lenslet
- Fibres with lenslet
- Fibres without lenslet
    - Sparse bundles
    - Hexabundles
- Slicers

Module 5.7. Microlenses gluing process

- Requirements
- Gluing set-up description
- Gluing phase tips and recommendations
- Optical bonds and epoxies

Module 5.8. Pseudo-slits

- V-groove
- Stack core
- Sliced slits
    - Bowen Wolraven slicer
    - Two flat mirror slicer
- Pseudo-slit shapes

Module 6: Multi Object Spectroscopy. Fibre positioning technologies

Module 6.1. Pick and place positioners

Module 6.2. Tilting Spines

Module 6.3. Radial arms positioners

Module 6.4. Starbugs positioners

Module 7: Manufacturing process

Module 7.1. Fibres specifications and requirements

Module 7.2. Fibres and microlenses manufacturer

Module 7.3. Manufacturing planning and process

Module 7.4. Manufacturing and delivery times

Module 7.5. Quality reports

Module 7.6. Tubing

Module 8: Integration and tests at the telescope

Module 8.1. Packaging and shipping

Module 8.2. Integration at the telescope

Module 8.3. Tests for a fibre-fed instrument at the telescope

Module 9: Tools and Software for a fibre-fed instrument

Module 9.1. Introduction

Module 9.2. Data reduction

Module 9.3. Data cube visualization

- IFU data reconstruction
- MOS data reconstruction

Module 9.4. Robot arrangement tool