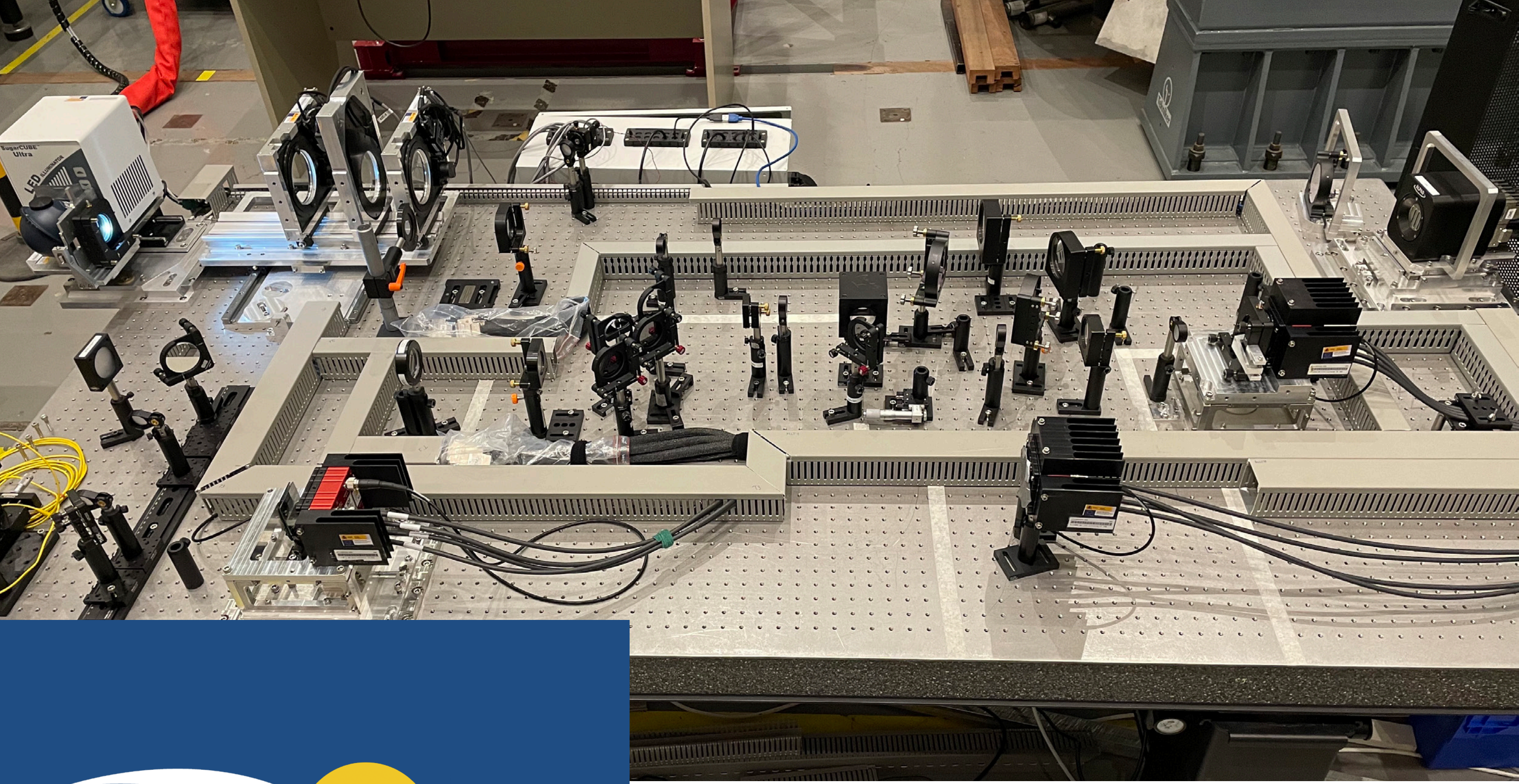


EST NEWS 9

THE EUROPEAN SOLAR TELESCOPE NEWSLETTER

DECEMBER 2021

INSIDE THIS ISSUE

COORDINATOR'S CORNER

Here is the latest issue of the EST Newsletter, with detailed information on the progress of the project.

We are proud that new members are joining the EST family. Now, we can inform with great pleasure that EST has been included, together with a few other selected infrastructures, in the Slovak Roadmap. Welcome Slovakia!

The EST Project Office is a reality, with more than 25 persons working for it. The preliminary design of key aspects like the telescope structure, primary mirror and adaptive secondary mirror are already on the way by the companies that were awarded the industrial contracts. The Project Office is monitoring closely the progress of these designs to make sure that they are developed according to the EST specifications. The most important news about them are described in this issue together with the progress achieved by the IAC AO-MCAO bench in the lab.

Instruments are key for the operation of any research infrastructure and the formation of consortia among interested partners is presently under discussion for task and responsibility distribution for their design and future development. Many meetings have taken place during the last months to refine the light distribution system. Updated information is included here, together with the most recent news about the (etalon-based) Tunable Imaging Spectropolarimeters and slicer-based Integral Field Spectropolarimeters. A paper describing in detail the scientific goals and technical solutions of EST is presently under preparation to serve as the EST reference for the next years.

We also highlight here some activities performed by our sister project, H2020 SOLARNET. The 3rd SOLARNET School on "High Resolution Solar Physics" and the 3rd Forum on Telescopes and Databases successfully took place during the last part of 2021.

M. Collados, PRE-EST coordinator

EST INCLUDED ON SLOVAK ROADMAP FOR RESEARCH INFRASTRUCTURES

In April 2021, the Government of Slovakia approved the first Roadmap for Research Infrastructures. EST is one of the five European infrastructures included in the Appendix of the Roadmap.

Left: Press release of the Government of Slovakia announcing the Roadmap for Research Infrastructures. Right: Roadmap website.

During the evaluation period (August 1, 2020 – September 30, 2021), the Astronomical Institute of the Slovak Academy of Sciences (AISAS), in close cooperation with the Presidium of the Slovak Academy of Sciences (SAS), performed all necessary steps to include EST on the first Slovak Roadmap for scientific infrastructures. Eventually, this activity was successful and EST is currently listed among a few selected infrastructures in the Slovak Roadmap.

The key task for the inclusion of EST on the Slovak Roadmap was to gain stronger general support for the EST project in Slovakia, especially from academic and governmental institutions. Therefore, the Director of the AISAS together with the President of the SAS contacted the four most important Slovak universities, scientific institutes and other institutions with a request for support for the project. They received support letters from three Slovak universities, three institutes of the Slovak Academy of Sciences, from the Slovak Central Astronomical Observatory in Hurbanovo and from the Ministry of Environment.

The first Slovak Roadmap for Research Infrastructures (SK VI Roadmap 2020–2030) was prepared by the Ministry of Education, Science, Research and Sports of the Slovak Republic in cooperation with World Bank experts and representatives of the Research Agency. It was discussed by several commissions responsible for the coordination of Slovak activities in ESFRI research infrastructures at the national level, acting as advisory bodies to the Ministry of Education and Sports of the Slovak Republic.

The Roadmap presents the structure of coordination of activities in the field of research infrastructures at the national level, defines the evaluation and selection criteria of research infrastructures and also describes in detail individual ESFRI infrastructures and ESFRI projects with current or future participation of the Slovak Republic.

The document briefly informs about the landscape of research infrastructures at the national and international level, identifies established international research infrastructures in which the Slovak Republic is an observer or member and also indicates forthcoming ESFRI projects in which the Slovak Republic is significantly involved.

The Roadmap identifies projects which are of high priority for Slovakia, but does not give any financial commitment to support them. However, the inclusion of EST on this Roadmap is the first crucial step for the next initiatives to support EST in Slovakia.

The Slovak ESFRI Roadmap is available here, and the full text in PDF format here. The Appendix describing the EST project can be found here.

EST PREPARATORY PHASE

A report of the activities carried out during the last 6 months is provided, with emphasis on the technical, legal and scientific work, and the upcoming evaluations of PRE-EST.

The Preparatory Phase of EST is already tuned with its objectives and milestones, thanks to the consolidation of the Project Office –with Canarian Government funds–, the participation of all relevant partners, and the approved extension of the project.

In order to guarantee the successful accomplishment of the technical, legal and financial objectives of the project, the PRE-EST Board approved to request an extension of the project until September 2022, which was granted by the European Commission at the beginning of July 2021.

The legal and financial characteristics of the selected legal figures for the interim phase (a European Economic Interest Grouping, or EEIG) and the construction and operation phase (a European Research Infrastructure Consortium, or ERIC) are under discussion and development both within the project and the Board of Directors. In parallel, important advances have been made by all partners in order to guarantee their national institutional support for making EST a reality.

Due to COVID-19, there was a delay during 2020 of the tendering processes for the design of three main EST subsystems, namely, the EST telescope structure (also including the pier and the dome), the primary mirror, and the adaptive secondary mirror.

The industrial contracts were awarded at the beginning of this year, and kick-off meetings for each subsystem were held between February and March 2021. The work of the selected companies is being carried out in close cooperation with the EST Project Office, and the design of the three subsystems is complying with the planned timetable, having all already met the contracts' Phase 1 "Consolidation of specifications and trade-off".

Members of the EST Project Office working at the EST headquarters in La Laguna (Tenerife, Spain).

In parallel to the EST subsystems definition, the Project Office continues its work in collaboration with the Science and Technical Advisory Groups for the design and definition of the light distribution model and instrument suite in the Coudé lab. Instrument consortia have been created to define the work pakages for the instrument design and ensure the optimal setup of the teams and coordinated work, with the objective of achieving the best results with the instruments and meet the scientific requirements.

The documentation corresponding to the third reporting period of PRE-EST was successfully presented at the end of November 2021. A second project review will take place on 25 January 2022, with the participation of the European Commision Project Officer and an external reviewer with large experience in management and consultancy in the fields of physics and astrophysics. As in the first project review carried out in January 2019, satisfactory results and important advice for a successful project finalisation are expected, thanks to the significant advances that have taken place during the last two years.

The next annual PRE-EST Board Meeting will be held online, due to the current COVID-19 restrictions, on 1 February 2022. All partners will have the opportunity to update the state of development of the technical, legal and financial tasks of the project, as well as to share the first impressions of the project review.

SOLARNET HIGHLIGHTS

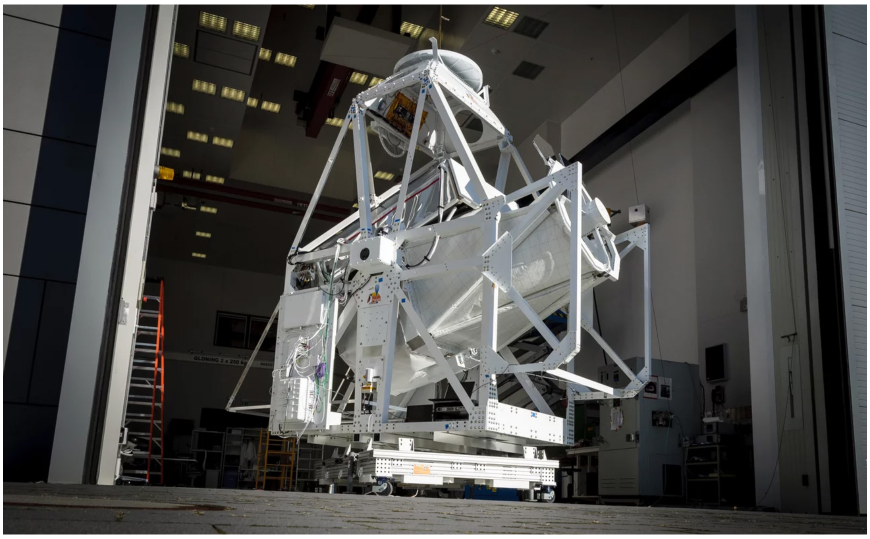
A summary of the events organised by the H2020 SOLARNET project in the last six months is given below.

3rd SOLARNET School on "High Resolution Solar Physics". Organised by the University of Graz, the 3rd SOLARNET School took place from August 30 – September 3, 2021 in online format after having being postponed by the COVID-19 pandemic. The aim was to provide PhD students and young postdocs with an up-to-date view of observational and theoretical aspects of high-resolution solar physics.

Topics centred around telescope instrumentation to understand the fine structure of the sun, numerical simulations to understand the dynamics of the solar convection zone and the photosphere, and complex phenomena like sunspots, chromospheric heating, flares, etc. Besides the lectures, the students were also strongly encouraged to give short presentations of their research work.

The school had 36 participants –18 females and 18 males–, from 19 countries around the world. After the school, all successful participants received a certificate of participation and were provided with all course material online. The organisers, Dr. Desmond Helmut Grossmann and Prof. Arnold Hanslmeier, shared their experience by saying "We were honoured to host talks by the world's most renown experts in this field. Simultaneously this school provided young, aspiring scientists the possibility to learn and share their own experiences with their peers."

3rd SOLARNET Forum on Telescopes and Databases. The forum was held on November 15, and again took place as a virtual event. Over 60 people from across the European Union joined the meeting to hear the latest news on some of Europe's finest solar observing facilities and network of data archives, access to which is provided by the SOLARNET Access Programme.



Hang test of the SUNRISE III telescope at MPS in October 2021. Credit: P. Chitta (MPS).

Representatives from the facilities provided updates on the operations that took place over the past year, along with the plans for the next observing season. There was some positive news for observing in the coming year, with GREGOR –the largest solar telescope in Europe– having been recently upgraded. Reiner Volkmer told attendees that a new coating applied to the mirror has led to improved alignment and pointing of the telescope, and that the GRIS instrument has received an upgrade. Andreas Lagg revealed that SUNRISE III, the balloon mission led by the Max Planck Institute for Solar System Research, is also progressing smoothly towards its proposed flight date in summer 2022. SUNRISE has recently completed a successful hang test and has also been able to record its first solar spectra (from the ground). However, it was not all good news. Recent observations at the SST have been impacted by the volcanic eruptions on La Palma.

The development of the Solar Virtual Observatory (SVO) is continuing as hoped. The goal is to collate metadata from many solar data archives in a common catalogue and make them available to the scientific community. A particular focus is the inclusion of data archives associated with the SOLARNET supported facilities. More details can be found in the description of the SOLARNET WP10. Recently added to the SVO were data taken with the SST during observing campaigns funded by SOLARNET. It is expected that the SVO will be populated with more data over the coming months.

Finally, a new data archive is now up and running. The Science Data Centre was launched by the Leibniz Institute for Solar Physics (KIS) and hosts data from some of Europe's solar facilities. This archive was funded through the Germany Ministry of Science and currently provides community access to data from GREGOR and the German Vacuum Tower Telescope at Observatorio del Teide (Tenerife, Spain). Further details can be found here.

EST SCIENTIFIC ARTICLE

The latest EST developments are being summarised in an article for Astronomy and Astrophysics that will serve as the EST reference until the end of the construction phase.

The European Solar Telescope project started in 2006. The progress on its design, supporting technological studies, and collaborations with international partners have been steady since that time. As a result, we have access to multiple peer-review publications in the literature where this progress was described and continuously updated. However, those publications aimed to show new developments and ongoing activities rather than to give a complete and thorough description of the EST project as a whole.

For that reason, and thanks to the significant progress made since the beginning of the preliminary design phase in 2016 when EST became part of the ESFRI Roadmap, we feel that this it is the right time to publish a complete article covering all the aspects related to the EST project. This includes topics like the top-level science goals of EST, the selected EST construction site, the instrument suite in the Coudé lab, the optical design of the telescope, or the EST Multi-Conjugate Adaptive Optics system. Thus, our goal is to present a canonical reference that covers the entire project and is completely updated.

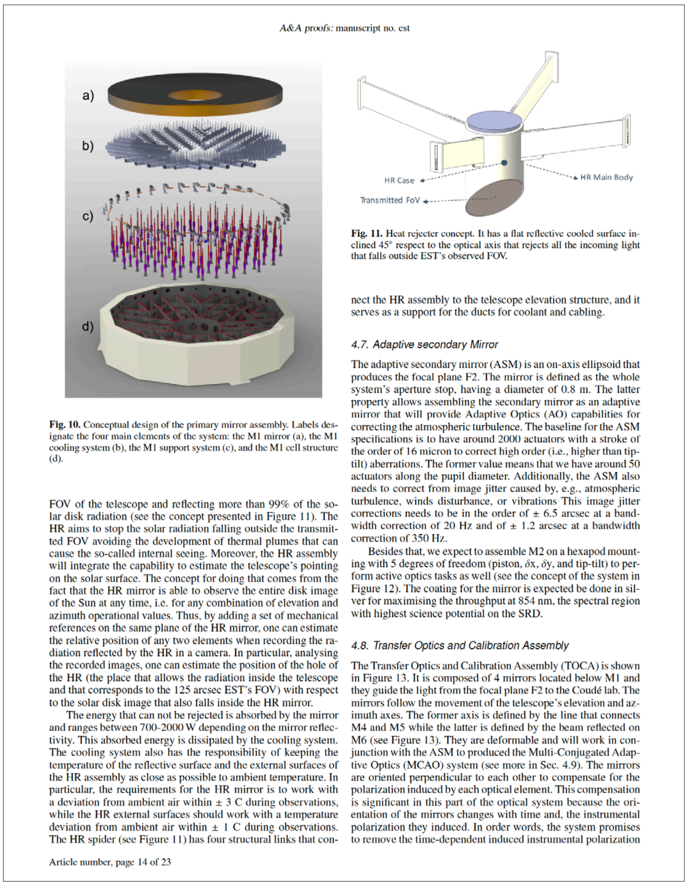

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Fig. 10. Conceptual design of the primary mirror assembly. Labels designate the four main elements of the system: the M1 mirror (a), the M1 cooling system (b), the M1 support system (c), and the M1 cell structure (d).

Fig. 11. Heat rejecter concept. It has a flat reflective cooled surface inclined 45° respect to the optical axis that rejects all the incoming light that falls outside EST's observed FOV.

FOV of the telescope and reflecting more than 99% of the solar disk radiation (see the concept presented in Figure 11). The HR aims to stop the solar radiation falling outside the transmitted FOV avoiding the development of thermal plumes that can cause the so-called internal seeing. Moreover, the HR assembly will integrate the capability to estimate the telescope's pointing on the solar surface. The concept for doing that comes from the fact that the HR mirror is able to observe the entire disk image of the Sun at any time, i.e. for any combination of elevation and azimuth operational values. Thus, by adding a set of mechanical references on the same plane of the HR mirror, one can estimate the relative position of any two elements when recording the radiation reflected by the HR in a camera. In particular, analysing the recorded images, one can estimate the position of the hole of the HR (the place that allows the radiation inside the telescope and that corresponds to the 125 arcsec EST's FOV) with respect to the solar disk image that also falls inside the HR mirror.

The energy that can not be rejected is absorbed by the mirror and ranges between 700-2000 W depending on the mirror reflectivity. This absorbed energy is dissipated by the cooling system. The cooling system also has the responsibility of keeping the temperature of the reflective surface and the external surfaces of the HR assembly as close as possible to ambient temperature. In particular, the requirements for the HR mirror is to work with a deviation from ambient air within ± 3 C during observations, while the HR external surfaces should work with a temperature deviation from ambient air within ± 1 C during observations. The HR spider (see Figure 11) has four structural links that connect the HR assembly to the telescope elevation structure, and it serves as a support for the ducts for coolant and cabling.

4.7. Adaptive secondary Mirror

The adaptive secondary mirror (ASM) is an on-axis ellipsoid that produces the focal plane F2. The mirror is defined as the whole system's aperture stop, having a diameter of 0.8 m. The latter property allows assembling the secondary mirror as an adaptive mirror that will provide Adaptive Optics (AO) capabilities for correcting the atmospheric turbulence. The baseline for the ASM specifications is to have around 2000 actuators with a stroke of the order of 16 micron to correct high order (i.e., higher than tip-tilt) aberrations. The former value means that we have around 50 actuators along the pupil diameter. Additionally, the ASM also needs to correct from image jitter caused by, e.g., atmospheric turbulence, winds disturbance, or vibrations This image jitter corrections needs to be in the order of ± 6.5 arcsec at a bandwidth correction of 20 Hz and of ± 1.2 arcsec at a bandwidth correction of 350 Hz.

Besides that, we expect to assemble M2 on a hexapod mounting with 5 degrees of freedom (piston, δx, δy, and tip-tilt) to perform active optics tasks as well (see the concept of the system in Figure 12). The coating for the mirror is expected be done in silver for maximising the throughput at 854 nm, the spectral region with highest science potential on the SRD.

4.8. Transfer Optics and Calibration Assembly

The Transfer Optics and Calibration Assembly (TOCA) is shown in Figure 13. It is composed of 4 mirrors located below M1 and they guide the light from the focal plane F2 to the Coudé lab. The mirrors follow the movement of the telescope's elevation and azimuth axes. The former axis is defined by the line that connects M4 and M5 while the latter is defined by the beam reflected on M6 (see Figure 13). They are deformable and will work in conjunction with the ASM to produced the Multi-Conjugated Adaptive Optics (MCAO) system (see more in Sec. 4.9). The mirrors are oriented perpendicular to each other to compensate for the polarization induced by each optical element. This compensation is significant in this part of the optical system because the orientation of the mirrors changes with time and, the instrumental polarization they induced. In order words, the system promises to remove the time-dependent induced instrumental polarization

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EST article draft being prepared for Astronomy & Astrophysics

The article will focus extensively on the science requirements presented in the 2019 Science Requirement Document (SRD), as they are the primary drivers of most of the technical specifications of the telescope and the instruments. For that reason, the first half of the article contains a summary of the science objectives included in the SRD. It also delves on a few representative open problems that the unique capabilities of EST will help solve. The second part of the paper contains a detailed explanation of EST subsystems and instruments, updated to reflect the work done since the beginning of the preliminary design phase in 2016. The publication covers both parts extensively, with around 30 pages in the 2-column journal format.

This publication aims to serve as the EST reference for the next years until the end of the construction and commissioning phase, a time where it will be replaced by a similar article describing the final design, performance of the telescope and instruments, and first-light observations. We are working hard to have this paper ready by spring 2022, so that the solar community can have access to it as soon as possible.

EST is a large solar telescope, and hence, designing it is a task of enormous scope that can only be done by a large team of scientists, engineers, technicians, managerial and administrative staff. Therefore, this publication will be co-authored by all the people that has contributed to the project at any time since its conception in 2006. We believe it is fair to acknowledge their contribution over this period and agree that no one will be excluded. So far, we have more than 200 co-authors, and we expect to have a larger number by the time of the submission.

We are excited to present this complete peer-reviewed report very soon, so both the solar and the broader astronomical community can examine our progress and developments. We aim to publish this article in Astronomy and Astrophysics, one of the leading European astronomical journals.

UPDATE ON THE EST INSTRUMENT SUITE

The EST light distribution system and instrument suite have been updated and international consortia are being formed to carry out the preliminary design of the instruments.

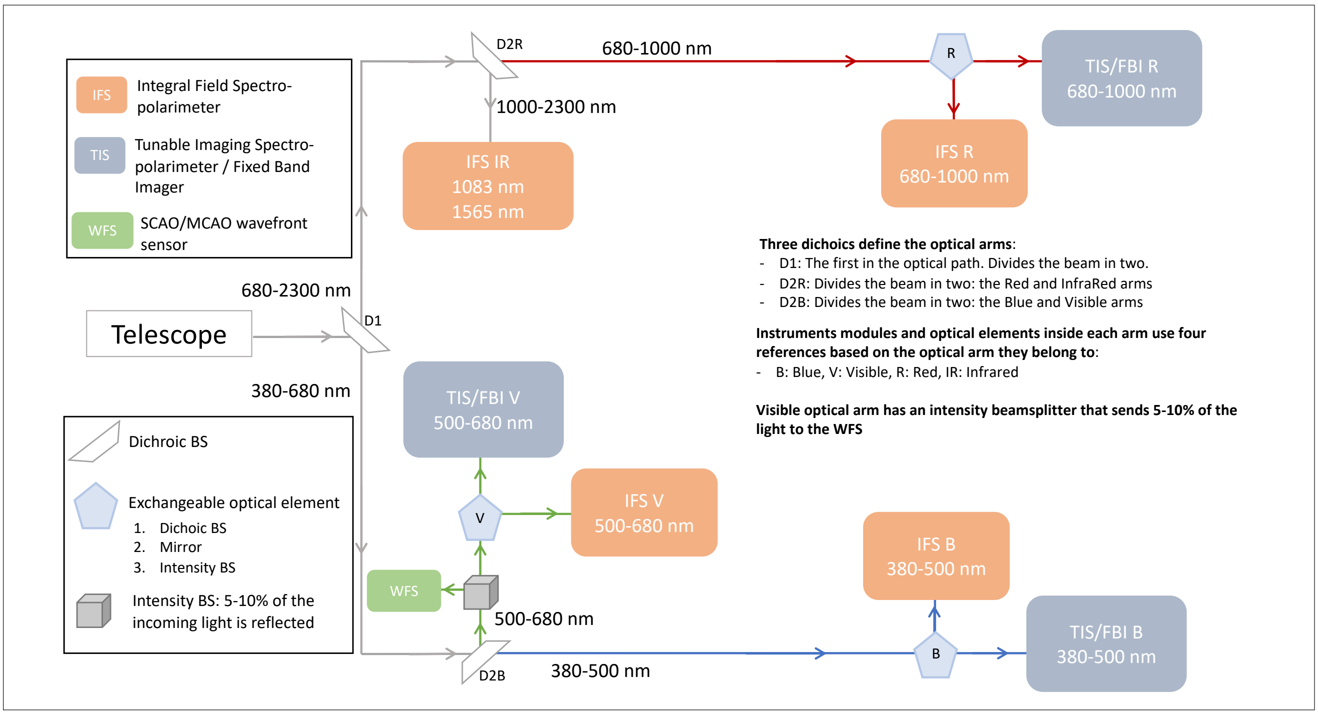
The June 2020 issue of the newsletter described a first concept of how the solar light would be distributed in the Coudé room of EST. That concept contained a tentative layout of the instruments EST should have to fulfil the science requirements included in the Science Requirement Document (SRD) prepared by the Science Advisory Group (SAG).

To implement that concept, the EST Project Office (PO) started approaching European institutions potentially interested in designing the instruments. The EST PO also helped create consortia of instrument developers formed by institutions that are world leaders in various instrumentation fields, from optics, mechanics, and polarisation analysis to data handling and data reduction. Those institutions helped improve the initial instrument suite design presented in June 2020, based on the input from the SRD and the EST Review Panel's advice, complemented with the comprehensive perspective, experience, and feasibility analysis provided by the instrument developers.

The updated concept, shown below, keeps the goal of having "modules" of a master design that share most of the elements. Therefore, there are only two types of instruments in the diagram: Tunable Imaging Spectropolarimeters (blue boxes) and Integral Field Spectropolarimeters (orange boxes). Those two types of instruments are replicated in different optical arms, allowing observers to perform strictly simultaneous multi-wavelength observations with the same kind of instrument. A first version of the light distribution concept was presented to the SAG in February 2021. After receiving its feedback, updates were included in the design, leading to the concept shown in the figure. The new concept was presented again to the SAG in May 2021. The SAG approved it and confirmed that it still fulfils the requirements stated in the SRD.

The institutions forming the two instrument consortia will develop smaller work packages that will be extended to the multiple modules presented in the diagram. Also, team leader designated institutions will manage the progress of the rest of the team members in each consortium. Moreover, the EST PO will support them in this task through the EST support scientist and a new instrument systems engineer that will help establish and will keep updated the interfaces between the telescope and the instruments.

Currently, both consortia are working on designing the instruments. A first general technical meeting will be held in mid-December 2021. There, each consortium will present its progress and instrument's concept. The goal is that the rest of experts attending the meeting



Current concept of the EST instrument suite, based on Tunable Imaging Spectropolarimeters and Integral Field Spectropolarimeters evaluate the designs and provide advice on issues that could appear during the design phase. Also, the consortia have agreed to formally express the interest of the institutions in working on the instrument design through a Memorandum of Understanding. The agreement will be signed at some point before spring 2022.

The institutions working on each consortium are the following:

Tunable Imaging Spectropolarimeters. Spanish Space Solar Physics Consortium (consortium leader), Istituto Nazionale di Astrofisica, Istituto Ricerche Solari di Locarno, Leibniz-Institut für Sonnenphysik, Mullard Space Science Laboratory, Queen's University Belfast, University of Catania, University of Rome Tor Vergata, and the Institute for Solar Physics (Stockholm University).

Integral Field Spectropolarimeters. The Institute for Solar Physics (consortium leader), Instituto de Astrofísica de Canarias (consortium leader), Astronomical Institute of the Czech Academy of Sciences, Instituto de Astrofísica e Ciências do Espaço of the University of Coimbra, Department of Optics of the Palacký University Olomouc, Istituto Ricerche Solari di Locarno. Max Planck Institute for Solar System Research, University of Applied Sciences Western Switzerland (HEIG-VD), and University of Applied Sciences and Arts of Southern Switzerland.

Some progress has also been made regarding the adaptive optics system. It has been found that it is preferable to have the high order wavefront sensor in the visible arm, receiving a certain amount of the incoming light (5-10%), as shown by the green box in the figure.

The process of revising the EST science requirements in early 2020, contacting different institutions to ask them to participate in the development of the EST instruments and then forming consortia to jointly design and build a complete set of instruments in 2021, is one the most important milestones achieved in the EST preliminary design phase. The reason is simple: EST is a project where the telescope needs to work seamlessly with the instruments. Hence, having progressed so much in the latter front means we are one step closer to making EST a reality.

TUNABLE IMAGING SPECTROPOLARIMETERS

Report on the latest Tunable-Imaging Spectropolarimer development activities.

One year has already passed since our first report in the EST newsletter on the so-called Tunable-Band Imagers or TBIs. Perhaps at a slower pace than desired, things have been moving on in the consortium. As promised by then, we have progressed and a general requirements document has been released, which should be a live document because of its own nature. The document must identify all the specifications needed to reach the goals of our instrument.

Features like the dual beam polarimetry, a circular field of view of 60 arcseconds in diameter, a diffraction-limited performance (which imposes constraints on the number of pixels in the detectors), a polarimetric sensitivity larger than 1000, and a cycle time per spectral line of less than 20 s have been specified as main requirements. A larger number of secondary requirements have also been recognised like a minimum spectral resolution of 50,000 (for the blue wavelengths). This document is paramount, since it will be used as the reference to check the validity of the design: the development should be a harmonic result of requirement specification and fulfillment.

Later on, the TBI team and the Broad-Band Imager (BBI) team met. The outcome of this meeting was that the best option for the EST project is for both TBIs and BBIs to merge. The resulting instruments (now called Tunable Imaging Spectropolarimeters or TISes), although significantly complex, save quite a few resources compared to those required by the separate development of the TBIs and BBIs.

The EST Scientific Advisory Group has already determined that the capabilities of the new concept fulfill the goals of EST. The resource reduction is a clear design goal: only four cameras will be used, instead of six or seven; the operation and control software will be more complex than the individual ones but simpler than two independent control software systems; although perhaps less versatile in operations performance, a better coordination between narrow-band polarimetric imaging and broad-band photometric imaging is anticipated.

The TIS development consortium is being shaped. It is a big consortium, hence complicated to manage, but all the institutional members have clearly expressed their wishes to contribute and to seek funds at the corresponding national levels. As requested by the EST Project Office, a Memorandum of Understanding is being prepared that serves as a declaration of interest of all the convening institutes, which are listed in the blue box on this page.

The work of the consortium will build upon the expertise and experience gained from previous European instruments like IBIS, CRISP, CHROMIS, TESOS, GFPI, VTF and IMaX. Each contributing institution will provide its know-how in given synergetic areas so that a harmonised development can be made in close collaboration with the others. The leading and coordinating role of the TIS development is taken over by IAA-CSIC. The work has been broken down into blocks, each under the leadership and responsibility of one or two institutions.

The following blocks and responsible institutions have been identified: filter wheel assembly (INAF-OCT/UNICAT), polarisation modulation package (S^{3}PC/IRSOL), etalon system (UNITOV/KIS), camera system (MSSL and QUB), ancillary optics (Italian institutes/KIS), opto-mechanics (INAF-OCT/UNICAT), calibration optics (S^{3}PC), optical design (Italian institutes/KIS), control software (ISP/UNITOV), inversion of the radiative transfer equation (S^{3}PC), graphical interface unit (ISP), project management (S^{3}PC), systems engineering (S^{3}PC), thermal engineering (S^{3}PC), integration into EST data control (S^{3}PC), assembly, integration and verification (S^{3}PC), and product assurance and quality assurance (S^{3}PC).

Any interested member of the consortium is welcome to participate in any of the developments, but the coordination corresponds to the above institutions.

It is obvious that not all the packages can start at the same time or at the same pace, but a lot of knowledge is inherited from previous work and some steps are expected in the next few months to consolidate a first conceptual design of the instruments. The overarching task of all these work packages is the revision of the general requirements document, which now should also specify the requirements of former BBIs to be incorporated.

TIS CONSORTIUM MEMBERS

- **Institute for Solar Physics, SU (Stockholm, Sweden)**
- **Leibniz-Institute für Sonnenphysik (Freiburg, Germany)**
- **Università degli Studi di Roma Tor Vergata (Rome, Italy)**
- **INAF-Osservatorio Astronomico di Roma (Rome, Italy)**
- **Università degli Studi di Catania (Catania, Italy)**
- **INAF-Osservatorio Astronomico di Catania, (Catania, Italy)**
- **INAF-Osservatorio Astronomico di Torino (Turin, Italy)**
- **Queen's University Belfast (Belfast, UK)**
- **Mullard Space Science Laboratory UCL (London, UK)**
- **Istituto Ricerche Solari (Locarno, Switzerland)**
- **Spanish Space Solar Physics Consortium (S^{3}PC), including:**

  Instituto de Astrofísica de Andalucía (Granada, Spain)
  Instituto Nacional de Técnica Aeroespacial (Torrejón A, Spain)
  Instituto de Microgravedad Ignacio da Riva UPM (Madrid, Spain)
  Universitat de València (Valencia, Spain)
  Instituto de Astrofísica de Canarias (La Laguna, Spain)

Report on TIS design options, released in December 2020.

INTEGRAL FIELD SPECTROPOLARIMETERS BASED ON IMAGE SLICERS

Integral field spectropolarimeters represent the evolution of long-slit spectrographs, making it possible to scan a 2D surface area with high spectral resolution and polarimetric accuracy.

Traditional long-slit spectrographs have been used in solar physics for more than a century. Their principle is relatively simple: the instrument observes a given (and narrow) area of the Sun with the size of the slit and records in the sensor the spectral information over a given wavelength range for each spatial point on the slit (see Figure 1 for an illustration). A wider area can be covered by setting the slit to scan adjacent positions of the solar surface. Adding all those positions together, a map of the Sun can be obtained.

However, this mode of operation is not ideal for spectropolarimetry. The reason is that the time spent per slit position is 1-10 seconds, meaning that covering a reasonably large area of the Sun takes 1 hour or more. In other words, long slit spectrographs can provide maps with enough polarimetric signal-to-noise ratio with a cadence of around 1-2 hours. A time span where the Sun is continuously evolving, so we can think of it as when taking a picture of a child running in a park. We can get an idea of what the kid is doing, but we cannot know if they will fall, have fun, meet new friends..., because during one hour a lot of things can happen in a park full of kids, like in the Sun!

Here is where integral field spectropolarimeters (IFS) come into play. They use a traditional spectrograph and additional optics to record the same type of map made by combining multiple slit positions, but in just one 1-10 s measurement. Thus, they represent the evolution of long-slit spectrographs. In this article, we focus on IFS based on image slicers due to space restrictions, but the reader should be aware that there are IFS based on microlenses and optical fibres.

Let us start with the general concept. An image slicer (see Figure 2) takes the input beam and, instead of recording a single "long" slit, divides it into multiple "shorter" sub-slits (see green in the leftmost panel). Each sub-slit behaves in the same way as the long slit in the traditional spectrograph, recording a given spectral range (rightmost panel) but covering a small fraction of the solar surface (see middle). However, one difference with respect to the traditional spectrograph is that the sub-slits can be arranged to scan a continuous two-dimensional area on the Sun (see green in the left panel). In other words, we can observe simultaneously a solar area with the size of each sub-slit times the number of sub-slits that can be accommodated in the optomechanical design. The result is a snapshot of the Sun over a given area with a cadence of only 1-10 s. Hence, these instruments are the future in solar physics and astronomy in general. In fact, they have been available in night telescopes for a longer time. Their status, the significant challenges they pose, and the plans we have for EST are described below.

There is currently one image-slicer IFS offered to the solar community since 2018. This IFS is the evolution of the GRIS spectrograph installed at GREGOR. The IFS uses an image slicer that divides the beam into 8 sub-slits of 100

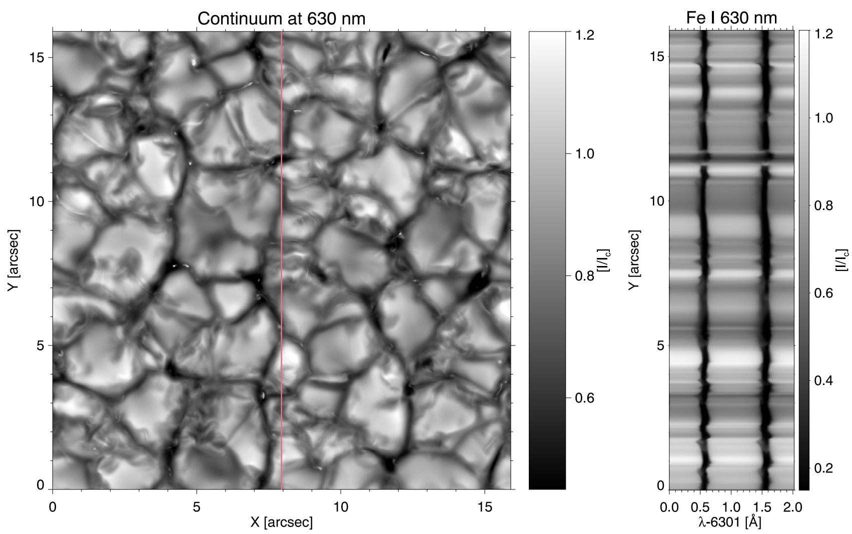


Figure 1. Left panel shows the continuum intensity at 630 nm. Red vertical line displays a reference slit position. Rightmost panel shows the Fe i 630.1 and 630.2 nm spectral lines for the reference slit. Image credit: Silvia Regalado Olivares (IAC).

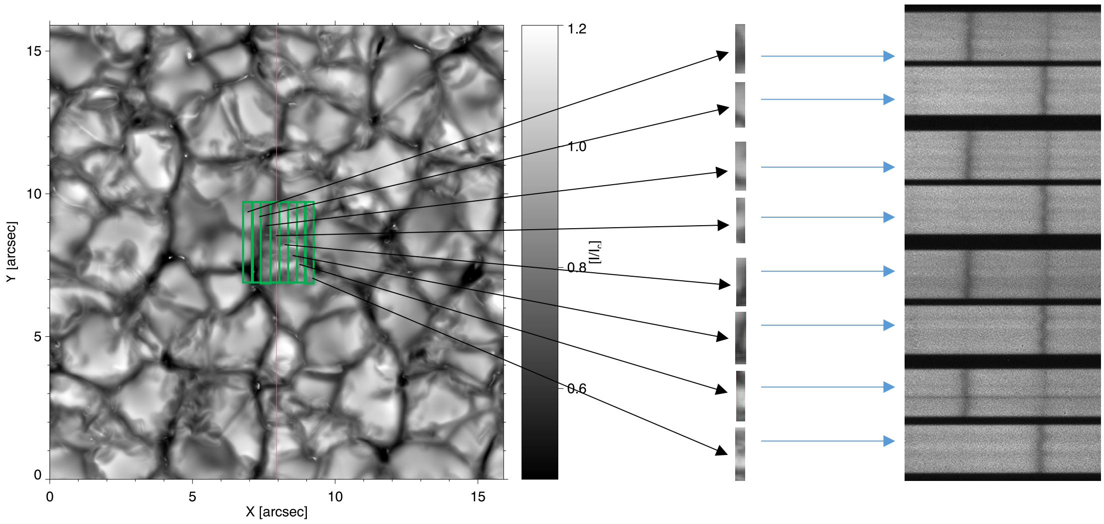


Figure 2. illustration of how an IFS based on image slicers works. Multiple sub-slits (green on the left) record a small FOV (middle), and a given spectral range over that FOV (right). Image credit: Silvia Regalado Olivares (IAC).

microns width. This configuration allows the instrument to observe an area of 3 x 6 arcsec^2 and a spectral range of more than 10 Å with a resolving power better than 250,000, strictly simultaneously. The rightmost panel of Figure 2 is an example of the spectra recorded by this instrument with 8 sub-slits.

Data from the GRIS IFS have been used in several peer-reviewed publications where the capabilities of simultaneously scanning a given solar area are exploited. For example, in Kaithakaal et al. (2020), the authors examine the magnetic properties of network fields, analysing their evolution and interaction with other fields for more than 30 minutes. Campbell et al. (2021) investigated the spatial properties and the evolution of very weak magnetic fields in the solar photosphere. Nelson et al. (2021) studied the evolution of long-period, high-amplitude oscillations of the magnetic field in a solar pore. In all these cases, the word "evolution" is used to describe their discoveries. The reason is that they could analyse the evolution of solar phenomena with a grating spectrograph for the first time, a capability traditionally reserved to Fabry-Pérot imaging spectrometers.

Unfortunately, the slicer technology is not mature enough to be implemented in EST. There are some challenges associated with the development and improvement of IFS based on image slicers. The first challenge comes from the vast number of pixels needed on the sensor to increase the observed FOV. In the case of long-slit spectrographs, one side of the sensor is reserved for the spatial domain of the slit, and the other side is used for the spectral domain. In the case of IFS based on image slicers, the solution adopted for GRIS follows the same strategy. That is, the sub-slits are rearranged one on top of the other (like in the long-slit case) along one side of the sensor, and the other direction is reserved for the spectral domain. However, this limits the instrument FOV to the small area that can be fitted into one side of the sensor. Therefore, the first step is simply increasing the sensor's pixel count. However, this will work only until some point due to the finite number of pixels available and, most importantly, restrictions on the maximum number of sub-slits we can fit in the optomechanical design (currently 16 sub-slits).

The developers of image-slicer IFS are looking for other strategies. One option is to have multiple long-slit like outputs from the image slicer. For example, if the output is equivalent to having a spectrograph with four long slits, the observed area would be multiplied by four. This option sounds promising, but it is technically more challenging. The sensor will have, in this example, four long-slit like arrangements of sub-slits that fill the spatial side of the sensor, but also four spectral windows in the spectral domain on the sensor. Imagine the rightmost panel of Figure 2 replicated four times, leaving blank spaces in between. Fewer pixels would be available for the desired spectral range, and narrow interference filters would have to be used to avoid the overlap of the spectrum of neighbouring long-slit like arrangements.

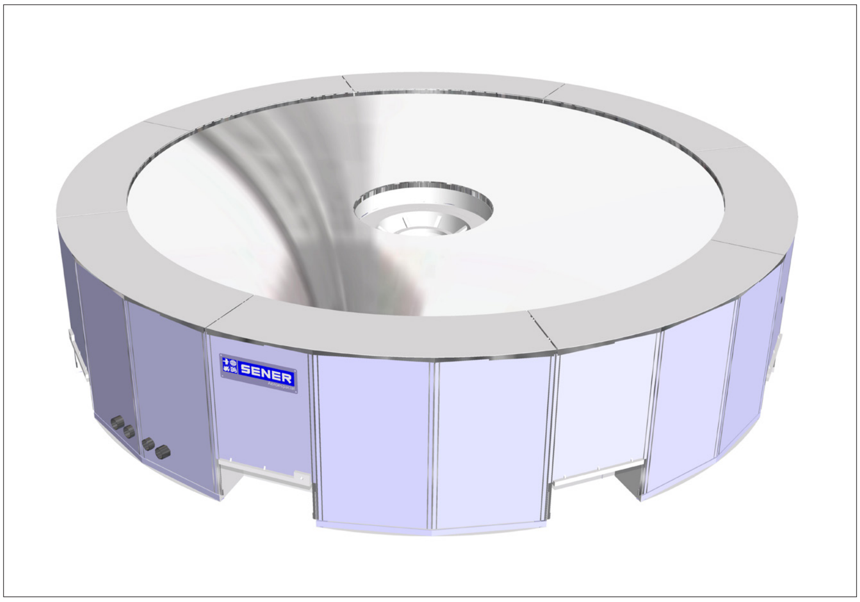
Still, IFS developers are making progress in that direction with one new prototype to be tested on GRIS in the future. The prototype is made by Canon Inc. with a sub-slit width of 35 microns (the width required to reach the diffraction limit of EST at 1083 nm and 3 times smaller than that currently used on GRIS). This design has two output long-slit like arrangements.

There is already a consortium formed by the Instituto de Astrofísica de Canarias (PI institution of the GRIS IFS) and the University of Coimbra (with long experience in optical instrumentation for astronomy and space) working on the design of an image-slicer IFS for EST for the wavelength range from 1000-2300 nm. The instrument will be an improvement of the GRIS design and is expected to be one of the largest leaps in solar instrumentation achieved in the next 10 years.

M1 ASSEMBLY PRELIMINARY DESIGN

An update of the main activities performed in the framework of the industrial contract for the preliminary design of the EST primary mirror and supporting cell is given below.

The EST M1 assembly consists of a 4.2 metre diameter mirror with near zero thermal expansion coefficient and the M1 cell, which includes the M1 mirror support system and the M1 thermal control system. The M1 cell also provides the interface that fixes the M1 assembly to the telescope structure.



3D model of the EST primary mirror and supporting mirror cell. Credit: SENER

SENER is the company in charge of carrying the preliminary design and analysis of the M1 assembly in order to achieve the requirements defined by the EST Project Office.

The M1 mirror is composed of a polished blank, made of Zerodur, and its coating. It also includes the required interfaces to fix it to the M1 mirror support. In the EST conceptual design phase, two alternatives were considered for the mirror: a thin solid meniscus blank and a thicker lightweight blank. During phase 1 of the preliminary design, finished in July 2021, strong efforts were put on analysing both options to select the best one. The solid meniscus blank was finally selected, since it complies with all requirements and minimises cost, risk and delivery time. Thermal inertia is a critical parameter on a solar telescope, so the mirror shall be very slim, with a challenging thickness of 70 mm.

The M1 mirror support system will support the mirror to the M1 cell, actively keeping the surface error of the mirror within the required accuracy during the telescope operation. It is composed of 80 axial actuators, 18 lateral actuators and 3 tangential isostatic definers. An intensive trade-off analysis was performed during Phase 1 of the preliminary design, considering 6 different technologies and strategies for the axial actuators. The so-called hyperstatic type was finally selected against other options as hydraulic or the classic isostatic actuators. The main drivers for this decision were excellent passive behaviour against wind, relative low complexity and maintenance, and proven technology in similar telescopes. In particular, behaviour against wind is very important because EST will be an open telescope (no dome during the observations), and so the M1 assembly will be completely exposed to wind.

The M1 thermal control system controls the temperature of the M1 mirror and the M1 cell during the telescope operation. If the temperature of any M1 assembly surface deviates significantly from that of the surroundings, then turbulences start to appear in the light path, with disastrous consequences for the seeing quality. To avoid that, the temperature with respect to the surrounding air needs to be maintained between +0.5 and -2.0 degrees Celsius in the case of the M1 mirror and within ±2ºC in the case of the M1 cell external surfaces. Jet impingement was selected for the M1 mirror cooling; a set of equally spaced nozzles will throw air, at around 15ºC below ambient temperature, to the rear part of the mirror. This technology has a much better transfer coefficient than radiative cooling options, and avoids the complexity of conductive cooling solutions.

The project is currently in Phase 2 of the preliminary design. Three main task are being addressed in this phase: generation and discussion of specifications for the interface with the telescope structure, design of actuator and cooling system prototypes and proposal for tests, and development of the M1 assembly design. We expect to have a first stable version of interface specification before the end of 2021, and prototype test campaign shall be performed during the first months of 2022. With respect to the development of the design, a strong effort is being made in the area of temperature control of the M1 cell.

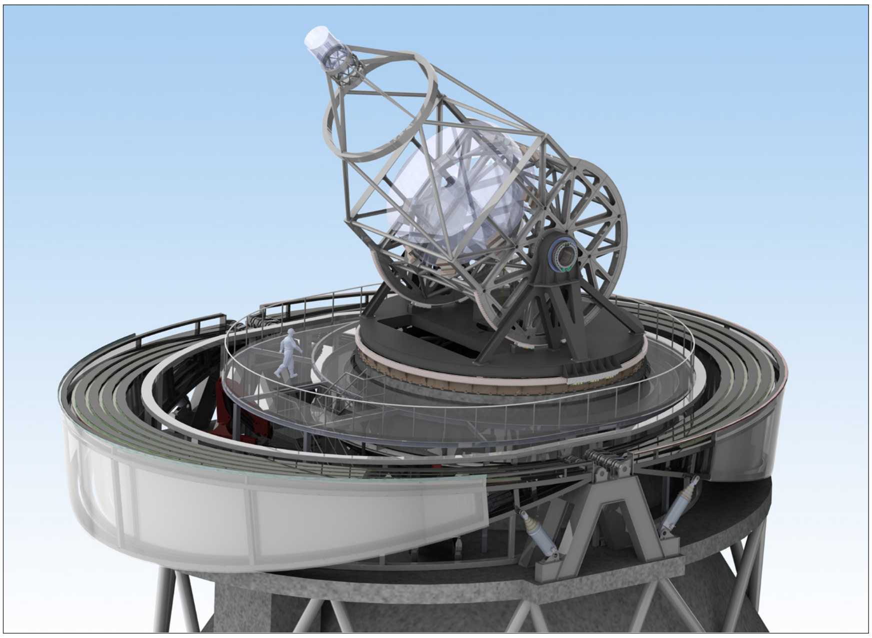
TELESCOPE STRUCTURE PRELIMINARY DESIGN

The industrial contract for the preliminary design of the telescope structure, pier and enclosure is making progress, as described in the following article.

The Telescope Structure, Pier and Enclosure preliminary design contract awarded to IDOM began in February 2021. This contract has been divided into three phases. Phase 1 finished on July 2021. The aim of this first step of the design was to define the baseline design for three main subsystem. To achieve the baseline design IDOM developed several trade-offs for the telescope structure, pier and enclosure. The Phase 1 review meeting was held at IDOM headquarters in Bilbao (Spain).

For the telescope structure the main trade-off was the selection of the azimuth structure configuration and the azimuth bearing. The yoke design was compared with a gantry design, and finally the gantry design with a hybrid bearing was selected. This solution is based on the use of hydrostatic bearings for axial loads and a central roller bearing for radial loads. The gantry design complies with the pointing and tracking requirements and this design allows a feasible M1 assembly integration manoeuvre. Also, other trade-off analyses of the thermal control strategies in the structure were carried out to verify that the requirement on the telescope structure being within ±1°C of the ambient temperature during observations was met.

Regarding the telescope pier, the main trade-off analysis dealt with the pier configuration. The options to compare were a single frame pier, an open double tower and a closed double tower, to study their effects on the image motion. The differences between them with respect to pointing and tracking with wind and thermal load was negligible. The open frame pier presented some advantages on maintenance and has shorter construction times, so it was selected as the best option.



3D render of the telescope structure and enclosure. Credit: IDOM

The enclosure trade-off analysis focused on studying the feasibility of a flexible enclosure (like that used by the GREGOR telescope) versus a rigid enclosure (like that used by the VTT telescope). The two options turned out to be feasible but the difficult maintenance operations of the textile cover, required by a flexible enclosure, led to the choice of a rigid enclosure for EST. Regarding the enclosure platform, some CFDs were analysed and an off-centred design has been considered preferable over a centred platform to reduce the platform area while allowing the main maintenance tasks to be performed with the enclosure closed.

Finally, the EST baseline design is a telescope structure with gantry configuration, with direct drive for the motion of the elevation and azimuth axes, rolling bearing for the elevation axis and a hybrid solution for the azimuth bearing, as mentioned before. The pier shall be an open frame, and the Coudé room will have three independent thermal controls for each floor. The telescope structure will be housed in a rigid enclosure with an off-centred platform.

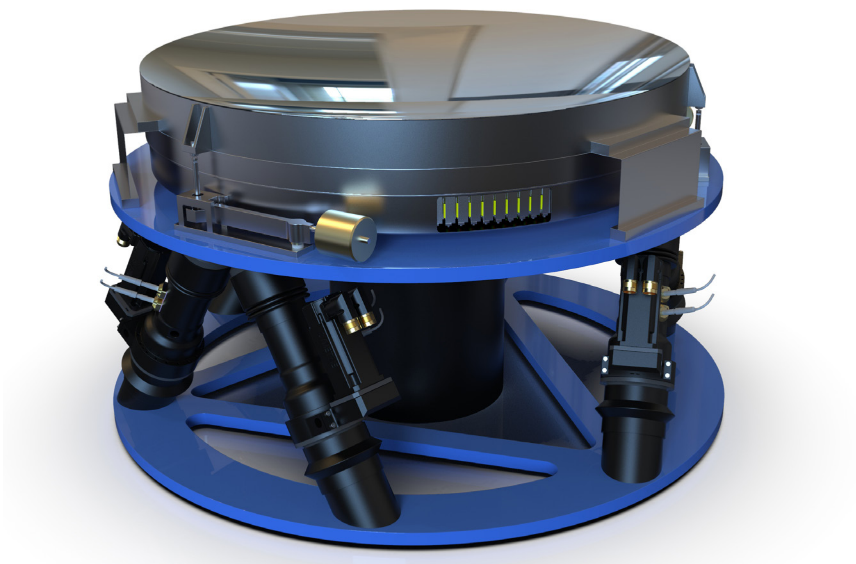
The EST Project Office and IDOM are currently working in Phase 2 of the preliminary design. Phase 2 focuses on the development and optimisation of the baseline design. Other objectives of Phase 2 are the consolidation of the interfaces and definition of the wind tunnel test campaign. Regarding the interfaces, the telescope structure is a key component because most of the EST subsystems are located on it.

Phase 2 will finish with a review meeting where the performance of each subsystem will be defined. Then Phase 3 will begin with the wind tunnel campaign to refine the models and complete the preliminary design. During Phase 3 other aspects like detailed specifications, the construction plan and maintenance tasks shall be defined.

ADAPTIVE SECONDARY MIRROR PRELIMINARY DESIGN

A description of the activities performed in the framework of the industrial contract for the preliminary desing of the EST adaptive secondary mirror is given in this article.

In 2019 a major review was performed on the existing EST optical design dating back from 2011 which considered a conventional secondary mirror (M2). The new EST optics design from 2019 considers an M2 which is also an adaptive secondary mirror (ASM). The contract for a preliminary design of the ASM was awarded in late 2020 to TNO – Netherlands Organisation for Applied Scientific Research. TNO has produced several prototype deformable mirros (DMs) for space optics applications within ESA projects. TNO is currently building an ASM to retrofit the UH88 telescope (Hawaii, USA) which is expected for commissioning in 2022.



3D render of the EST adaptive secondary mirror. Credit: TNO/B. Dekker.

The ASM preliminary design project held its kick-off meeting in April 2021, starting the design Phase 1 where a number of trade-offs were conducted and resulted in a baseline design presented at the end-of-phase 1 review meeting in mid-September 2021.

The EST ASM baseline design relies on a 2.5-mm thin boroflat reflective membrane with 0.8 m optical aperture. The membrane material trade-off compared boroflat, Zerodur and ultra-low expansion material. Boroflat was chosen in the baseline design as it meets the specifications in terms of optical quality and thermal control requirements, while resulting in the most cost-effective material to fabricate.

The EST ASM will have 1950 actuators on to the back of a silicon carbide (SiC) reference support structure. The SiC structure is also an integral part of the thermal control of the ASM (see below) as it helps to evacuate the heat on the optical surface by flowing coolant through a complex network of tiny channels within the SiC structure. The actuators have very thin rods traversing the support structure and are physically bonded to the boroflat membrane, leaving a ~0.3 mm gap in between the reference support structure and the membrane. In Phase 1, TNO compared the actuators in the UH88 ASM versus a new generation of actuators (part of an on-going internal TNO project). Due to the higher number and density of actuators in the EST ASM, the baseline design relies on the new actuators which improve the performance, simplify integration and assembly and reduce notably the cost as they are more suitable for mass production.

The SiC support structure with the actuators is mounted on an independent tip-tilt stage providing large-stroke and fast tip-tilt corrections to correct image motions caused by atmospheric turbulence, wind-shake or other types of disturbances that could be transmitted to the telescope structure. In turn the tip-tilt stage sits on top of an hexapod with large stroke tip-tilt and de-centring corrections as part of the telescope active optics strategy to compensate for optical misalignments due to changing thermal and gravity conditions (i.e. changing elevation) during the observations.

Regarding the ASM thermal control, besides the aforementioned cooling channels in the SiC structure there is also an actively cooled shroud for the whole ASM to avoid dissipating any heat to the surrounding environment from the actuators drive electronics, hexapod motors and tip-tilt stage.

At the time of writing, we are in Phase 2 and about to hold the Interface Consolidation Meeting. Phase 2 will end in February 2022 with a design of a prototype to be built and tested during Phase 3. The preliminary design contract is expected to conclude in September 2022.

SINGLE-CONJUGATE ADAPTIVE OPTICS FOR POINT-LIKE SOURCE: FIRST STEP TOWARDS MCAO FOR EST

The latest upgrades of the EST MCAO testbench and the results of measurements carried out to validate single-conjugate adaptive optics for point-like sources are described in the following article.

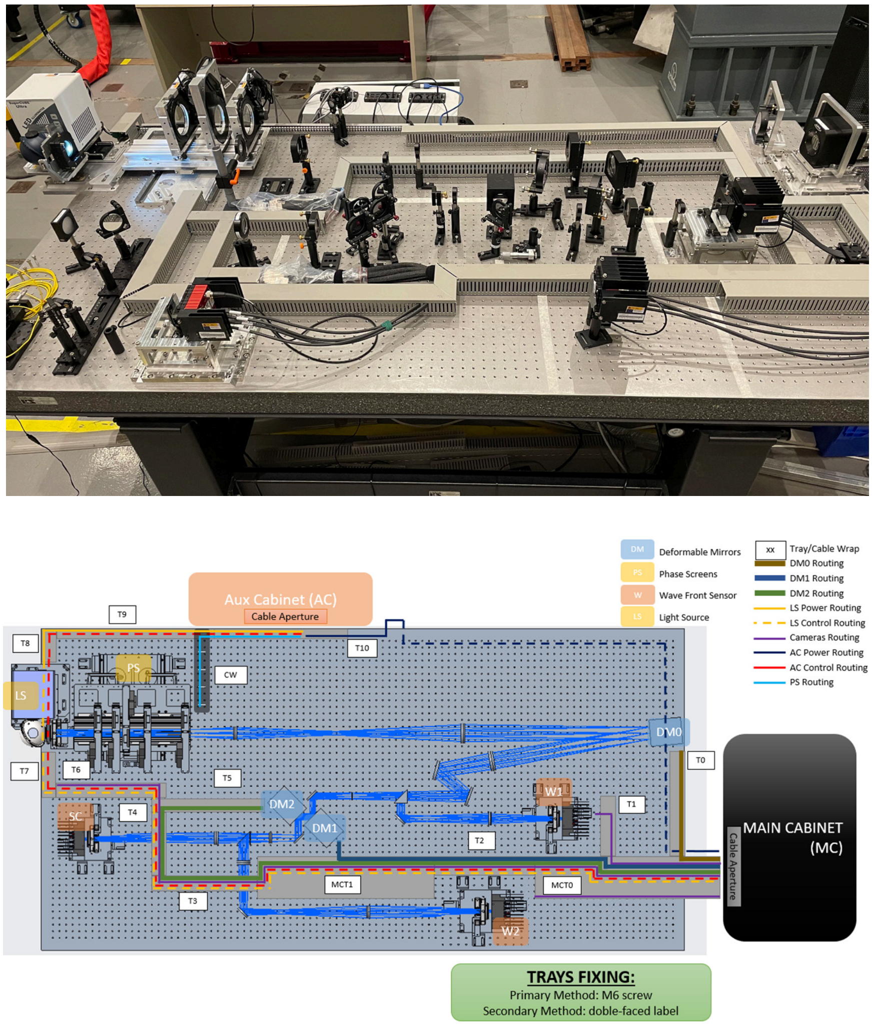


Figure 1. EST MCAO testbench (top) and schematic (bottom). Credit: C. Quintero/IAC

The European Solar Telescope is planned to include a Multi-Conjugate Adaptive Optics (MCAO) system capable of correcting the image blurring introduced by the Earth's atmosphere. Unlike traditional Single-Conjugate Adaptive Optics (SCAO), MCAO is based on several deformable mirrors (DM) to perform a seeing compensation that is uniform over an extended field of view (FoV). The deformable mirrors are placed into the conjugate planes of different altitude layers. Multiple wavefront sensors (WFS) or, alternatively, multi-direction wavefront sensors, measure the aberrations along various guide directions. Finally, a real-time controller modifies the DM shape to counteract the disturbances introduced by the atmosphere.

EST is required to have high spatial resolution over a square FoV of 40"x40", while achieving a high temporal resolution (frequency rate of 2 kHz). Initially, EST will be equipped with two WFS and five DMs conjugated to different altitudes: 0 km (ground layer), 5 km, 9 km, 12 km and 20 km. MCAO systems constitute a very complex and still not mature technology from both the optics and control points of view. Consequently, using equivalent requirements to EST, the EST MCAO testbed demonstrator is being developed by the IAC within SOLARNET WP7. The main objective of this demonstrator is to test both new and existing concepts of solar MCAO that will guide the final design of the EST MCAO system.

A picture of the optical bench and a schematic of the layout is depicted in Figure 1. It has been designed to include three DMs and two WFS. The atmospheric disturbances are introduced by phase screens designed and manufactured to represent different seeing conditions. The AO real-time controller is based on DARC, developed by Durham University.

Before MCAO implementation, different AO configurations must be first understood and tested. SCAO for point-like sources has been defined as the first step towards MCAO. This configuration is based on a DM with 820 actuators (DM0) and a WFS with 33x33 subapertures (W1). From the control engineering perspective, a reconstructor must be available to translate the measured wavefront into actuator commands to

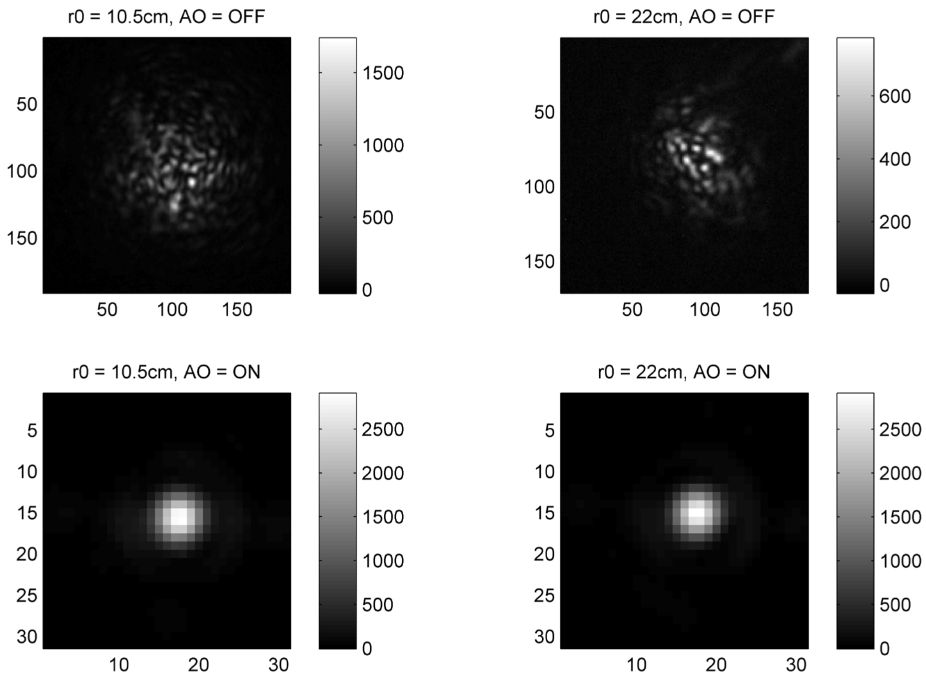


Figure 2. Point spread function (PFS) of the uncorrected wavefront for r0 = 10.5 cm (left) and r0 = 22 cm (right), and best corrected PSF achieved (top and bottom panels, respectively)

close the control loop. The suitability of different reconstruction algorithms to deal with point-like source SCAO in the EST MCAO bench has been tested from July to September 2021. The main results and conclusions of these tests are summarised below.

Four different interaction matrices, including 2 zonal and 2 modal-based approaches, were measured to characterize the influence of an individual actuator (or a single mode) in the WFS. For the modal approach, up to 819 Zernike and Karhunen-Loève (KL) modes were individually applied to the DM. For the zonal approach, each actuator was individually poked. A frequency-based zonal method for the actuation of all the 820 actuators simultaneously was also performed. To obtain the reconstruction matrix, different methods were performed. Not only the pseudo-inverse based on the widely-used singular vector decomposition (SVD) method, but also their regular versions to penalize poorly sensed information, were computed. A closed-loop strategy based on a proportional-integral controller was the default option to control the system. However, a pseudo open-loop control (POLC) to include an estimation of the turbulence in open-loop from the closed-loop setup was also evaluated. The resulting RMS wavefront error as well as the Strehl ratio (SR) achieved by the different reconstruction algorithms was evaluated. Two scenarios considering different seeing conditions were proposed, with Fried's parameters r0 = 22 cm and r0 = 10.5 cm.

The algorithms were tuned to obtain closed-loop stable responses. The results evinced that regardless of the seeing condition, the zonal methods showed a better performance compared with the modal strategies. Specifically, the frequency-based zonal method outperformed the classical poke zonal method. More importantly, the regular zonal matrix seems to provide the best results with good seeing conditions. Regarding the modal-based alternatives, Zernike modal basis reported slightly better results compared with KL modes, although no significant difference was found. In addition, no improvement was observed when using POLC. Finally, SR up to 0.60 (r0 = 22 cm) and 0.48 (r0 = 10.5 cm) were reached. An example of the corrected PSFs when applying the outstanding reconstruction method for each of the two scenarios is shown in Figure 2.

SCAO for extended object tests are planned for the last trimester of 2021. Correlation images will be used as a measure of the wavefront. Similar reconstruction matrices to those tried with SCAO for point source will be tested likewise. Next, Ground Layer Adaptive Optics (GLAO) for large uniformly compensated FoV based on ground layer compensation will be tested. For this scheme, DM0 and the two WFS will be tentatively used. The main key of this scheme will lie in a multi-direction WFS (W2) for a wide FoV, instead of using multiple narrow WFS. Finally, Multi-conjugate adaptive optics schemes will be tried. The combination of the altitude deformable mirrors (DM1 and DM2) together with the analysis of the required number and location of the different WFS will be evaluated.

EST THERMAL MODEL REVIEW

The thermal model of EST has been approved by a group of experts and is now ready to analyse multiple telescope configurations.

Introduction. EST will collect 14 kW of energy from the Sun due to its 4.2 metre primary mirror. In addition, the telescope surfaces (not considering optical surfaces) will receive direct and/or reflected radiation from the Sun and other surfaces, in visible and infrared wavelengths, respectively. This may generate temperature variations of the surfaces during the day, depending on the telescope position and the environmental conditions around it, which would produce thermal gradients between the ambient air and the telescope surfaces. If that happens, thermal plumes and eddies would appear near these surfaces, degrading the image quality of the telescope. This effect is commonly known as local seeing degradation.

Telescope Thermal Control. The EST thermal control is crucial to minimise the turbulence generated by the telescope itself. For this purpose, different thermal control systems applied to different areas of the telescope have been analysed, and their operation simulated in complete 24-hour cycles for different environmental conditions. In this way, compliance with the thermal requirements specified for each zone of the telescope can be verified. The most critical areas are those closest to the optical path, such as the telescope structure or the azimuth platform, which must maintain a maximum gradient of ±1°C with respect to the ambient air temperature. Areas farther away, such as the enclosure platform or the external surface of the pier, must maintain a maximum gradient of ±3 degrees.

Thermal Simulations. The thermal behaviour of EST is analysed using a thermal simulator, which calculates the temperature of all the surfaces of the telescope at each moment of the day (24 hour cycles), for each position of the telescope and at different moments of the year (summer, winter, etc). The software, named Taitherm, belongs to Thermoanalitycs Inc., and was acquired by the EST Project Office for its capabilities to simulate complete observation cycles and thermal systems operating under changing environmental conditions.

Review panel. Left to right: F. Godillon, K. Kethireddy, N. Vega, S. Jelic, V. Ranganathan.

The EST Project Office is working to develop a thermal model of the telescope according to the solutions proposed by the companies in charge of designing the different subsystems. The telescope model is subsequently analysed in the simulator under multiple conditions, to know if the telescope surfaces meet the associated thermal requirements, at any time of the day and any time of the year.

Thermal Model Review. The EST thermal model has been developed for several years. The model aims to collect every important component that can affect the thermal behaviour of the telescope, including the topography of the observatory. To ensure its correct operation, given the large number of variables and parameters to configure, the model has been reviewed by a team of experts from the company in charge of developing the software.

This review took place at the beginning of October 2021 in the headquarters of Thermoanalytics (Munich, Germany), For two days, details about the software configuration and the methodology used to carry out the analyses were reviewed. The main points covered in the review were the model geometry, the convergence parameters, the view factors, the boundary conditions (weather files and temperature profiles, terrain configuration), the simulation of ventilation systems, the simulation of water and air cooling systems, generic cooling systems, the data post-processing, and the coupling of the thermal and CFD models.

The evaluation of the thermal model by the experts has been very positive. The review guarantees that the project is working with an optimal thermal model. This ensures that the configuration of the model is correct, the analyses were configured correctly, the results are reliable, and the future evolution of the model is structured.

BACK TO IN-PERSON OUTREACH ACTIVITIES

After hard times for public events, in-person activities are being carried out along with virtual ones to spread information about the EST project and solar physics research.

The European Researchers' Night is probably the largest outreach event in Europe. This year it took place on the streets again on September 24, after the virtual edition of 2020 enforced by the COVID-19 pandemic. The European Solar Telescope could not miss this event, and several partners organised activities in their countries to promote the project and the challenges of solar physics among the general public.

In the Czech Republic, solar researchers at Ondřejov Observatory organised observations of the Sun in the historical Western dome and offered a tour of the Solar Department. Besides, participants built their own spectrometer following the guidelines of the EST Virtual Solar Kit in a special workshop organised by the Observatory.

The EST partners in Italy organised different talks. Francesca Zuccarello gave a public lecture about the EST school contest "The Sun at a glance" at the Università di Catania. Furthermore, members of the INAF-Osservatorio di Catania set up a booth to explain the project and distribute EST promotional material. In Rome, Francesco Berrilli (Università di Roma Tor Vergata) mantained an online meeting with high school students, and Alessandro Berlingeri (Scienza Impressa) recorded a video talk about space weather and the European Solar Telescope.

The Observatório Geofisico e Astronó-mico da Universidade de Coimbra (OGAUC, Portugal) joined the European Researchers' Night 2021 with a stand where scientists showed the four episodes of The QuEST cartoon video series and offered explanations related to solar astronomy. In Granada (Spain), the event took place again at its usual place on the street together with other scientific institutions. The booth set up by the Instituto de Astrofísica de Andalucía (IAA-CSIC) was one of the most visited and the EST members shared promotional material and information of the project with the public.

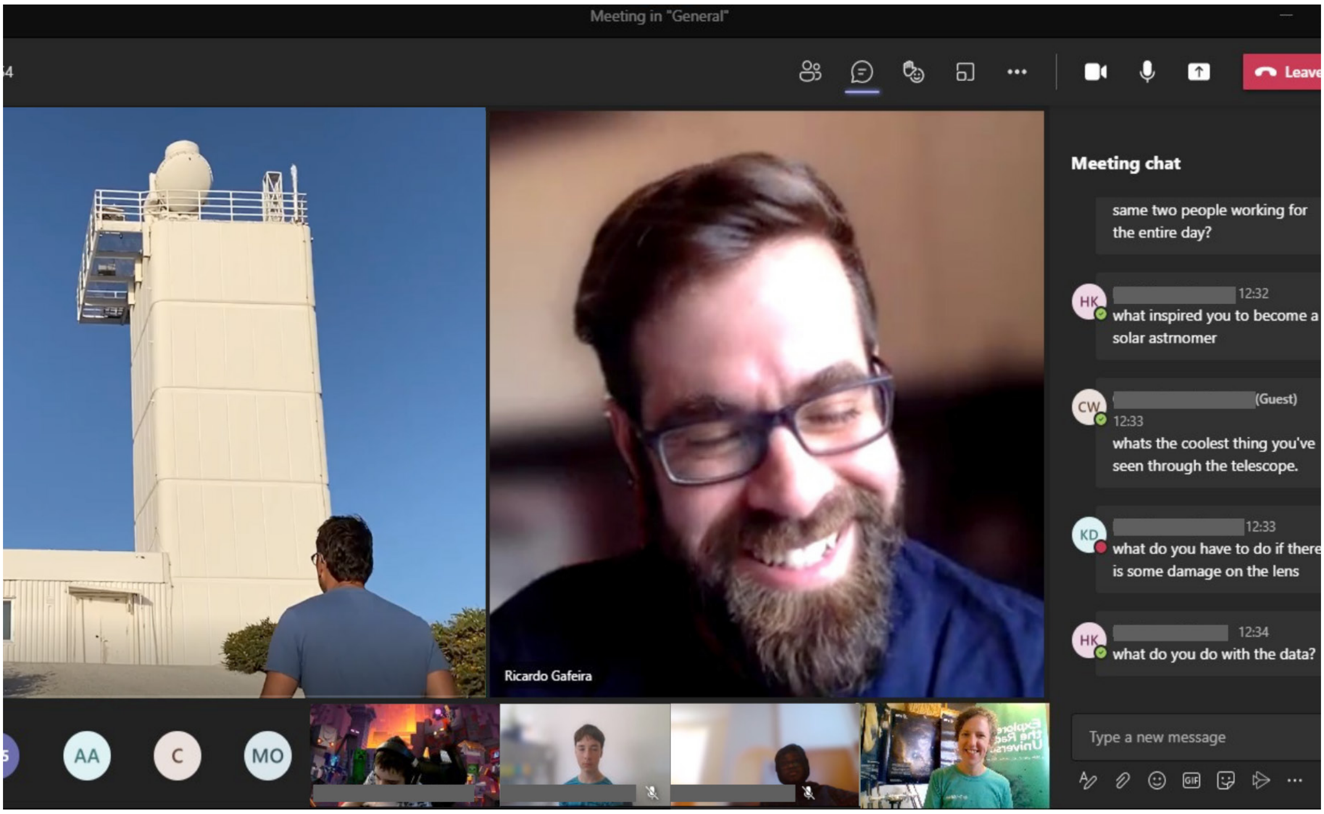
EST stand set up by IAA-CSIC at the European Researchers' Night 2021.

Other outreach events

The ERN2021 was not the only outreach event with participation of the European Solar Telescope in the last six months. The Hungarian Solar Physics Foundation organised the second Astronomical Day in Gyula on July 23, with explanations of solar observations carried out by Robertus Erdelyi and Mariana Korsós. On September 8, the Astronomical Institute of the Czech Academy of Sciences (AIASCR) was present in the Festival vědy organised in Prague. The Czech solar physicists displayed the EST roll-ups and distributed EST promotional material among the visitors. Furthermore, the Instituto de Astrofísica de Andalucía (IAA-CSIC) was invited to different activities of the outreach event "Desgranando Ciencia" in Granada. Víctor Aníbal López was interviewed about the videogame "Solar Mission EST" at the first Scientific Game Fair held on Instagram on September 9. He also gave a talk on September 18 in one of the plenary sessions of "Desgranando Ciencia".

I-LOFAR Astro Camps

Another successful experience was the participation of the European Solar Telescope in the virtual Astro Camps organised by the Irish Low Frequency Array (I-LOFAR) and the Trinity College Dublin in July and August 2021. This activity was aimed to engage kids with astronomy research. EST scientists Luis Bellot (IAA-CSIC), Sara Esteban (IAC), Ricardo Gafeira (OGAUC) and Ada Ortiz (Expert Analytics) shared their experiences as solar astronomers and explained to the kids what solar physics research is about. The three camps were attended by kids in the age range from 10 to 15, interested in science and space research.



Ricardo Gafeira (OGAUC) and Luis Bellot (IAA-CSIC) participating in the first session of the I-LOFAR Astrocamps.

Public talks

Several public talks have been given in this period by EST members. The Italian outreach organisation "Space is cool" invited Francesco Berrilli twice, on June 24 and November 12, to speak about the European Solar Telescope and the most relevant phenomena that takes place in the Sun. Besides, Luis Bellot (IAA-CSIC) gave a talk to celebrate the 40th Anniversary of the Astronomical Society of Granada on September 24. He described the challenges of solar physics in the era of large telescopes and space missions, highlighting the European Solar Telescope project.

EST in the media

The European Solar Telescope and its importance for advancing our knowledge of the Sun raised much interest in the media during these months. The EST coordinator Manuel Collados (IAC) was interviewed at length in "Materia", the scientific section of "El País", one of the most relevant Spanish newspapers. Collados also explained the latest news about EST in the program "Doble Hélice 3.0", broadcasted by Radio Nacional de España (RNE), the Spanish public radio company. Moreover, an interview to Ada Ortiz (Expert Analytics) was broadcasted in "Punto de enlace", another RNE program. The interview dealt with solar physics research and the goals pursued by EST.

Last, but not least, the European Solar Telescope project was featured in the Spanish edition of the National Geographic magazine, the weekly magazine "El Cultural", distributed in Spain with the "El Mundo" newspaper, and the 'Titan' website, managedd by the University of Oslo. Titan is devoted to research news on science and technology.

EST overview published in National Geographic Spain in August 2021

EST DOCUMENTARY "REACHING FOR THE SUN"

The TV documentary is now finished and will be released by the beginning of 2022. This is a high impact activity that will allow the project to reach out to a very large audience.

Opening title sequence of the documentary Reaching for the Sun. The documentary was filmed in 2:35 format.

One of the main activities included in the PRE-EST Communication, Education and Outreach Plan is a 55 minute documentary for television, entitled *Reaching for the Sun*. Europe has studied the Sun for centuries using innovative telescopes and instruments. The documentary shows some of these telescopes, explaining at the same time basic solar physics concepts and key milestones achieved by the facilities. Apart from the history of solar physics, the documentary presents EST and the ground-breaking science that it will enable, explaining why such a large infrastructure is necessary for the European solar physics community. This is a high-impact activity that will allow the European Solar Telescope project to reach out to a much larger audience than would be possible using other channels.

The documentary is based on interviews with scientists, complemented with short historical passages showing how solar physics flourished in Europe over time and infographics explaining several science and technology concepts. To complement the funding provided by the PRE-EST project, the EST Communication Office submitted a proposal to the Spanish Foundation for Science and Technology (Fundación Española para la Ciencia y la Tecnología, FECYT) in December 2017. The proposal was highly ranked and approved in March 2018.

The documentary was filmed between May and June 2018 with professional equipment (4K cinema cameras and drones) to ensure it meets the standards demanded by the leading distribution companies. A crew of 6 people visited 12 telescopes and institutions across Europe, interviewing 16 people from the PRE-EST consortium. More than 15 hours of recordings were obtained. This material was used to produce a trailer with subtitles in 7 different languages which was uploaded to the EST YouTube channel (https://youtu.be/pVNumhH-IXM) and promoted through the EST website and social media in January 2019. It is one of the most successful videos in the EST YouTube channel, with nearly 2100 visualisations to date.

The historical passages make use of illustrations that have been created specifically for this documentary. There are four blocks of illustrations featuring Galileo Galilei, Joseph von Franhoufer, Jules Jansen, George Ellery Hale and Richard Carrington. The illustrations have been animated and integrated with the footage. For the infographics we have prepared specific video animations synchronised with the scientist's explanations of the internal structure of the Sun, the different layers of the solar atmosphere, convection, and the magnetic configuration of sunspots.

Drones were used to obtain aerial views of the telescopes in Teide Observatory (Tenerife, Spain), the Einstein Tower in Potsdam (Germany), the Pic du Midi Observatory (France), and the city of Freiburg (Germany). The drone sequences are integrated in the documentary to show the European facilities used for solar research from a different perspective.

After significant efforts devoted to interview transcription and footage selection, a preliminary version of the entire documentary was released in July 2020. However, it still did not include the narration, original music soundtrack, or title sequences, and was not treated for color.

All these aspects were fixed during the last year. In particular, the narration was recorded by a professional voiceover artist in March 2021, following several attempts to involve actor Liam Neeson in the documentary as an alumnus of Queen's University Belfast. Unfortunately, and despite all the work put in by the solar physics group at Queen's, this possibility did not materialise in the end. The titles were completed in April 2021. The infographics made for the documentary were finalised in May 2021. The sound was edited and mixed in June 2021. The original music soundtrack was produced between June and August 2021 and the color grading was performed in October 2021.

As a result of these efforts, we now have a final version of the EST documentary and are working on permissions and credits. Currently, the planned release date is February 2022.

If the COVID-19 situation allows it, we will organise a premiere at an iconic location, easily accessible from the main European cities, such as the Accademia Nazionale dei Lincei in Rome (Italy) or the Residencia de Estudiantes of the Spanish National Research Council in Madrid (Spain). Also, we we will contact international distribution companies to ensure a proper dissemination of the documentary among leading TV broadcast channels in the different European countries, contingent upon their interest in this production.

Stills from the TV documentary showing footage, drone sequences and animations.

EST NEWCOMERS

CLAUDIA RUIZ

INSTRUMENT SYSTEMS ENGINEER

Claudia started her career at INTA's optoelectronics laboratory in 2007. She moved to France in 2009 to start a PhD in Optical Instrumentation at the Institut d'Astrophysique Spatiale d'Orsay (IAS), thanks to a CNES & Thales Alenia Space grant. Since 2013 she has been actively working as a permanent staff at IAS in many ESA Cosmic Vision missions (SO/PHI, JUICE/MAJIS and PLATO). Due to her extensive experience and skills in the fields of optical instrumentation and systems engineering management, she has joined the EST team as Instrument Systems Engineer. She is very happy to contribute to such a cutting-edge project.

CRISTINA PADILLA

FACILITY ENGINEER

Cristina has a degree in Industrial Engineering from the University of Las Palmas de Gran Canaria with a specialization in mechanics. She has experience in the private sector carrying out facility projects from the basic design to the execution of the works. She has also contributed to the campaign to reduce light pollution at the observatories of La Palma and Tenerife while working at the office for sky quality protection at the Instituto de Astrofísica de Canarias. She joined the EST team in 2021 as a Facility Engineer.

FERNANDO MERLOS

SOFTWARE ENGINEER

Fernando has a Bachelor in Computer Science from the University of Castellón, following part of his studies at the University of ENSSAT in France. He has extensive experience as Embedded Software Engineer in the private sector on biometric control systems and automotive. In the last five years he was involved in an startup as an associate, making the company grow 4 times larger since his incorporation. During that time, he managed and built solutions for big companies in the industrial sector.

FRANCISCO YERAY RAMOS

PROJECT MANAGER

Yeray obtained his degree in Psychology at the University of La Laguna (ULL) in 1999. He started his professional career as a researcher in the aeronautics sector in two European projects led by Trinity College Dublin, as part of the ULL team in the field of Organisational Culture. Afterwards he specialised in project management, acquiring expertise in managing a wide range of projects dealing with funding from diverse agencies. He joined EST in June 2021 as a member of the management team.

EVENTS

EST INVITED TALKS

Due to the COVID-19 pandemic, most meetings have been postponed. Until normal activity resumes, a list of EST invited talks in past international meetings will be given here. An updated list is available on the EST website at http://www.est-east.eu/est-invited-talks

THE SECRETS OF SUNSPOT PENUMBRAE AND STATUS DESCRIPTION OF EST
Rolf Schlichenmaier, Colloquium Talk at Udaipur Solar Observatory, Udaipur (India) 27 July 2021

PHOTOSPHERIC MAGNETIC FIELDS: CHALLENGES AHEAD
Luis Bellot Rubio, in *Advances in Observations and Modeling of Solar Magnetism and Variability*, IIA Bangalore (India), online, 1 March 2021

FORMATION OF SUNSPOT PENUMBRAE AND THE UNIQUENESS OF EST
Rolf Schlichenmaier, Colloquium Talk at Astronomical Institute, Tatranská Lomnicka (Slovakia) , 7 October 2020

INVESTIGATING THE X1.6 FLARE IN THE GREAT ACTIVE REGION 12192
Francesca Zuccarello, in *106th National Congress of the Italian Physical Society*, online, 14-18 September 2020

OTHER EVENTS

SCIENCE WITH SO/PHI MEETING
Granada (Spain), 26-27 January 2022

5TH NCSP DKIST TRAINING WORKSHOP: HELIUM I DIAGNOSTICS IN THE SOLAR ATMOSPHERE
Online, 31 January-4 February 2022

EGU GENERAL ASSEMBLY 2022
Vienna (Austria), 3-8 April 2022

INTERNATIONAL SCHOOL OF SPACE SCIENCE: THE DIFFERENT SCALES OF SOLAR MAGNETISM
L'Aquila (Italy), 11-15 April 2021

IAU 365: DYNAMICS OF SOLAR AND STELLAR CONVECTION ZONES AND ATMOSPHERES
Moscow (Russia), 23-37 May 2022

COOL STARS 21
Tolouse (France), 4-9 July 2022

COSPAR 2022
THE DYNAMIC SUN AT SMALL SCALES
Athens (Greece), 16-24 July 2022

SPIE ASTRONOMICAL TELESCOPES AND INSTRUMENTATION
Montreal (Canada), 17-22 July 2022

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EST NEWS
ISSN: 2792-4289
Instituto Astrofísica Andalucía, Granada

This newsletter is supported by the European Commission H2020 pogramme under Grant Agreement No. 739500 (PRE-EST)