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Conceptual design of a high-resolution, integral field spectrograph for the European Solar Telescope

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Abstract

This communication presents the current status of the conceptual design of a high resolution, integral field spectrograph with multi-slit and multi-wavelength capabilities, designed for the 4 meter European Solar Telescope (EST).

1 Introduction

The European Solar Telescope [4], still under study, will be the largest solar telescope of Europe and, together with the American ATST [7](Advanced Technology Solar Telescope), the largest of the world, both with the same primary mirror diameter of 4 meters. EST [8] is promoted by the European Association for Solar Telescopes (EAST), to keep Europe in the frontier of Solar Physics. The telescope will be located in the Canary Islands. It will be optimized for studies of the magnetic coupling between the deep photosphere and upper chromosphere. The leading institution is the IAC [3], which also leads the grating spectropolarimetry workpackage and whose proposal is described in this communication.

2 General description

The IAC proposal [1] is an integral field spectrograph with multi-slit and multi-wavelength capabilities, with a superb spectral resolution, following the EST [2] science requirements. A FOV of 9×9 arcsec^2 is cut and reorganized using an integral field unit (IFU) into 8 long slits, each one with 200 arcsec length by 0.05 arcsec width, which allows the observation of an area 8 times larger than using a conventional long-slit spectrograph. To cover different solar regions a field of view scanning system is used, so that a bigger field of view can be observed sequentially.

The spectral range that will be covered by the spectrograph goes from 390 to 2300 nm. Eight wavelength intervals, 5 from the visible range and 3 from the NIR one, will be observed simultaneously. Different combinations of spectral lines are possible [2], what gives versatility to this instrument. The spatial resolution is 0.1 arcsec with a plate scale of 0.05 arcsec/pixel and the spectral resolving power is $R \equiv 300\,000$.

The output telescope focal ratio is F/50 and the spectrograph is a 1:1 F/40 system. The conversion from F/50 to F/40 is done with the integral field unit. The telescope and spectrograph are, thus, perfectly coupled avoiding possible losses of light or resolution. At the spectrograph image focal plane a reimaging system is required in order to have the appropriate scale on the detectors, converting the spectrograph F/40 to F/10.3 for the visible spectral range and to F/20.6 for the NIR one.

A detector per wavelength is used, covering the image of the 8 entrance slits associated to a given wavelength. 4k×4k detectors are considered, with a pixel size of 10 μm for visible wavelengths and 20 μm for the NIR ones.

The instrument itself can be structured like a set of coupled successive modules: field scanning system, integral field unit, predisperser, spectrograph, reimaging system and detectors, listed in the light advance direction.

2.1 Spectrograph

The spectrograph is a grating, reflective collimator-camera 1:1 system, in which each wavelength is observed in a different order. Collimator and camera are off-axis parabolic mirrors that belong to the same global parabola. Commercial diffraction gratings from the Newport catalogue have been considered. In order to improve the efficiency of the gratings in the whole spectral range, from 390 to 2300 nm, the instrument has been divided into four spectrographs that are conceptually identical, two used to cover the visible range, called: VIS-I, VIS-II, and two for the NIR: IR-I, IR-II.

At the telescope focal plane the beam is divided into two using a dichroic beamsplitter giving rise to different focal planes, one for visible and another for infrared. Each one is again divided generating the entrance to the four spectrographs.

Echelle commercial diffraction gratings from the Newport catalogue have been selected. With the chosen gratings, the efficiency [1] for all the wavelengths is very high, what is not trivial when the simultaneous observation of several spectral lines is required and with the limitation of using this kind of gratings, that present their optimum behavior for a given wavelength but might not work so well for others. The use of commercial gratings has conditioned the designs. Their physical sizes have limited the pupil sizes and, for a given focal ratio, the focal lengths too, that for the four spectrographs have a value between 7 and 8 meters. These focal lengths have been calculated as the best compromise to have the most compact systems, satisfying the requirement of spectral resolution. The spectrographs F/40 focal ratio has been obtained as the optimum in terms of optical quality, showing diffraction limited images for all the spectral ranges.

In order to avoid the wavelengths overlapping at the image focal plane, each spectrograph is preceded by a predisperser.

2.2 Predisperser

The predispersers are also 1:1 reflecting collimator-camera systems with the same focal ratio than the spectrographs, for an optimum coupling. Again, as for the spectrographs, collimator and camera are off-axis parabolic mirrors that belong to the same global parabola.

Their input is the 8 long slits generated by the IFU and, at its image focal plane, a mask is located, with 8 slits per wavelength. Different masks will be available for different combinations of simultaneous wavelengths. The selected gratings are also commercial, covering the full wavelength range with a high efficiency. The optical quality is excellent, with the rays contained within the Airy disk for all the wavelengths of the required interval.

En each case the predisperser is a prefilter that only allows the pass of a narrow spectral range, previously calculated and limited by the width of the mask slits. In addition it is in itself a spectrograph that separates the wavelengths avoiding their overlapping once the spectrograph is coupled.

2.3 Integral field unit

Integral field spectroscopy is a recent technique that offers simultaneously the spectrum of all points of a bidimensional field. It represents a very big advance to observe extended objects and it is absolutely innovative for solar physics.

The main concept can be summarized as the decomposition of a bidimensional field of view and its reorganization, generally into one long slit, or , as in our case, for the multi-slit capability, into 8 long slits. There are different alternatives to do this. Two of them are currently under study for this proposal: (1) the combination of optical fibers with input and output microlenses, and (2) image-slicers, which will be described below more in depth.

2.3.1 Image-slicer

An image slicer is composed by 2, or 3, depending on the design, arrays of mirrors that decompose a bidimensional field of view and whose output is a long slit. It might include refractive optical elements but only reflective ones are considered for this proposal. Two telecentric alternatives are under study based on two great systems already manufactured and tested: FISICA and the IFU of MUSE.

FISICA [5] presents 3 elements: the first one is called “slicer mirror” because it is formed by an array of mirrors to cut the entrance field of view. The width of each slicer mirror is conditioned by the required spatial sampling. This element is located at the telescope focal plane and its size is the field image size that will be later reorganized into the long slit. The second element is placed in the pupil position, and, for that reason, it is called “pupil mirror”. It is important for a telecentric system to control the location of the pupil. In addition these mirrors collimate the field. This collimated beam is focused by the last array of elements, whose name is “field mirror”. This last array focuses the field generating the output long slit and sends the pupil to the infinity. For our proposal, the field mirror makes the conversion from F/50 to F/40. All the elements are powered spherical mirrors.

In the case of MUSE [6], the number of elements is 2. The slicer mirror, called "Image Dissector Array" (IDA), with the same description than for the previous system. The difference is that in the position of the pupil a mask is located instead of the "pupil mirrors". This mask allows the pass of the pupil images and avoids the contribution of scattered light. The second element is the "focusing mirror array" to generate the long slit and send the pupil to infinity.

The two concepts are being adapted for this proposal and currently some preliminary designs already exist, with diffraction limited optical quality.

In order to have 8 slits, a "macro-slicer" is needed at the telescope focal plane. This element is composed by 8 flat mirrors with different orientations, to divide the field of view into 8 smaller ones. Each sub-field of view is the entrance field for an image slicer. The size of the "macro-slicer" is 8.73 x 8.73 mm^2 (9 × 9 arcsec^2). The field of view of each image slicer is 8.73 mm length by 1.09 mm width (9 × 1.125 arcsec^2).

2.4 Field of view scanning system

A bidimensional field of view scanning system has been devised to increase the field of view accessible to the IFU (and, consequently, to the spectrographs), without affecting the performance of the rest of the instruments operating in EST. The proposed system is based on a quad-mirror concept, composed by 4 flat mirrors organized in two pairs orthogonal to each other. The first 2 mirrors scan one axis, while the last 2 mirrors act over its orthogonal axis, so that a larger bidimensional field of view is covered. In addition to the required scanning capability, the system has the property of being polarimetrically compensated. It is worth mentioning that it may also be used as a focusing mechanism.

2.5 Reimaging system

In order to have the appropriate scale on the detectors, a reimaging system per detector is needed at the spectrograph focal plane, transforming the F/40 of the spectrographs to F/20.6 for the infrared systems and to F/10.3 for the visible ones. Different solutions are currently being studied. One of them consists in the combination of 2 elliptical mirrors offering a good optical quality, however other solutions might even be better.

3 Conclusions

This communication presents the conceptual design of four high resolution, integral field, multi-slit, multi-wavelength spectrographs for the 4 meter European Solar Telescope. The results represent the best compromise reached until this date, in order to satisfy the different requirements imposed to the instrument. The optical designs of the predispersers and spectrographs are finished, with diffraction limited optical quality, however some changes may still be possible, considering that this is a conceptual design. Other subsystems, like the integral field unit or the reimaging systems, are currently under study. In addition, another near-future step is the design of the predisperser masks associated to different combinations of wavelengths. An important point is the decision of the optimum position to locate a polarimeter, to offer high spatial and spectral resolutions, integral field spectropolarimetry.

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