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European Solar Telescope: Progress status

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In this paper, the present status of the development of the design of the European Solar Telescope is described. The telescope is devised to have the best possible angular resolution and polarimetric performance, maximizing the throughput of the whole system. To that aim, adaptive optics and multi-conjugate adaptive optics are integrated in the optical path. The system will have the possibility to correct for the diurnal variation of the distance to the turbulence layers, by using several deformable mirrors, conjugated at different heights. The present optical design of the telescope distributes the optical elements along the optical path in such a way that the instrumental polarization induced by the telescope is minimized and independent of the solar elevation and azimuth. This property represents a large advantage for polarimetric measurements. The ensemble of instruments that are planned is also presented.

1 Introduction

One of the most important challenges for Solar Physics at the present moment is to understand the processes that generate and concentrate magnetic energy in the lower photosphere, or below it, and the physical mechanisms that transport this energy to the higher layers of the solar atmosphere and release it to heat the plasma and give rise to energetic chromospheric and coronal phenomena. As the spatial resolution achieved by the solar telescopes is increased, it is clear that the sizes of the fundamental processes giving rise to magnetic phenomena have not been reached yet. Dark cores observed in penumbral filaments with the Swedish Solar Tower (Scharmer et al. 2002) or chromospheric spicules observed with Hinode (De Pontieu et al. 2007) are clear examples in this sense.

Since the magnetic field mainly leaves its imprint on the polarization of the spectral line profiles, its properties must be studied through spectropolarimetry. However, this technique requires a lot of photons to reduce the noise level clearly below the amplitude of the polarimetric signals. Typically, a signal-to-noise ratio of 10^3 is enough to study the most apparent magnetic features at the photosphere. However, the weak internetwork signals require a better accuracy. The same happens with the chromosphere. Usually, this layer is studied using deep and broad spectral lines for which the polarization signals due to the Zeeman or Hanle effects are very small.

In general, solar telescopes are not optimized for polarimetric measurements, implying that precise calibration measurements are often needed (Skumanich et al. 1997; Collados 2003; Beck et al. 2005; Elmore 2010). Only the telescope THÉMIS was conceived from the beginning to perform the polarimetric analysis in front of any folding mirror that could vary the polarization state of the input light (López Ariste, Rayrole & Semel 2000). Other telescopes have a configuration such that the instrumental polarization can be considered negligible on certain days or minimized by inserting an appropriate retarder in the right location (Martínez Pillet and Sánchez Almeida 1991). An interesting configuration is obtained if a pair of mirrors, located sequentially in the optical train, can be installed with perpendicular incidence-reflection planes. In this case, their induced polarization can be compensated (Cox 1976).

The European Solar Telescope (EST) is an ambitious project to build a 4-meter class solar telescope, to be located in the Canary Islands. EST is presently finishing its conceptual design phase. EST is promoted by the European Association for Solar Telescopes (EAST), a consortium formed by research organizations from 15 European countries (Austria, Croatia, Czech Republic, France, Germany, Great Britain, Hungary, Italy, The Netherlands, Norway, Poland, Slovakia, Spain, Sweden and Switzerland).

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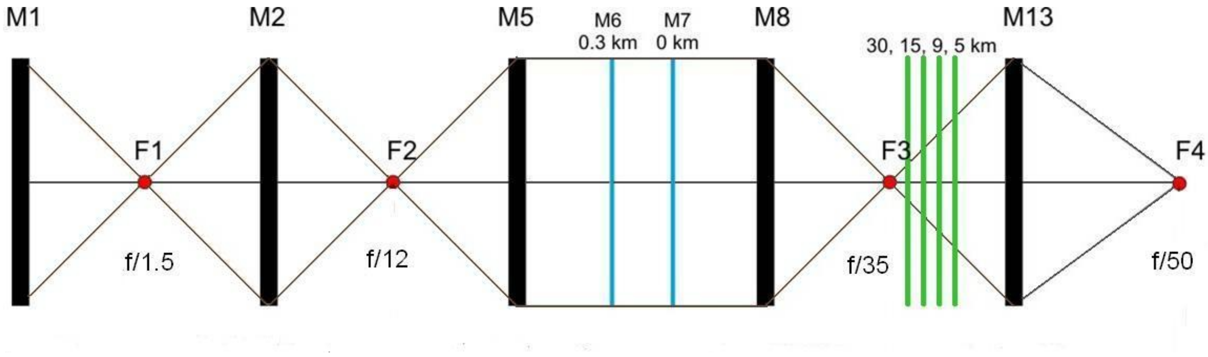

Fig. 1 (online colour at: www.an-journal.org) Functionality scheme of the current EST optical design.

The final aim of EST is to study the magnetic coupling of the solar atmosphere, from the photosphere up to the upper chromosphere, by performing accurate high-spatial and high-temporal resolution polarimetry in many wavelengths simultaneously.

According to the present plans, EST construction is expected to start in 2014 and first light is foreseen in 2019. Together with the American Advanced Technology Solar Telescope (ATST, Rimmele 2008; Keil 2010), EST will represent a major step towards our understanding of the solar phenomena. With their 4-meter apertures, they will make feasible the study of many phenomena that are not accessible with the present 1-meter class telescopes.

The basic characteristics of the present design are described below. Given that the conceptual design study is still in progress, some of them may change in the future, if more adequate technical solutions are found.

2 General configuration

EST is a 4-meter class solar telescope with an on-axis Gregorian configuration, to achieve a good polarimetric performance, and with a main station at its Coudé focus with three types of instruments, each one composed of different channels to observe different wavelengths:

- broad-band imager,
- narrow-band tunable filter spectropolarimeter,
- grating spectropolarimeter.

The telescope includes adaptive optics (AO) and multi-conjugate adaptive optics (MCAO) that are integrated in the telescope optical path (rather than being an extra, bypassable unit, in order to maximize the telescope throughput), and provide simultaneously a corrected image at the Coudé focus for the three types of instruments.

The preferred telescope mechanical configuration is alt-azimuthal, given that it allows a simpler and more compact system, and with better primary mirror air flushing, compared to the equatorial mount. This configuration also makes possible to achieve a polarimetric compensated optical design with less optical surfaces than an equatorial configuration. The telescope structure is determined by the optical layout described below. The optical layout has the elevation axis placed 1.5 m below the M1 vertex in order to facilitate M1 air flushing, and allowing space enough for the M1 cell and for an adequate placement of the transfer optics train vertically from the telescope to the Coudé focus where the instruments are placed. This unusual configuration of the elevation axis below M1 produces a large unbalance around the elevation axis, which is balanced by the structure below M1. In addition, the azimuth and elevation axes are decentered with respect to the telescope optical axis because the optical path is fold in an asymmetric way to produce a polarimetric compensated layout, with a telescope Mueller matrix that is independent of the telescope elevation and azimuth angles.

Two designs have been evaluated for the enclosure: one is based on a completely retractable enclosure and the other on a conventional dome. Both enclosure concepts seem feasible, with the foldable enclosure providing better local seeing conditions with less effort, but higher wind effect on image quality, while, in the case of a conventional dome, the effect of wind on image quality will be lower, but the local seeing degradation will be larger or, at least, more effort will be needed to minimize local seeing degradation. An important advantage of the completely foldable enclosure is that it allows the use of a reflecting heat rejecter at the Gregorian focus, while with a conventional dome it is necessary to absorb the heat inside the dome. Preliminary analyses of wind load on the primary mirror shows that there are feasible solutions to keep the wind buffeting deformation within the required values for an open air configuration. In this case, the primary mirror must be a light-weighted thick mirror, in order to improve its stiffness and ensure a good thermal performance. Tip-tilt and focus correction capabilities must be provided by M2 in order to compensate for wind buffeting effects.

The instruments, composed of different channels placed at the Coudé focus, will be enclosed in an instrumentation laboratory with a controlled environment. Since each instrument is composed of several channels, the space required at the Coudé room is large. To accommodate all the instrument channels, they are distributed in two floors. A light distribution system composed of dichroic and intensity beamsplitters will be placed at the Coudé focus in order to feed

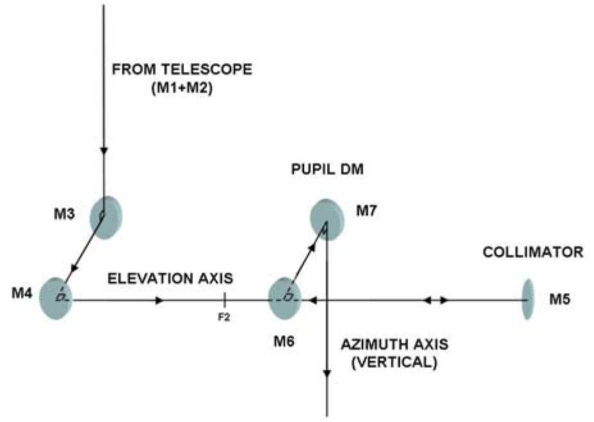

Fig. 2 (online colour at: www.an-journal.org) Optical elements just below the telescope. Mirrors M3 and M4 (and M6 and M7, as well) are polarimetrically compensated. The elevation axis is defined by the line joining M4 and M5, and the azimuth axis is defined by the vertical passing through M7.

different instrument channels, making it feasible to have different ways of light distribution using a flexible number of simultaneous instruments/channels.

An auxiliary full-disc telescope (AFDT, Klvana, Sobotka & Svanda 2008) will be used for the orientation of the observer on the solar disc and its surroundings, for an easy target selection, and, also, to perform other tasks to facilitate the work of observers and technical personnel. The AFDT can also be used as an autonomous robotic telescope for synoptic observations and records of solar activity when no observations are carried out at the main telescope. The AFDT has an aperture of 150 mm and will operate simultaneously in three spectral regions: Ca II K (394 nm), Hα (656.3 nm), and white light (450–460 nm).

3 Optical design

Figure 1 shows the basic layout of telescope with the minimum required surfaces, i.e, those with an optical functionality. The position of the various focal positions, F1 to F4, is also marked. Focus F1 is the Gregorian focus generated by the primary mirror, M1. A heat-stop is located there to remove most of the solar light and allow a field-of-view of (2–3)$\times$(2–3) arcmin^2. Focus F2 is generated by the secondary mirror, M2. This is the place where calibration optics will be installed to analyze the polarimetric performance of the rest of the telescope, and also possibly polarimetric modulators for polarization measurements. A collimator, M5 in the figure, produces an image of the pupil where a deformable mirror, DM, indicated by M7 in the figure, is located to correct for the ground-layer turbulence. A nearby flat mirror, M6, will have tip-tilt correction capabilities to avoid image motion. The light is then focused on F3 by mirror M8. The conjugated layers where the MCAO mirrors are located can be found immediately after F3. The present design has four MCAO DMs, conjugated at 5, 9, 15 and 30 km, although the exact heights may change depending on future MCAO studies. The exact tuning with height of the DMs does not have any impact on the concept of the telescope. Finally, mirror M13 is responsible for the generation of the science focal plane, F4. With this layout, the minimum number of surfaces that is required is eleven: five mirrors with power to generate the four focal planes and the pupil plane, and six mirrors for the AO and MCAO systems (a tip-tilt mirror and five DMs – one for the ground layer and four conjugated at different high-altitude layers-). This number could be reduced to ten if M2 is provided with tip-tilt capabilities (and eliminating M6). A bandwidth of 150 Hz seems to be achievable with a mirror as large as M2 (at $\sim$3 db level), but, if a larger bandwidth is required, a second smaller and faster tip-tilt mirror, M6, is necessary.

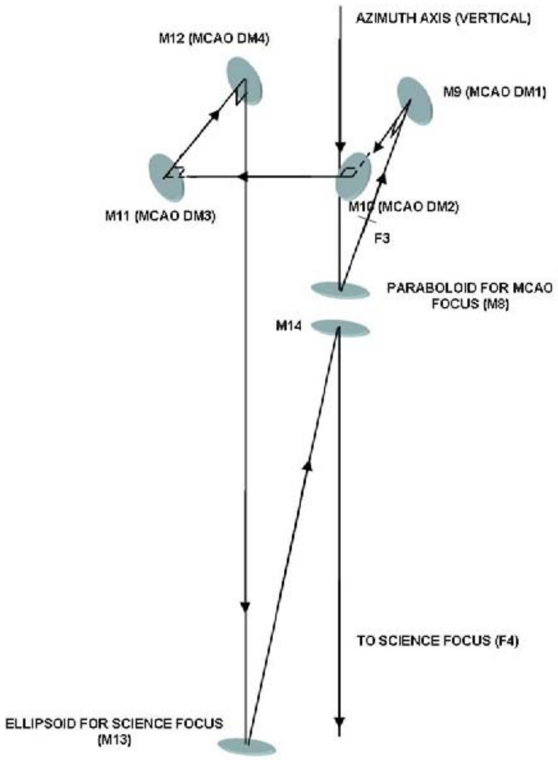

Fig. 3 (online colour at: www.an-journal.org) Transfer optics distribution. Mirrors M9 to M12 are the MCAO mirrors and are polarimetrically compensated.

The present optical design adds three additional flat mirrors to this basic layout. The first two define the elevation axis of the telescope, and are placed in such a way that their incidence-reflection planes are perpendicular one to the other (see mirrors M3 and M4 in Fig. 2). This is an interesting configuration, because their instrumental polarization is cancelled, provided their reflection coatings have the same properties. Furthermore, M6 and M7 (tip-tilt mirror and pupil DM, respectively) are also arranged with the same philosophy, being also polarimetrically compensated.

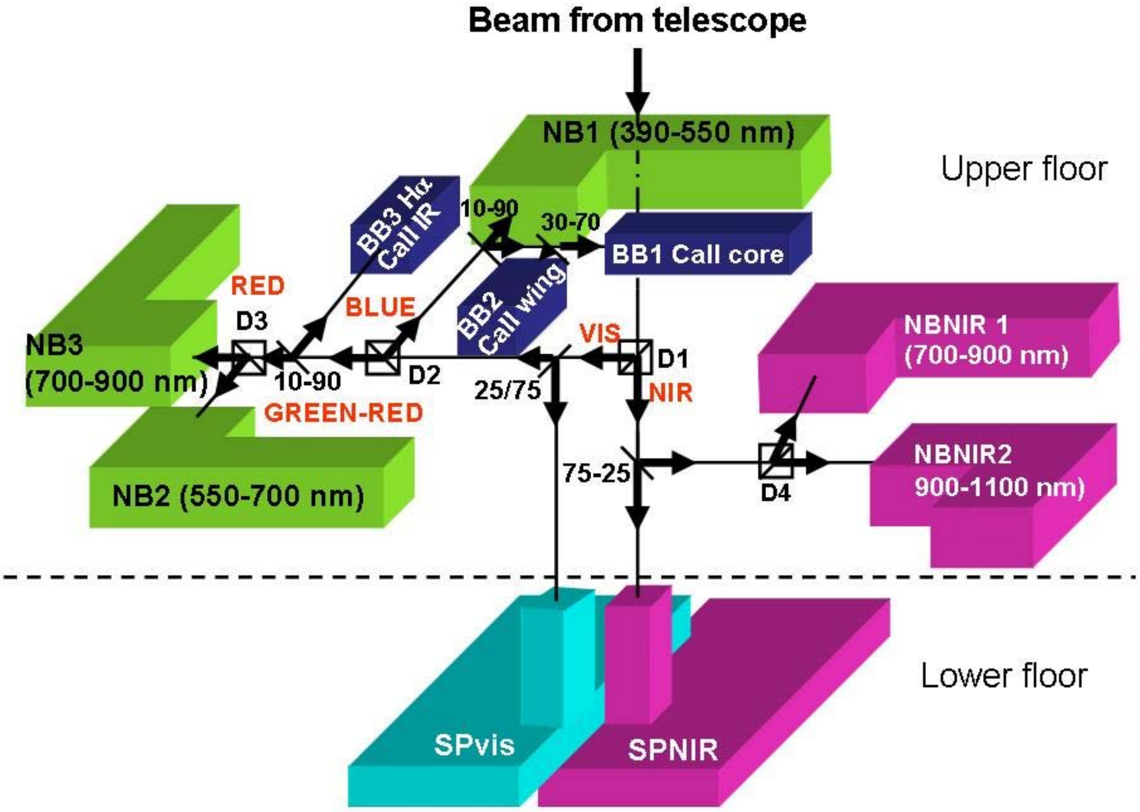

Fig. 4 (online colour at: www.an-journal.org) Light distribution system. Dichroic beam-splitters are indicated with squares and intensity beam-splitters with inclined lines crossing the light beam. The numbers at the side of the latter indicate approximate reflection/transmission percentages for an adequate illumination of all channels.

Given that the elevation axis is defined by the line joining M4 and M5 and that the azimuth axis is given by the line joining M7 and M8, it turns out that the polarization of the incoming light is not modified, independently of the pointing of the telescope to any direction on the sky.

The transfer optics, which includes the MCAO system, is shown in Fig. 3. As can be seen, the four high-altitude DMs are also distributed to compensate their polarization properties. M14 is introduced, in addition, to send the light downward. The incidence angles on M8, M13 and M14 are very small, and their influence on polarization is very small.

Besides being polarimetrically compensated, the transfer optics has another interesting property. Given that it is composed by seven mirrors (M8 to M14), it can be used as an optical de-rotator if the input optical axis (defined by the line joining the centers of M7 and M8) and the output optical axis (line joining M14 and F4) coincide. This is very convenient for the instruments, especially the grating spectrographs, where the slit must be kept along the same direction on the sky to allow for long time series observations.

With this, the main properties of the present optical design can be summarized as follows:

- The necessary DMs to correct for turbulence layers are included, with one pupil DM, for the AO system, and four high-altitude DMs, for the MCAO system. The required versatility to account for the variable distance to the high turbulence layers is, thus, ensured.
- The full optical design is polarimetrically compensated, i.e, the telescope Mueller matrix is practically unity, independently of the elevation and azimuth angles of the telescope.
- The transfer optics represents an optical de-rotator with Mueller matrix unity. Thus, the image can be oriented at the science focal plane with any angle, without affecting the polarization properties of the light. Furthermore, this avoids the inclusion of any optical or mechanical derotating device at instrument level, such as a rotating platform. Instruments can then be kept fixed, ensuring a better stability.
- Polarimeters can be located near F2 or at instrument level, without modifying their performance. Optics for polarimetric calibration can also be located above and/or below the transfer optics.

Other optical configurations than the base-line presented here are still being studied, in which some of the above properties are varied: different number of MCAO DMs, or no polarimetric compensation at different levels, or no derotation capabilities by the transfer optics. With this, an ensemble of optical designs, with 11 to 14 mirrors, are still under consideration.

4 Light distribution system and instruments

A light distribution system composed of dichroic and intensity beam-splitters will be placed to feed the different instruments channels, making it feasible to have different ways of light distribution for simultaneous observation using a flexible number of instruments/channels.

As shown in Fig. 4, the light is first split by dichroic beam-splitter D1 in a visible and a near-infrared beam. For a larger flexibility, two D1 elements will be available with cut-off wavelengths at 700 or 900 nm. Dichroic beam-splitters D2 and D3 are used to split further the visible beam in three narrower band-passes (390–550 nm, 550–700 nm, and 700–900 nm), where the corresponding broad-band and narrow-band channels are placed. Intensity beam-splitters are then used to feed all the instrument channels. They are indicated by inclined lines crossing the beam in Fig. 4 with an approximate reflectivity/transmission ratio for an adequate illumination of all channels. The same philosophy applies to the near-infrared branch, where an intensity and a dichroic beam-splitter, D4, are included. All the beam-splitters may be removable from the light beam or replaced by mirrors, if only one channel on a given branch is required for a given observing setup. This philosophy guarantees that the maximum light intensity is sent to the required channels, upon the observer needs.

The broad-band imager has two different operational modes: a high resolution mode (1×1 arcmin^2, 0.015 arcsec/pix, 4k$\times$4k detectors), to exploit the diffraction limited quality of the telescope + AO-MCAO system; and a large field of view mode (2×2 arcmin^2, 0.03 arcsec/pix, 4k$\times$4k detectors) to exploit the full telescope field of view. To ensure the maximum flexibility of each observing mode, both will have to be available to the user in an independent way for each channel.

From the analysis done about the technical feasibility of a narrow-band, tunable filter imaging system, using standard techniques, it turns out that only a system based on Fabry-Pérot interferometers with air gaps can meet most of the science requirements. There are two different philosophies to mount the etalons within the optical light beam. In the collimated version, the etalons are mounted in a parallel light beam near an image of the telescope entrance pupil; in the telecentric configuration, the etalons are mounted in the convergent light beam nearby an image plane. Both configurations have their own advantages and disadvantages and impose similar demands on the quality and size of the required etalons, and no decision has been made yet about the most appropriate setup.

Concerning the grating spectropolarimeters, four concepts are under study:

- long-slit Standard Spectrograph,
- multi-Slit Multi-Wavelength Spectrograph fed with an integral field unit,
- tunable Universal Narrow-band Imaging Spectrograph (TUNIS; López Ariste et al. 2010),
- new generation Multi-channel Subtractive Double Pass (MSDP).

Each alternative has a visible and a near-IR design, especially adapted to the adequate wavelength intervals. Efforts are being done to merge them all into a single concept with compatible insertable/removable modules.

5 Summary

The current status of the conceptual design of EST has been outlined. The design study covers all aspects of the telescope: optical design of telescope and transfer optics, telescope opto-mechanics, adaptive optics, instruments, building and dome. Most of present solutions are still under debate and may suffer modifications in the near future. It is expected that all technical solutions will be established in early 2011.

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