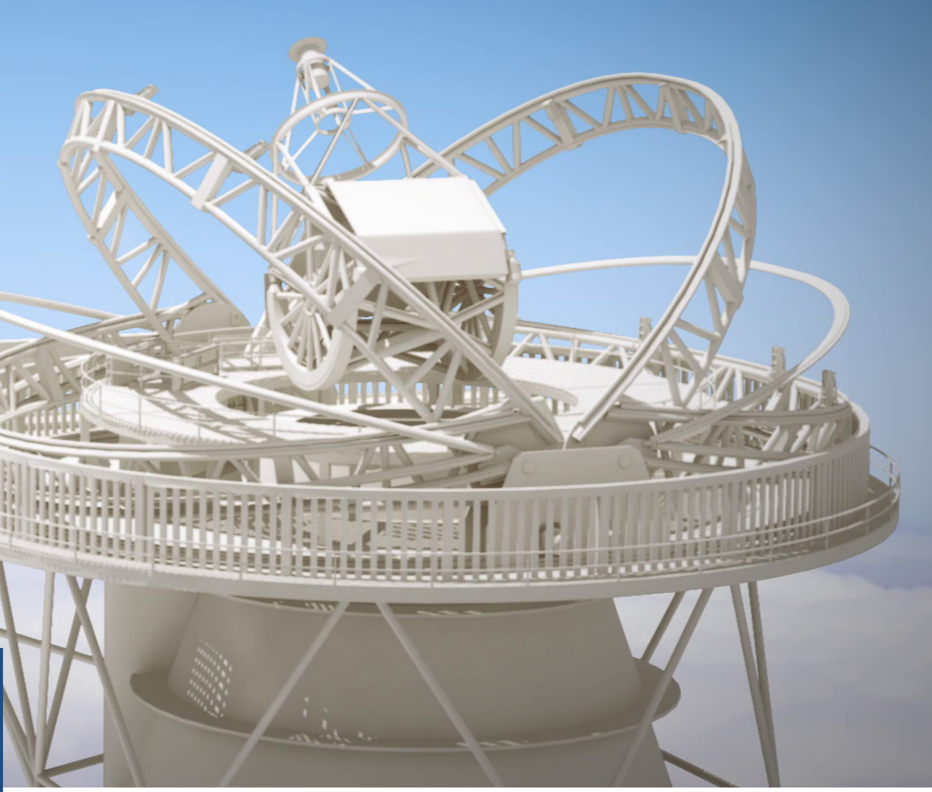

EST NEWS 8

THE EUROPEAN SOLAR TELESCOPE NEWSLETTER

JUNE 2021

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COORDINATOR'S CORNER

Step by step, EST is achieving milestones. The most recent one is the approval by the International Scientific Committee of the Canarian Observatories of the site where the telescope will be built: a location in the area of the Dutch Open Telescope at the Roque de los Muchachos Observatory (La Palma), very close to the Swedish 1-m Solar Telescope, an excellent site that is well known and acknowledged by solar physicists world-wide. With this relevant decision, the project is now in the position to adapt the design specificities to the particular site, which, in turn, will open the door to the required environmental study and to the further request of the construction permit to the local authorities.

In parallel, the Board of Directors is studying actions to create an interim legal figure —the EST European Economic Interest Grouping— for the completion of the EST Construction Plan and pave the way for the creation of an ERIC, the legal entity that will finally manage the construction itself and further operation of the facility.

As part of the EST activities, we cover in this issue the preliminary designs currently addressed by the companies awarded the public calls for tenders. A novel technique to measure absolute polarisation developed by the IRSOL group, the options for image restoration and the sensor requirements for the instruments working in visible wavelengths are also presented here.

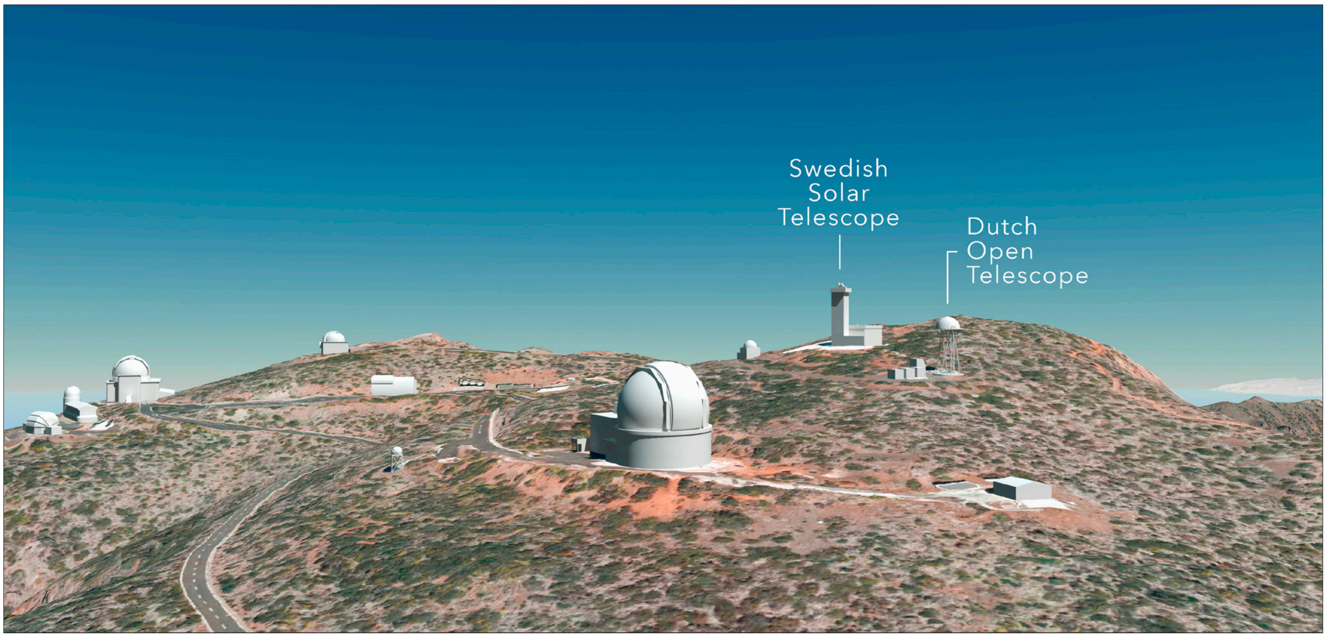
The most recent news in terms of outreach and interaction with stakeholders is also described. In particular, the EST School Contest needs to be highlighted. This initiative aims to promote STEM (Science, Technology, Engineering and Mathematics) vocations among secondary school students while producing material for the upcoming EST Solarpedia.

Certainly, the coming months will bring us more exciting news about the progress of the European Solar Telescope.

M. Collados, EST project coordinator

EST LOCATION AT ROQUE DE LOS MUCHACHOS OBSERVATORY APPROVED

The European Solar Telescope will be located at the Roque de los Muchachos Observatory in the area of the Dutch Open Telescope, near the Swedish Solar Telescope.



Area approved for the installation of EST, very close to the Dutch Open Telescope at ORM (La Palma, Spain). Image credit: Gabriel Pérez (IAC)

The selection of an excellent site for a solar telescope is of primordial importance to ensure the success a project like EST. The European Association for Solar Telescopes (EAST) already established in its 2007 Terms of Reference that "EAST shall promote and manage the design, development and construction of a next-generation large aperture European Solar Telescope (EST), to be built in the Canaries".

Since then, in-depth studies of the characteristics of the two Canarian observatories (Teide Observatory —OT— in Tenerife and Roque de los Muchachos Observatory —ORM— on La Palma) were performed. The main characteristics of both observatories have been analysed, from sky conditions (turbulence, radio electrical or atmospheric pollution, air routes...) to existing infrastructures (accesses, telecommunications, electricity, water supply, sewerage and other facilities). Climate and meteorological conditions have also been especially studied by the IAC Sky Team. In particular for EST, the average meteorological and turbulence conditions at OT and ORM were studied for the period 2003-2019 and a comparative analysis was made specifically for the EST candidate sites. Dedicated site-testing campaigns were performed as well at both observatories. These studies concluded that there is no global significant difference between both observatories and that the particular location at one of the observatories and the final height of the building above the ground are the most critical parameters.

All the studies conducted during decades at both observatories have also been considered. In particular, the LEST project back in the 80's made an extensive site testing campaign during 5 years of 3 candidate observatories (Hawaii, Teide, and Roque de los Muchachos). The campaign confirmed the excellent performance of the site where the Swedish Solar Telescope (SST) is presently placed and a site for LEST was chosen close to that location.

After considering all these aspects, two sites were pre-selected at both OT and ORM. Finally, the EST Board decided on October 4, 2019 to propose a location near the SST at ORM as the preferential site for EST. The high quality demonstrated by the SST during its 30 years of operation (as a 0.5 m telescope since 1985 until 2000 and as 1 m telescope after its upgrade in 2002 until now) has been crucial for the final decision.

Any new installation at OT or ORM needs the approval of the International Scientific Committee (CCI for its initials in Spanish) of the Canarian Observatories. The CCI Subcommittee for the Astronomical Characteristics of the Canary Observatories (SUCOSIP) made up of representatives of the countries involved in the observatories has the role of ensuring that new infrastructures do not degrade the scientific quality of the observatories. Several interactions were needed between the EST project and the CCI/SUCOSIP committees to minimise the impact on facilities already operating in the surroundings of the proposed EST site while keeping the good observing conditions for EST.

For the evaluation of potential sites in the surroundings of the SST, local turbulence (due to the area orography close to the ravine) and local geological conditions were the two main worries in the process of identification of EST alternative candidate sites in the area. A wind analysis was also performed by the IAC Sky Team to identify changes in the wind direction and speed in the area. A preliminary study of the geological and geotechnical characteristics of this area of interest was also subcontracted, in order to determine its suitability for the installation of EST.

With these arguments, the CCI approved on May 21, 2021 a site for EST in the area of the Dutch Open Telescope, near the SST.

This important milestone opens the door for the fine-tuning and optimisation of the telescope building and services during the EST preparatory phase.

EST BOARD OF DIRECTORS

The EST Board of Directors met virtually on December 20, 2020, to review the project status.

The Board of Directors is a governing body formed by representatives of EST partner institutions, national ministries, and other entities providing significant resources to the project. It aims to decide and implement the measures that are needed to consolidate the project and obtain the required funding commitments by the participating countries. Its terms of reference and remit apply initially to the design phase of the project and shall evolve into a subsequent Construction Phase Project Board at the appropriate time.

During its most recent meeting held on December 10, 2021, Prof. Svetlana Berdyugina, from the Leibniz-Institut für Sonnenphysik (Germany), was elected as the Board Chair, with Dr. Benedetto Lepori from Università della Svizzera Italiana (Switzerland) as vice-Chair. New members were also introduced: Dr. Daniel Weselka from the Austrian Federal Ministry of Education, Science and Research (replacing Prof. Arnold Hanslmeier from University of Graz), Dr. Marco Romano from University of Catania representing the Italian universities involved in EST, Dr. Ricardo Conde from Portugal Space (replacing Dr. Chiara Manfleti), and Dr. Peter Gömöry from the Astronomical Institute of the Slovak Academy of Sciences.

Relevant points such as a proposal for a legal interim legal figure for EST, the strategy for the financial feasibility of the project, and the site proposal for the construction of EST were discussed during the meeting.

The Board of Directors was briefed about these topics by members of the EST Legal Team and the EST Project Office, and discussions took place where actions and resolutions were adopted to make progress towards the consolidation of the project and the definition of an interim phase later, as a bridge between the preparatory and the construction phases.

EST PREPARATORY PHASE

A report of activies carried out by the project during the last 6 months is provided, with emphasis on the efforts to set up an interim legal figure for EST.

PRE-EST Board meeting on February 3, 2021.

The Preparatory Phase machinery is rolling at full speed and many exciting milestones for the project can be seen in the horizon.

The EST Project Office team is now consolidated and supported by scientific and technological committees formed by senior scientists, partners that had previous technical responsibilities on the EST conceptual design with instrumental background or members from the solar community who are experts in instrumentation. All these teams are working jointly to give shape to the EST design and EST future instrumentation.

In order to fulfil the planned schedule, the PRE-EST coordinating institution, the Instituto de Astrofísica de Canarias, released on 9 March 2020 the publication of the call for tenders for the design of three main EST subsystems: the telescope structure (also including the pier and the dome), the primary mirror and the adaptive secondary mirror. This was an important milestone but now more design calls are on the way and soon will be published.

Thanks to the work of the EST Project Office, in collaboration with the IAC Sky Team and the EST consortium, a site for the construction of EST has finally been approved by the International Scientific Committee of the Observatorios de Canarias. This allows the project to refine the design and advance in the license request process to the local authorities.

In April 2018, the European Research Infrastructure Consortium (ERIC) was chosen by the PRE-EST Board as the most appropriate legal figure for the construction and operation of EST. However, the procedure of establishing an ERIC requires a formal commitment of each state to become a member or to host the ERIC. At this stage, members of the EST consortium have not yet succeeded in securing commitments from their respective national ministries for establishing or joining the EST ERIC.

The current Preparatory Phase will end in 2022 and an Interim Phase will commence as a bridge towards Construction Phase. An interim legal entity shall therefore be established to provide the project with the adequate vehicle to work towards the completion of the EST Construction Plan and to provide a legal framework until readiness for an ERIC legal entity is achieved. The EST legal team has been working on the analysis of legal options for this Interim Phase and the European Economic Interest Grouping (EEIG) has been chosen as the most suited vehicle to meet these goals. The preparatory work is being carried out for the establishment of the EST EEIG.

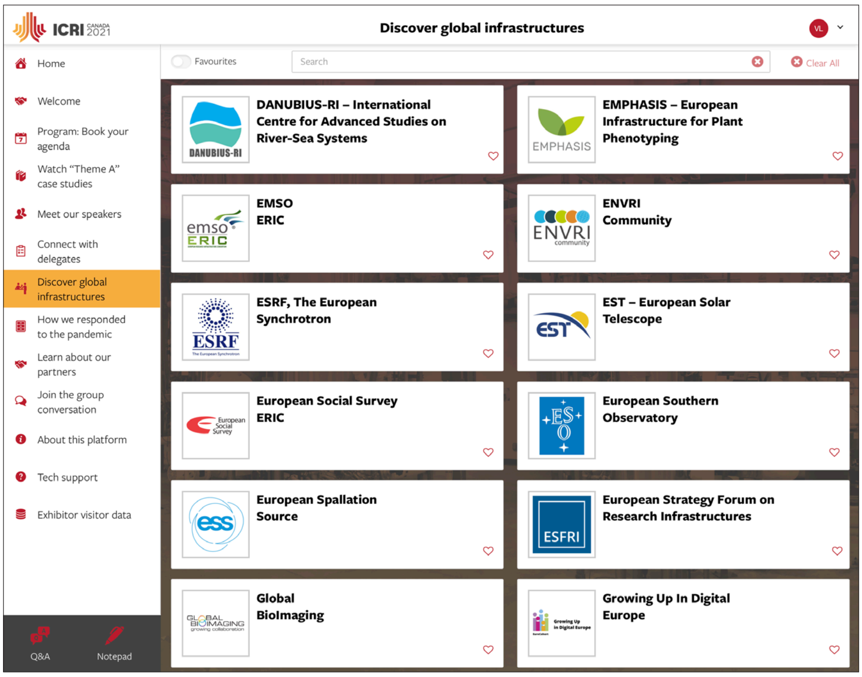
The EST Board of Directors was established already one year ago, to agree and implement the measures that are needed to consolidate the project and obtain the required funding commitments by the participating countries. During this year important steps have been taken to consolidate the financial compromise with the project and to shape its next phases.

In parallel to these actions, a multilevel communication is taking place at European scale, where EST approaches the scientific community, the industry, policymakers and the society.

The PRE-EST Board met on 3 February 2021 and the Project Officer from the European Commission, Mina Koleva, attended the meeting. She was pleased to see the project evolution and achievements. The Board agreed to request an extension of PRE-EST until 30 September 2022, in order to guarantee that companies have the necessary time to implement the expected designs and prototypes.

EST PARTICIPATES IN ICRI 2021

EST was present at the International Conference on Research Infrastructures 2021, held virtually from June 1-3, and set up a dedicated booth to showcase the project.



Some of the international research infrastructures present at ICRI2021, including EST

The International Conference on Research Infrastructures (ICRI) takes place every two years, with the aim of engaging policy experts, facility managers, leading researchers, and a variety of other stakeholders to discuss challenges and emerging trends for research infrastructures around the world.

ICRI 2021 was held on June 1-3, supported with funds from the Horizon 2020 programme of the European Commission, and hosted by the Canada Foundation for Innovation. This was the fifth edition of the event, and the first in a North-American country. However, it had to be carried out in virtual format because of the ongoing COVID-19 pandemic.

This invitation-only event brings together experts in the development, financing, and exploitation of research infrastructures across all disciplines and areas of research to discuss how to best enable excellent research, technology development, and innovation in all sectors of society. The European Solar Telescope was invited to participate for the third time. The project was also present in the editions held in South Africa in 2016 and Austria in 2018.

EST WAS INVITED TO ICRI FOR THE THIRD TIME

Several members of the EST team attended the plenary sessions that addressed the role of research infrastructures in sustainable development, and the importance of building connections between stakeholders and decision-makers across the globe. Moreover, EST followed with special interest several parallel sessions related to the research infrastructures governance. In this forum, the EST members had the opportunity to get to know cases of operational global research infrastructures as well as others being currently implemented. The sessions explored different types of global research infrastructures, like centralised, distributed, multifunctional, or multi-service infrastructures. Besides, different governance models and their rationale, legal forms, and current challenges were also analysed.

ICRI 2021 provided an excellent opportunity to promote the European Solar Telescope among other large scientific facilities. The event featured 44 virtual stands where the invited infrastructures and institutions shared their projects with the rest of the participants. EST set up a virtual booth to give a global overview of the project, including its scientific objectives and technological challenges. In addition, examples of the activities carried out by the EST consortium were presented, like educational and outreach actions aimed at engaging the public with solar physics.

THE EST BOOTH SHOWCASED THE PROJECT GOALS

More than 20 unique visitors from other institutions and large research infrastructures all over the world stopped by the EST booth. The project raised interest among representatives of other ERICs, and policymakers from different countries, just as scientists and communication and public relations officers from several European institutions and ESFRI projects. The members of the EST team were available during the three days of the event for meetings and to provide information about the project.

INDUSTRIAL CONTRACTS FOR THE PRELIMINARY DESIGN OF THREE MAIN EST SUBSYSTEMS

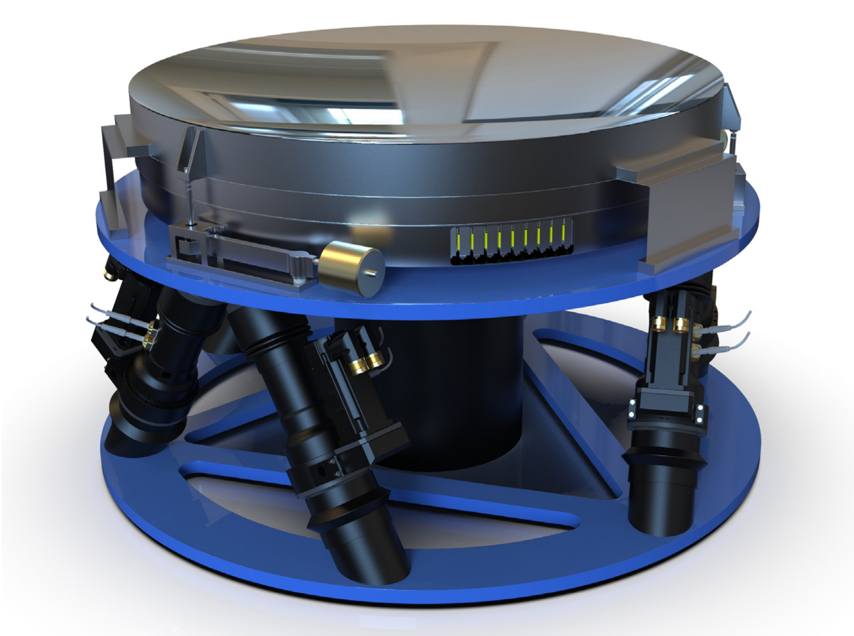
The industrial contracts for the design of the telescope structure, pier, and enclosure, the primary mirror assembly, and the adaptive secondary mirror have started in the first semester of 2021.

In August 2020, the Instituto de Astrofísica de Canarias released a call for tenders on behalf of the PRE-EST consortium for the preliminary design of three main EST subsystems: the telescope structure, pier and enclosure, the primary mirror assembly, and the adaptive secondary mirror.

Following the European Commission guidelines, the call was open to companies all around the world to guarantee proper competition and the best value for money. A total of 9 companies from 5 European countries submitted bids in response to the call.

After some delays in the administrative proceedings derived from the COVID-19 pandemic, three different companies were awarded the contracts, for a total amount of 1,840,000 €. IDOM will be in charge of the telescope structure, pier, platform and enclosure. SENER Aerospacial will be responsible for the primary mirror assembly. Finally, TNO will take care of the adaptive secondary mirror.

In the first semester of 2021, kick-off meetings have been held with these companies to start the corresponding design works.



3D model of the EST adaptative secondary mirror. Image credit: TNO / B. Dekker

EST telescope structure, pier, and enclosure

The telescope structure includes the telescope itself and a system to support six mirrors, the heat rejecter, and all their auxiliary systems. It also includes the mechanisms required to precisely rotate the telescope for an accurate pointing and tracking of the solar image.

Using an alt-azimuth configuration, the telescope structure shall be able to rotate up to 270 degrees in azimuth and move up to 90 degrees in elevation. Additionally, a very fast pointing mechanism is needed: with an intended pointing speed of 3 degrees per second in azimuth and 1 degree per second in elevation, the telescope should be able to go from North to South in less than 2 minutes. The design must be rigid enough to minimise wind vibrations. The pier, the platform and the retractable enclosure will be considered in the study to guarantee correct interfaces between all the components.

Primary mirror assembly

The EST primary mirror assembly consists of a 4.2 diametre glass ceramic mirror and the supporting cell. It has critical requirements for positioning and cooling. During the conceptual design study, several alternatives for the primary mirror optomechanical design were identified. A major decision is the choice of a thin or a thick lightweight solid meniscus blank. Regarding the options for the blank material, Zerodur and Ultra-Low Expansion glass were considered during the conceptual design phase.

The preliminary design will lead to the choice of the most efficient options among the different alternatives. It will also focus on the design of the cell, its actuators and thermal control. All these topics remain open and have to be decided during this phase.

Adaptive secondary mirror

EST will use an adaptive secondary mirror (ASM) that can rapidly change shape to correct the optical distortion of the solar image caused by turbulence in the Earth's atmosphere. The EST ASM is a 80 cm diametre concave ellipsoid which defines the telescope pupil. It will be mounted on actuators that will change its shape to achieve excellent image sharpness. The solution proposed by TNO includes a deformable mirror with 2,000 state-of-the-art actuators that are precise, robust, predictable, and more efficient than classical actuators.

The EST ASM will be located after the field stop. It will be equipped with mechanisms to compensate for the gravity deformations of the telescope structure and the vibrations produced by the wind. The use of an ASM as the first deformable mirror of the EST multi-conjugated adaptive optics simplifies the telescope optical design to a large extent, reducing the number of optical elements from 14 mirrors down to only 6 mirrors plus a doublet lens.

Objectives

The three contracts have a common objective, namely to consolidate the baseline design for each subsystem. The companies will develop the designs and validate them through modelling and analysis. They will verify the key components by test campaigns on breadboards or prototypes. Furthermore, they will define the production plans and schedules, including detailed designs, manufacturing, assembly, integration and verification, and an estimation of the production costs.

The preliminary designs delivered by the companies will be reviewed by the EST Project Office and technical experts. Once approved, they will be the cornerstone for the detailed design and construction of the various subsystems.

The kick-off meeting with IDOM was held on February 12, 2021. It was attended by a team of 13 IDOM staff and 9 members of the EST Project Office. The contract duration is 65 weeks. SENER Aerospacial started to work on the primary mirror assembly design on March 12, 2021. Eight members from the EST PO plus 9 members from SENER

Virtual kick-off meeting with IDOM held on February 12, 2021.

attended the kick-off meeting. The study will continue for another 65 weeks. Finally, the kick-off meeting with TNO took place on April 16, 2021, with the participation of 7 TNO members and 11 EST representatives. The development of the EST ASM will be carried out over a period of 78 weeks.

Company profiles

IDOM is a Spanish firm with extensive experience in the design and construction of scientific equipment for astronomy, including telescopes, domes and instrumentation. It has developed the prefocal stations for the Extremely Large Telescope, the Cassegrain station for the Gran Telescopio Canarias, and the enclosure of the Daniel K. Inouye Solar Telescope, among others.

SENER Aeroespacial is a Spanish engineering company with more than 20 years' experience in large ground-based telescope projects. It is recognised internationally for critical mechanisms and optomechanical systems for space, like the High Gain Antenna mechanism on the Mars Perseverance rover. SENER Aeroespacial work in astronomy includes optical and electromechanical systems, instrumentation and large mirror drive systems for both ground-based telescopes and space assets. The list of precision mechanisms delivered so far includes, among others, a rotator for the Very Large Telescope, the drive and primary focus corrector systems for the William Herschel Telescope, and the cells of the Extremely Large Telescope M2-M3 and M5 mirrors, plus the M1 segment manipulator.

TNO is a Dutch engineering company with long experience in developing state-of-the-art adaptive mirrors for telescopes. The company will partner with VDL ETG, which will provide the high-precision actuators of the ASM. This is the second time TNO and VDL ETG together have applied this technology to telescopes. In 2019, as part of a joint venture with the University of Hawaii, the team designed a 63 cm-diametre adaptive secondary mirror as an upgrade for the UH88 telescope in Hawaii. That ASM, now being assembled, will be actively shaped by 210 actuators. The team has also built deformable mirrors for the European Space Agency and the University of California's Center for Adaptive Optics.

Upcoming call: EST heat rejecter

The next EST subsystem to be tendered will be the heat rejecter. This is an essential component used to stop the solar radiation from outside the transmitted field of view, minimising internal seeing. The call for tenders, with the code LIC-21-026, will be issued soon. The preliminary announcement is available here and on the EST website. The contract amounts to 270,000 €.

HIGH-PRECISION ABSOLUTE SPECTROPOLARIMETRIC MEASUREMENTS

Using a novel technique, systematic errors hindering high-precision absolute spectropolarimetry have been significantly reduced at the IRSOL telescope in Locarno, Switzerland. As part of the EU-funded H2020 SOLARNET project, the potential of this technique for EST will be investigated.

Introduction. Spectropolarimetry is the ultimate instrument to draw the most detailed picture of the solar atmosphere. The amount of detail attainable does then not only depend on the spatio-temporal and spectral resolution achievable by the telescope, in combination with the instruments, but also on the precision and accuracy of the polarimeter.

Figure 1. The Telescope Calibration Unit mounted in front of the IRSOL telescope.

The polarisation of light is a delicate parameter, since any optical element may imprint spurious signatures to the measurements, which are sometimes hard to calibrate. While the precision of polarimeters (the ability to measure variations in the polarisation, limited essentially by photon noise) can reach a few parts per million of the incoming intensity, the accuracy (the ability to measure the absolute polarisation value or the absolute zero reference value) is usually not better than a few tenths of a percent. This discrepancy is caused by systematic errors induced by telescopes and instruments contaminating polarimetric measurements.

For this reason, the optical path of the EST self-corrects for systematic errors induced by the mirrors, which are placed in such a way that the telescope polarisation is automatically compensated, making EST the largest polarisation-free solar telescope worldwide. Still, besides the mirrors, other optical elements may prevent the achievement of high polarimetric accuracy and therefore the determination of the absolute level of polarisation.

One sub-work package within the EU-funded H2020 SOLARNET project aims to explore a novel technique which drastically reduces spurious instrumental effects to increase the accuracy of spectropolarimetric measurements. This technique has been applied successfully to measure the continuum polarisation at the IRSOL telescope in Locarno, Switzerland. The IRSOL telescope is a Gregory-Coudé setup, which means that telescope polarisation can be significant for certain times of the year. So it presents an ideal test case to explore the novel technique.

The technique consists of a zero-order retarder film mounted on a rotation stage in front of the IRSOL telescope. This film is slowly rotated and thereby adds an additional slow modulation to the fast modulation of the modulator and ZIMPOL, the high-precision polarimeter at IRSOL. This slowly rotating retarder system is called the Telescope Calibration Unit (TCU).

The systematic errors in spectrograph measurements reduced with the method are: telescope induced polarisation, cross-talk induced by the telescope, background variation in spatial and spectral dimension, fringes introduced by the liquid-crystal based modulator, and some detector defects.

Method. The choice of a zero-order retarder film implies that polarimetric measurements at wavelengths apart from the design wavelength suffer from additional cross-talks. We showed

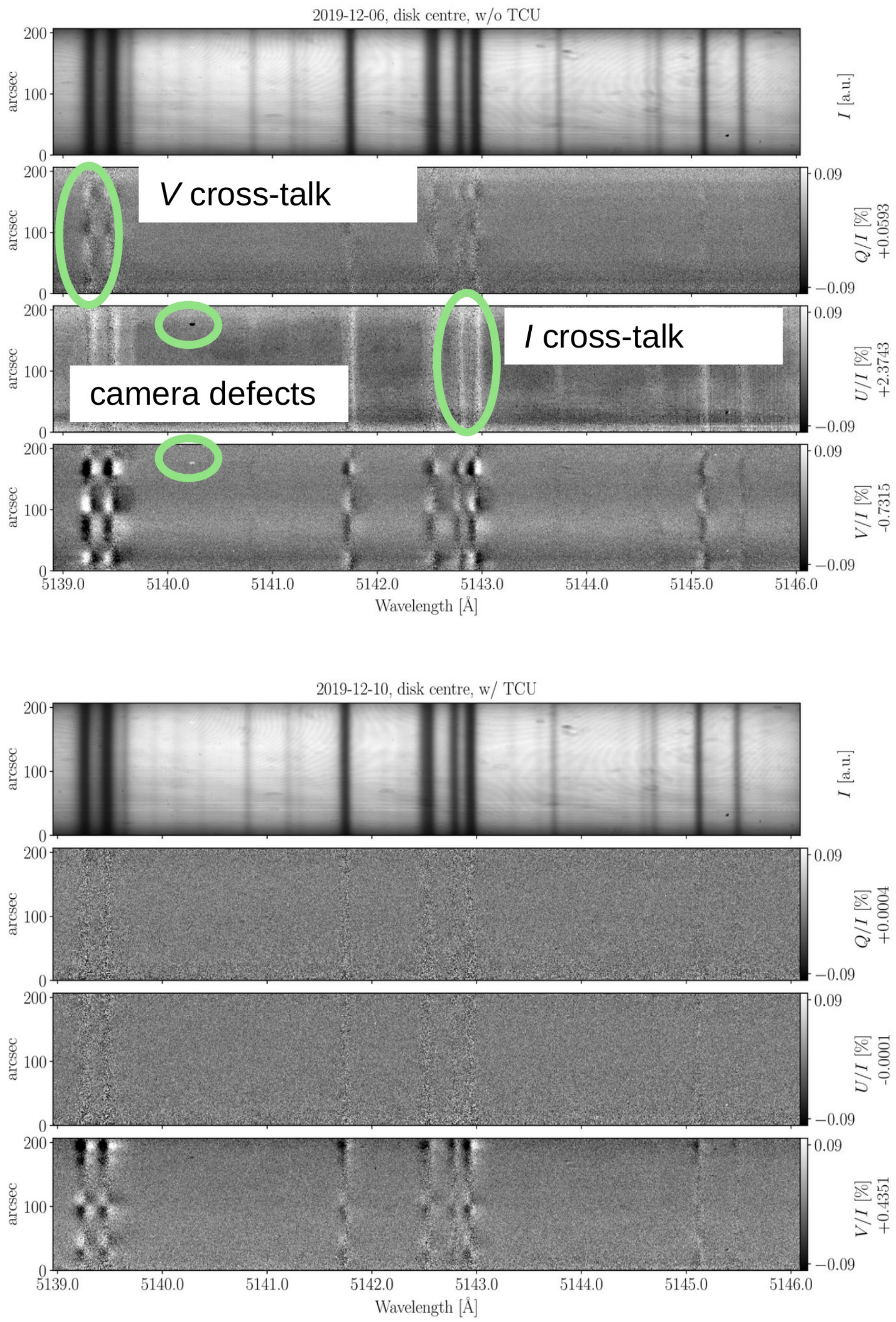


Figure 2. Spectrograph measurements with and without the TCU, at disk center (bottom and top panels, respectively).

that by combining measurements at pre-defined positions of the retarder, these cross-talks plus temporally stable systematic errors vanish for all wavelengths, so that in principle the method works independently of the wavelength. Despite this independency of the working principle, the efficiency of the correction method for the linear and circular polarisation certainly depends on the wavelength. The efficiency for linear and circular polarisation is only equal for two specific wavelengths. Thus, a collection of retarders at different design wavelengths are needed to cover a large wavelength range with high efficiency. Also, choosing a suitable retarder depends on the scientific question.

Results. The study of the method at IRSOL reveals a significant increase in the absolute precision (see the spectrograph polarisation measurements with and without TCU in Figure 2). We studied the method in the visible wavelength range, and consistently found that the absolute level of polarisation improves by two orders of magnitude. This was tested at disk center, where the mean linear polarisation level is expected to be zero. Additionally, cross-talks by the telescope and other systematic errors are significantly reduced. As a next step, the method will be tested at GREGOR (Tenerife, Spain), the largest European solar telescope currently in operation.

IMAGE RESTORATION: BASICS AND REQUIREMENTS FOR EST INSTRUMENTATION

Post-observation image restoration is necessary for reducing residual seeing effects after adaptive optics correction. Instrument design must take image restoration into account.

The Earth's atmosphere is optically active, perturbing the image formed by a telescope. This effect, known as *seeing*, is the result of turbulence in the Earth's atmosphere, stirring air with varying temperature and therefore varying refractive index. This produces rapidly varying phase aberrations in the wavefronts entering the telescope, continually changing the image. These changes can be described as the convolution of the real image, the *object,* with varying point spread functions (PSFs).

EST will have Adaptive Optics (AO), which reduces the effects of seeing in real time. However, AO cannot remove these effects completely because there is necessarily a time lag between measurement and correction and they both have limited resolution.

We will reduce the effects of residual aberrations by using image restoration based on multiple short exposures. Short exposures, on the order of milliseconds, retain high resolution information, although scrambled. A long total integration time is needed to get a useful signal in many observing scenarios but in a long exposure different instances of the seeing are averaged, thus blurring the image and hiding the details. So the image restoration algorithm needs to combine multiple short exposures, but with the aberrations removed.

Untangling the object from the PSF in a single image is an ill-posed problem known as Blind Deconvolution. You need constraints to solve it. With varying aberrations and an object that evolves much slower, the problem becomes easier. Multi-Frame Blind Deconvolution (MFBD) uses a model-fitting approach to find the single object and the aberrations that fit multiple exposures. MFBD estimates the PSF in each exposure and uses this information to restore a sharper image.

The Fixed Band Imagers (FBI) of EST will collect data through narrowband (NB) filters, that can be changed with a filter wheel. How should they be designed so the data are good for MFBD? Figure 1 shows three alternative designs, with the first one as the simplest case. If you collect multiple exposures with a single camera behind a filter, you can do image restoration with MFBD. This brings out many of the small features in between the larger granules. The upper-right part of Figure 2 demonstrates the results with data from SST/CHROMIS. For comparison, the upper left part corresponds roughly to keeping the image steady while taking a long exposure. However, we then leave it to the atmosphere to provide the variations that we need to do it well.

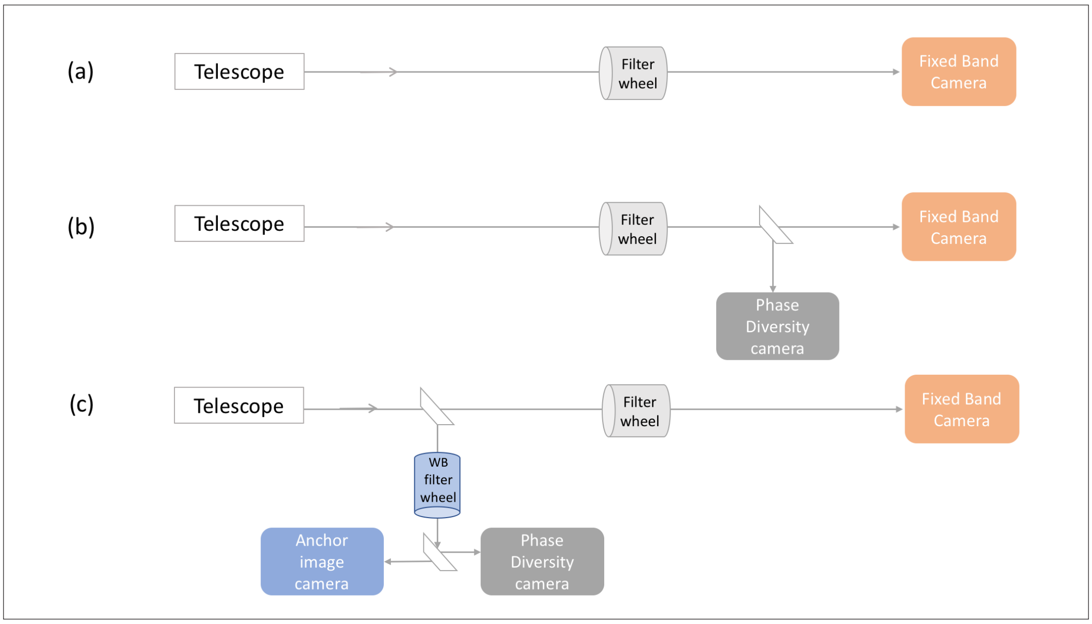


Figure 1. Conceptual design for the EST FBIs. (a) The simplest setup: one camera and a filter wheel with narrowband filters. (b) As (a) plus a beamsplitter and a synchronised, defocused camera for Phase Diversity. (c) The chosen setup, as (a) plus a Phase Diversity pair of cameras behind a wideband filter wheel. Graphics courtesy C. Quintero Noda.

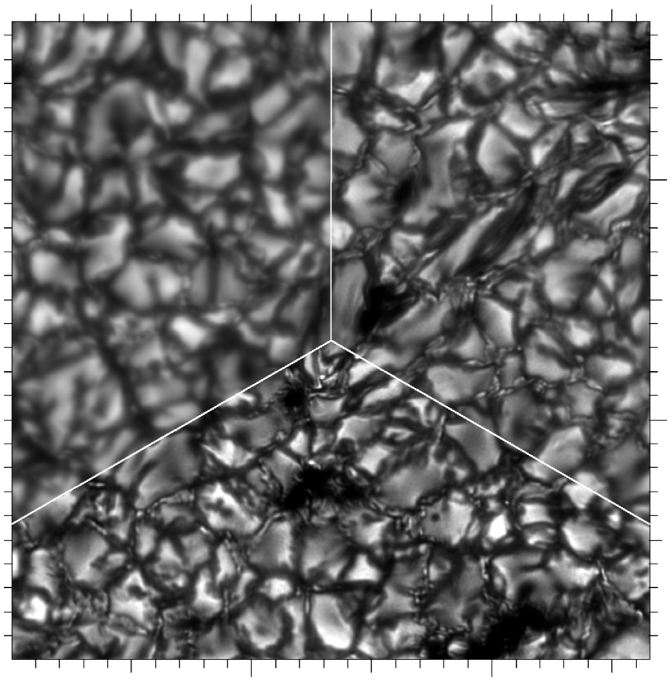


Figure 2. Contrast and image quality comparison. Top left: shift-and-add by subfield. Top right: MOMFBD. Bottom: MOMFBD with PD. Based on 110 exposures in SST/CHROMIS Ca II continuum.

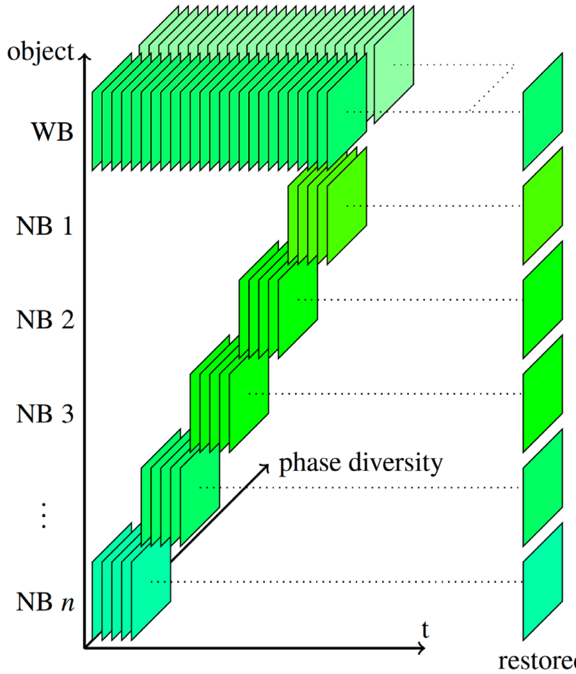


Figure 3. Schematic representation of a MOMFBD dataset with Phase Diversity. The WB images force MOMFBD to align the restored NB images.

So if random variation in the aberrations helps with the restoration, can you introduce intentional, known variation, that is better? Yes, add one camera and put it slightly out of focus, as in Figure 1b, and you get Phase Diversity (PD). This can improve the MFDB algorithm's ability to identify and compensate for the aberrations considerably, as demonstrated in the bottom part of Figure 2. The trick here is that with synchronised cameras, you can collect pairs of images where the object is exactly the same and the wavefront phases differ in a specific way, corresponding to the amount of defocus. This constrains the problem and makes it easier for the algorithm to select the best of several solutions that fit the in-focus images almost equally well.

The chosen design, shown in Figure 1c, has three cameras. The PD camera pair is now behind a wideband (WB) filter, the light to which is split off before the NB filter. What do we gain by adding a third camera? As before, the cameras are synchronised so they all share the same aberrations and we assume the filter wavelengths are similar. This means we can find the aberrations in the WB, where there are plenty of photons, while the NB might be darker and noisier due to a narrower passband and perhaps being in an absorption line. We also do not waste precious NB photons in the out-of-focus image. We can use a variation of the MFBD algorithm where the WB and NB images can be processed together as a single data set: Multi-object MFBD (MOMFBD). We then solve for the aberrations of all exposures and two objects, one in the WB and one in the NB. Both the MFBD and MFBD+PD results in Figure 2 are actually processed as MOMFBD datasets as for the chosen FBI design.

MOMFBD allows for datasets where we switch NB filter while collecting the data. Then you get the kind of data set illustrated in Figure 3. Here we have to find the restored image of a single WB object and multiple NB objects. Because the fitted aberrations include image motions, which are then removed by the deconvolution, all the NB images come out aligned to the WB image—and therefore also to each other.

This is a useful property of the MOMFBD processing, as the NB images can look very different, e.g., in the core and in the wings of a spectral line, and therefore be difficult to align with other methods.

The continuum, on the other hand, is fairly similar in different parts of the spectrum. So even if the NB wavelengths are too far separated for processing as a joint MOMFBD dataset, the WB images are still useful for alignment. If the WB filter is also switched to nearby continuum wavelengths, the continuum images can be used post-restoration to find the misalignment and apply it to the restored NB images.

MOMFBD image restoration can be used for the Tunable Imaging Spectropolarimeter (TIS) instruments as well. The TIS design is not fixed yet, but from an image restoration point of view it can be very similar to the chosen FBI design. Just add an extra NB camera and a polarising beamsplitter for dual-beam polarimetry and replace the NB filter wheel with tunable Fabry-Pérot etalons and a polarisation modulator. With or without the PD WB camera, the image restoration problem becomes larger but is in essence the same as for the FBI instruments.

SENSOR TECHNOLOGIES FOR EST

Sensors are key elements of any instrument. Hence, they deserve special attention in the preliminary design phase of the European Solar Telescope as we show below.

EST will have a set of instruments that will observe the Sun simultaneously and at complementary spectral regions. This unique approach aims to provide researchers with unprecedented height resolution to understand the solar phenomena and answer long-standing questions in solar physics. Among the multiple systems in a given instrument, there is one that is sometimes considered critical, namely the sensors. They constitute the last item on the optical path and are responsible for converting the incoming light—photons— into information that the solar astronomer can analyse. Hence, they deserve special attention and the EST team, together with experts in the field, has been working on defining the general sensor requirements to fulfill the EST science goals.

Our aim here is to cover some of the sensor elements crucial to our research leaving out the rest of the items that, even being essential, are too specific for this article. Moreover, to illustrate the concepts we have tried to compare most of the requirements to situations of our daily lives in which we use a similar type of sensors, i.e. when we use our smartphones.

KEY SENSOR TECHNOLOGIES ARE EVOLVING QUICKLY

The advent of smartphones with excellent photography capabilities allows everyone to capture important moments with very high quality and less effort than in the past. There are multiple reasons for that, one of them the quick evolution of sensor technology. Fortunately, this also happens in the field of astrophysics. We have experienced a massive leap in several areas like the sensor pixel count (the equivalent to the number of megapixels in a smartphone's camera), the frame rate (some of you probably enjoy taking slow-motion videos), or the dynamic range (similar to the case where you switch on HDR when taking a nice picture of a sunset), among others. These parameters are quickly evolving year after year. With that in mind, we decided to adopt the following strategy. First, we revised the EST Science Requirements Document (available on arXiv) to define the ideal sensor that would meet those requirements. The results of the analysis are summarised below. In a second step, we will interact with companies to check whether that sensor already exists or if it is on their roadmap to have access to them a few years from now.

Before starting, let's meet the highest limiting factor when performing observations from the ground—the Earth's atmosphere. It changes rapidly in different ways at various heights (e.g., the wind patterns at the telescope level and 10 km above the telescope are usually completely different). We have adaptive optics systems that measure the atmosphere's changes and correct them almost in real time, compensating for the atmospheric disturbance. However, the correction, even in the ideal case, still leaves residual effects. Those effects can result in an image that is blurred.

The experience on ground-based telescopes establishes that a fast frame rate can attenuate this effect as you are almost "freezing" the atmosphere during the observation time. Thus, one of the key elements for EST sensors is that they should have an extremely high frame rate. Let's bring a daily life example of the previous situation. Imagine that you are taking a picture with your smartphone. The shake of your hands (similar to the atmospheric disturbance) can make the image blurred. So, smartphones nowadays have image stabilisation mechanisms (like our adaptive optics system) that reduce to some extent the impact of your shaking hands. However, that needs to be coupled with a high frame rate to effectively freeze the motion of your shaking hands and make it as accurate as possible.

Therefore, we should aim at the highest frame rate possible. However, we need to bear in mind additional specifications that will affect the frame rate considerably. The first one is the pixel count. Current telescopes use sensors with a pixel count between 2000 (2k) or 4k pixels on a side. If we consider an imaging instrument, each pixel corresponds to a spatial region of the Sun. In other words, the more pixels we have in the sensor, the larger the area we can cover on the Sun. This is critical because we can move from imaging just a tiny part of a sunspot (see Figure 1) to observe it entirely at once. The latter is critical if we aim to understand what triggered, for instance, an eruptive event like a flare or a coronal mass ejection.

However, if you record a slow-motion movie you will see that the frame rate is much higher, but the resolution has also dropped. Sensors used in astrophysics show the same behaviour: the larger the pixel count (e.g., a higher smartphone slow-motion resolution), the lower the frame rate. This is the first trade-off we have found. The EST sensors should reach a frame rate of 50-100 frames per second (fps) to freeze the atmosphere, but the pixel count should be at least

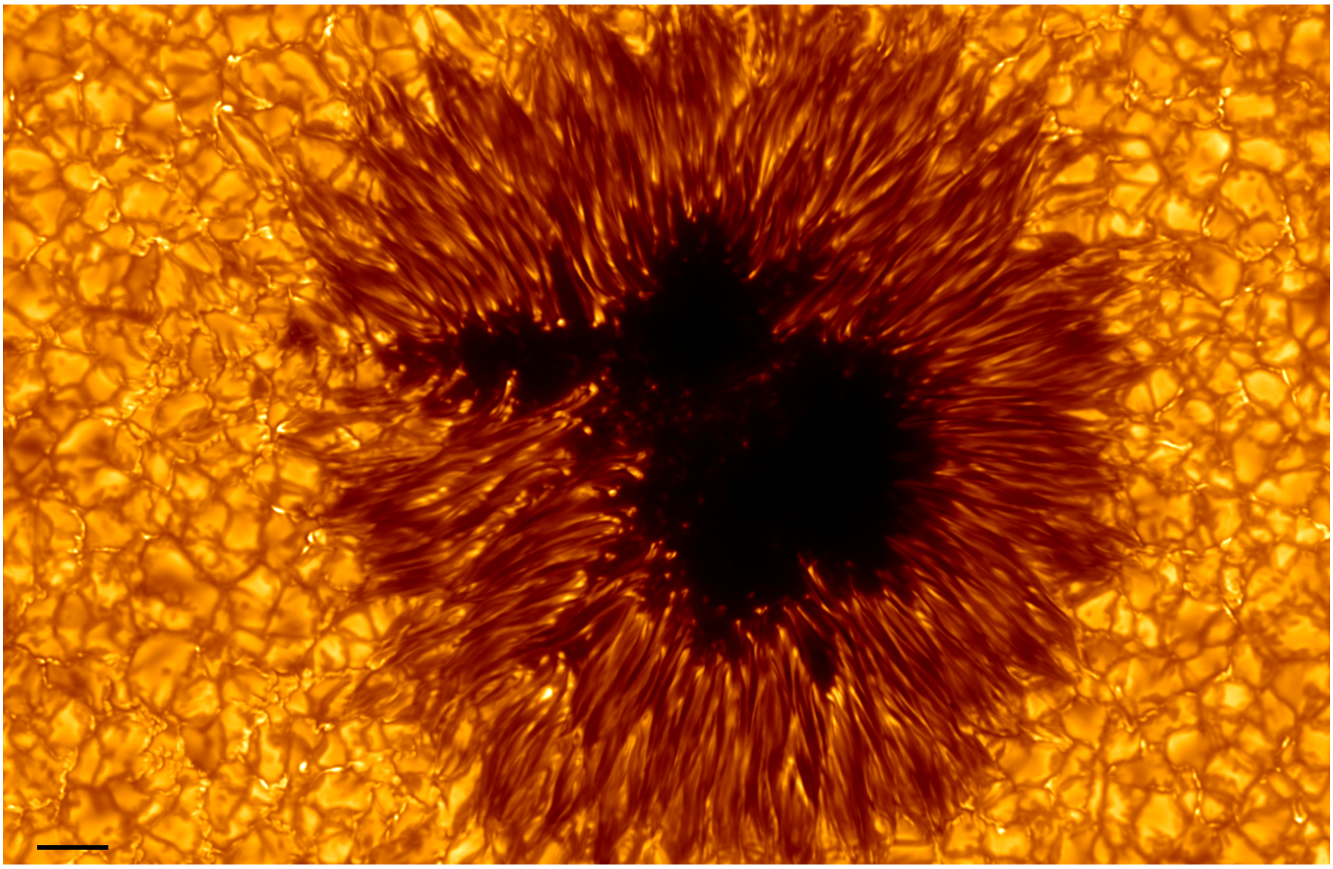


Figure 1. Example of a sunspot. They are the most prominent magnetic structures on the Sun and responsible for eruptive events, like flares and coronal mass ejections. Imaging instruments on EST aim to observe them in one go using large-format sensors with high pixel count. Image credit: L. Rouppe van der Voort (ITA), S. Jafarzadeh (ITA), J. de la Cruz Rodríguez (SU).

4k or even 6k pixels to cover a wide enough solar region, especially in the blue part of the spectrum. Finding a balance between the two requirements seems doable, but now we enter into a new dichotomy. Sensor (or camera) manufacturers offer different frame speed based on the type of shutter used to read the sensor's pixels. In particular, the two leading technologies are global and rolling shutter. First, let's try to understand what they are and the implications they could have on EST observations.

Rolling and global shutter refer to how the pixels are read on the sensor. In the case of a global shutter, all the pixels are read strictly simultaneously. In the case of a rolling shutter, the reading of the pixels is done by rows, for instance, from the centre of the sensor towards the edges. Thus, the pixels at the edge of the sensor are read with a delay with respect to those in the central part. This is, in general, a problem when you have moving elements. An example is shown in Figure 2: the distortion of the fan blades on the left when using a rolling shutter is apparent. This situation motivated that, in the past, a global shutter was a requirement for optimal solar observations.

However, recent developments in rolling shutter technology allow reaching high speeds even with 4k sensors (the minimum requirement for EST) up to around 80-100 fps. The same sensor can sometimes work with a global shutter, but the speed of that mode is usually half or less than that obtained with a rolling shutter. So, this opens a new window of consideration for EST. The critical element is that the rolling shutter's effect (or distortion) is related to the object you are observing. The faster the object moves, the worse the distortion (see the fan blades). However, as we said, new sensor technologies are offering much higher speeds for rolling shutter, so we will explore if the EST observations will be affected by any rolling shutter effects when using modern cameras before making a final decision. The primary test we plan to do is to check whether image restoration techniques can be successfully applied using a rolling shutter. We will also evaluate whether the required accuracy of the measurement of the polarisation signals is maintained or not.

Finally, the last simile we want to present is the demanding observing conditions we have when performing spectropolarimetry. This technique aims to detect traces of magnetic fields in the solar atmosphere. Those traces are generally subtle and produce perturbations in the incoming light of the order of 1/1000 of the total radiation. So, no matter how bright you think the Sun is, solar observations are always photon starved. The reason, as

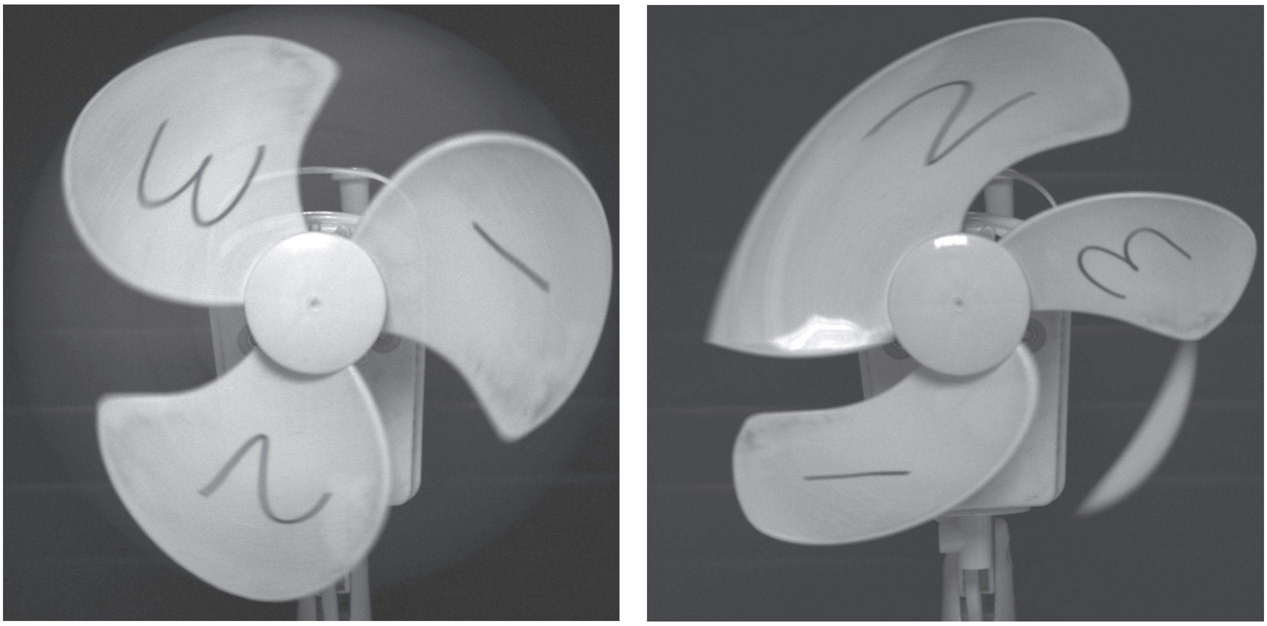


Figure 2. Example of the distortion produced by a rolling shutter when the reading speed is on the order of the speed of the photographed object. Left: Global shutter. Right: Rolling shutter. Image credit: Andor and Oxford Instruments Company.

said before, is that we need to go as fast as possible to avoid atmospheric disturbance, and we are interested in intensity fluctuations that are a tiny fraction of the total incoming radiation. Think about this situation: you believe that your smartphone's camera is excellent, but, at the same time, you know that the pictures you take when having dinner in a fancy restaurant with dimmed light are going to be less impressive than what you expect, with a grainy pattern and maybe a bit blurred due to the shake of your hand and the increased exposure time due to the poor lightening conditions.

On top of that, the sensors we are looking for should behave in a way that the noise generated when reading the sensor should be small, and the pixels should be able to capture the dark pattern of the shadows in the restaurant and the bright and relucent smile of your dinner partner as well.

At this moment, we have defined general sensor requirements that are the ideal ones for fulfilling the EST science goals (see Table 1). The next step is to interact with manufacturers and the instrument developers to check what can be achieved and what is out of reach, but most importantly, to decide where we impose trade-offs to maximise the capabilities of the EST instrument suite. The ultimate goal is to get access to a "universal" sensor that fulfils the requirements of EST instruments. In particular, we wish to have the same sensor in all the imaging instruments to seamlessly cover the solar spectrum from 380-900 nm. The number of sensors for the imaging instrument goes up to 12, so we expect to reduce research and development costs considerably. As the sensors are identical, the budget needed to purchase spare units for maintenance activities is also reduced. Moreover, having only one sensor type makes synchronisation and operation easier. The data reduction software will also be identical, simplifying the software development and future updates. In other words, having a "universal" sensor for all the imaging instruments is a strategic decision that reduces costs and simplifies the operation of the EST instrument suite.

Table 1. General requirements for the sensors of the EST imaging instruments.

	Requirement	Goal
Framerate	30 fps	100 fps
Pixel count	4k x 4k	6k x 6k
Field of view	40 x 40 arcsec	60 x 60 arcsec
Shutter	Global or rolling	---
Full well depth	40000 e-	80000 e-
Readout noise	10 e-/DN	1 e-/DN

Acknowledgements. We thank Andor and Oxford Instrument Company (especially Dr. C. Coates) for providing the example used in Figure 2, and for the extensive comparison between global and rolling shutter presented in their official website at https://andor.oxinst.com/learning/view/article/rolling-and-global-shutter.

OUTREACH ACTIVITIES DURING COVID-19 TIMES

Virtual events, online meetings, and social media have been the main channels used by the EST consortium to carry out its outreach activities in the first half of 2021.

Communication and outreach activities during the COVID-19 pandemic have changed their usual places. Institution halls, conference rooms, streets, and squares have turned into screens and virtual spaces. However, the PRE-EST partners have successfully strived to keep engaging society with solar science.

One of the events that turned online was the Potsdamer Tage der Wissenschaften. The event took place from 3-9 May 2021 in a virtual format for the first time. This event gathered more than 30 universities and research institutions in the region, including the Leibniz-Institut für Astrophysik Potsdam (AIP).

Announcement of the Potsdam Science Days activities on the AIP website

The institutions presented themselves on a knowledge platform, accessible to all visitors from home. It was an excellent premiere for the new German version of the cartoon video series *The QuEST*. The four episodes tell the stories of a number of famous solar astronomers and explain some of the scientific goals of EST in an entertaining and understandable way. The translation of the script and recording of the German narration were possible thanks to the collaboration of PRE-EST partners AIP and the Max-Planck Institut für Sonnensystemforschung (MPS).

The platform is still available to watch *The QuEST*. All the episodes are also on the EST YouTube channel, with versions in German, English, Italian, Slovak, and Spanish. Subtitles in 15 European languages can be added to the English version.

Public Engagement Workshop

The Public Engagement Workshop organised by the SOLARNET project was scheduled to take place in Newcastle (UK) in March 2020, but had to be postponed to April 12-13, 2021 due to the COVID-19 pandemic.

More than 20 participants from across Europe joined the meeting. This was the first of two dedicated workshops aimed at improving the capacity in European solar physics for undertaking and delivering public outreach.

The workshop was hosted virtually by Northumbria University and the training was delivered by Northumbria University STEM Office, a team of professional science communicators and educators. The activities and discussions focused on numerous areas of public outreach.

During the first day, different sessions were carried out to highlight the importance of identifying and understanding the audience to plan outreach activities. Schools, families, adults, or the general public, should be considered when designing an educational event. At the same time, evaluation should be part of the planning to measure the success of the activity and to help to carry out further activities. In the second day, participants could learn from many interesting experiences developed by different institutions, from school workshops to street performances. These activities combine a wide range of techniques like art, handcrafts, entertainment shows, new format exhibitions, and scientific knowledge to engage the public. Participants also had the chance of reflecting on unconscious bias, like gender or race, when creating public engagement activities.

The event provided an opportunity for networking, with participants sharing what they had learned from their previous and ongoing outreach activities. In order to continue building a community around solar physics-based public outreach, a Slack channel was established for the workshop. The Slack channel is open to anybody interested in meeting others involved with public outreach, and access can be granted by emailing Richard Morton, from Northumbria University.

11F 2021: Women in Solar Physics

EST supports the visibility of women in science. To celebrate the International Day of Women and Girls in Science, we recorded video interviews with women solar astronomers and engineers and published them on the EST YouTube channel and social media profiles. Beatriz Aparicio, Azaymi Siu Tapia and Hannah Strecker, from the Instituto de Astrofísica de Andalucía (IAA-CSIC), shared their experience in the field of solar physics and encouraged young girls to pursue STEM careers. The campaign of video interviews and posts reached a total of 24,057 people on the different channels.

Technology of EST

In the first half of 2021, eleven articles were prepared for the *Technology of EST* series, devoted to the technological challenges faced by EST. The articles explain in some detail the technical achievements of the project and how scientists and engineers work together to develop and implement cutting-edge solutions that will allow EST to fulfill its scientific objectives.

EST in the media

EST has been quite present on the media these months. Different Spanish regional newspapers showed interest in EST, and several members of the consortium were interviewed in TV and radio programs. Luis Bellot, from IAA-CSIC and head of the EST Communication Office, participated in two programs of the Andalusian TV Broadcasting Corporation, Canal Sur TV, explaining the European Solar Telescope project.

“A golpe de bit”, a program of the Spanish Radio Broadcasting Corporation (RNE), also interviewed Rafael Rebolo, director of the Instituto de Astrofísica de Canarias, and Joan-Manel Casalta, from SENER Aerospacial. The topic was the industrial contract awarded to SENER to perform the preliminary design of the EST primary mirror assembly.

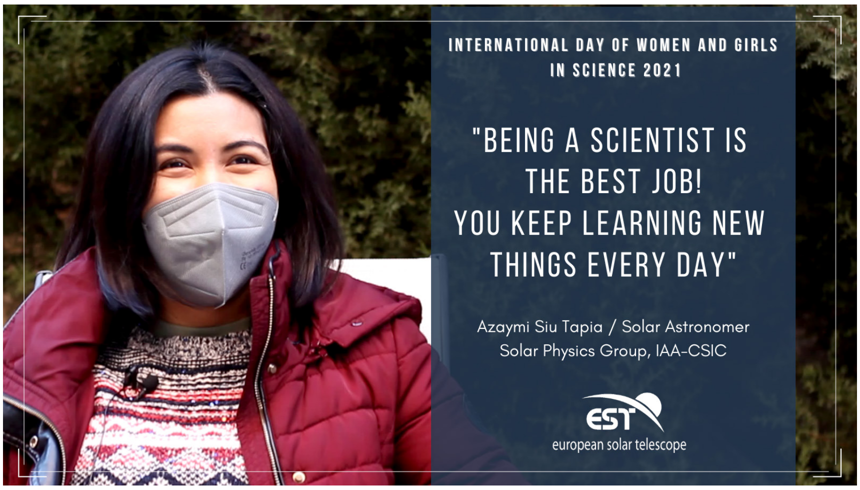
Besides, some regional newspapers put their eyes on the project. EST was mentioned in an article published in ElTime.es, covering the four large telescopes that could be installed on La Palma (Spain). The IDEAL newspaper in Granada interviewed Luis Bellot, who introduced the project and its science goals.

EST site announcement

The recent decision of the International Scientific Committee of the Canarian Observatories approving the final location of EST near the Dutch Open Telescope at Observatorio del Roque de Los Muchachos (La Palma, Spain) raised great interest among televisions, newspapers, and social media.

The EST coordinator, Manuel Collados, was interviewed in the news program "Buenos días Canarias" of Radio Televisión Canaria (RTVC) in May 2021, and four regional newspapers published articles about the announcement in their printed versions. Moreover, a total of 52 news about the topic have appeared so far in different national and regional digital media, like the website of the Spanish National Broadcasting Corporation (RTVE.es) or some of the main Spanish TV and radio channels (LaSexta.com or COPE.es).

Many institutions and authorities have expressed their satisfaction about the news, like the President of the Canary Islands Government and other local, regional, and national politicians.

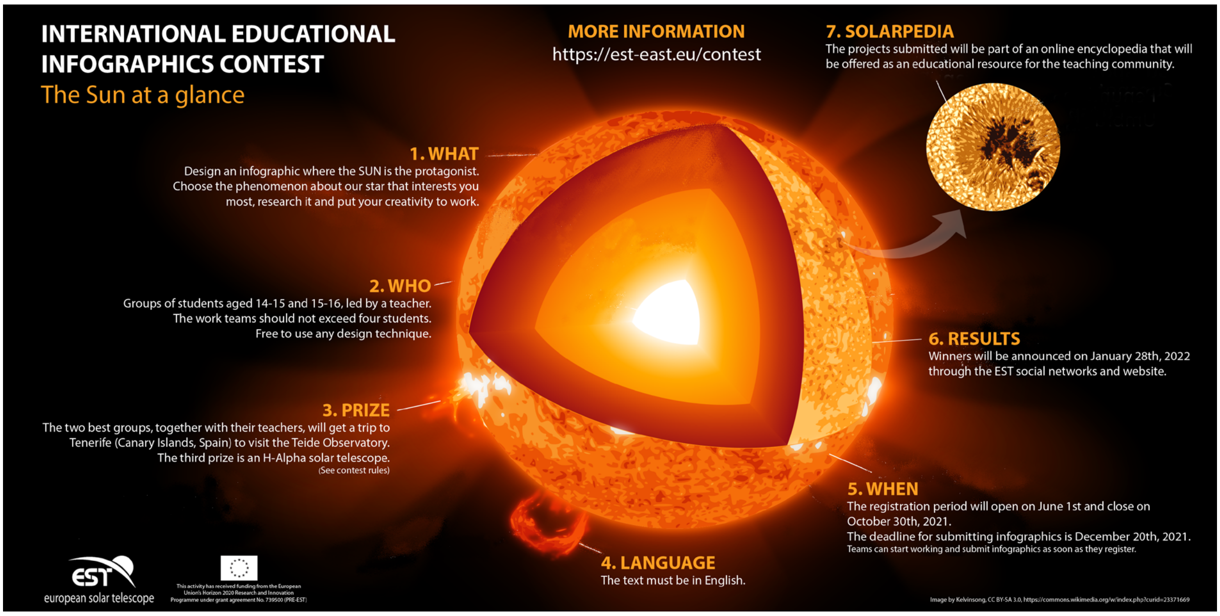


Campaign prepared for the International Day of Women and Girls in Science 2021.

The EST project coordinator, Manuel Collados, interviewed in RadioTelevisión Canaria.

EST SCHOOL CONTEST: THE SUN AT A GLANCE

The EST project is holding an infographic school contest all over Europe. The goal is to promote STEM vocations among students while producing material for the EST Solarpedia.



Announcement poster for the EST school contest, available in 8 different languages at www.est-east.eu/contest-rules.

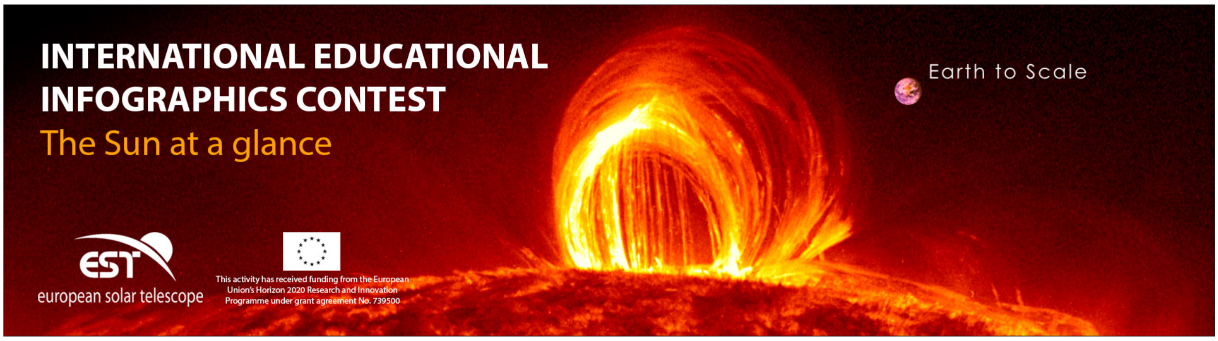
On May 28, 2021 the EST project launched the school contest "*The Sun at a glance*" in all countries of the European Union plus Andorra, Iceland, Liechtenstein, Norway and the UK. The contest is aimed at students in the school years corresponding to the age groups 14-15 and 15-16, who will work in small teams led by one of their teachers. They will have to produce an infographic, consisting of an attractive image and minimal text, to explain in a clear and concise way any aspect of our star, solar-terrestrial relations, solar observations, or solar telescopes, including EST.

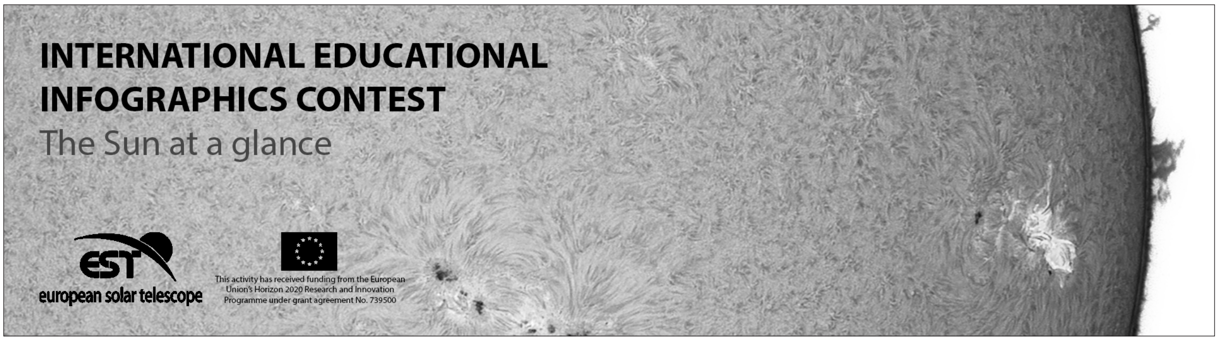
The topic of the infographic is free. The EST Communication Office has compiled a list of possible subjects to aid the participants choose one, but any theme will be accepted as long as it is related to the Sun. Most of the topics deal with the physics of the Sun, solar magnetic fields, optics, and telescopes, but other aspects are also proposed, like artistic representations of the Sun, the Sun in ancient cultures, societal aspects, history of solar physics, or famous solar astronomers.

Each student group can submit one infographics, in English. The entries will be evaluated by an international jury formed by solar physicists, science communicators and professional designers. The two best designs will win a trip to Tenerife (Spain), to visit Teide Observatory and the solar telescopes in operation there. PRE-EST will take care of all the expenses for the two winning student groups plus their teachers. The third prize will be a complete solar telescope with an Halpha filter for observations of the solar chromosphere. This telescope will remain the property of the school. The three prizes of the contest are meant to expose the participant to real solar research while promoting the partipation, as an attractive reward to the work carried out by teenage students.

The infographics submitted to the contest will be used to create the EST Solarpedia, an online encyclopedia of the Sun that will be offered to the educational community and the general public as a comprehensive resource of solar physics, solar observations and solar telescopes. The student work will be included in the EST Solarpedia under a Creative Commons BY-NC-ND 4.0 International License, with full attribution to the authors. We believe this common effort to build a valuable resource will motivate the students and their teachers to a great extent, boosting the participation all over Europe.

The work is meant to be done in the classroom, under the guidance of a teacher that may want to seek the collaboration of fellow colleagues to enhance the student creations. This is an excellent opportunity for collaborative work in multiple disciplines that should teach the





Registration and submission forms. They are available in four different languages through https://est-east.eu/registration. We use Google Forms to handle the registration of participants and submission of entries.

students how science research works in reality, involving steps such as documentation, research of a topic, discussions within a team, and presentation of results in an attractive manner and in English, the international language of science. We hope the contest will be used by the teachers as an opportunity to work the curriculum of Physics, Biology, Maths, English, Art, IT, and even History!

This activity has been organised by the EST Communication Office and the EST-Comm group with a clear pan-European dimension from the outset. To spread the information among the schools in the different countries, a contest poster has been produced in Czech, Greek, English, Hungarian, Italian, Portuguese, Spanish and Swedish. Also the official contest rules are available in different languages so teachers get all the information easily. For the same reason, the information needed to register can be submitted in different languages.

A dedicated contest website has been set up. It contains examples of infographics from different disciplines, as a way to inspire the participants. There is also a section of national contact points, meant to offer assistance to teachers participating in the contest. A great effort has been made by the EST consortium members to name contact persons and ensure that they are available to help and solve questions in their local area of influence. Currently, 19 EST institutions are actively involved in the contest. They represent the following 13 countries: Belgium, the Czech Republic, Germany, Greece, Hungary, Ireland, Italy, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom..

This immense effort will certainly make the contest a success. In return, we hope to raise awareness about solar physics and the need of the European Solar Telescope. In the long term, this activity will allow us to put together the EST Solarpedia, a unique educational resource that will be hosted on the EST website for the benefit of the teaching community and the general public in Europe and elsewhere.

Registration is mandatory. Student groups can sign up for the contest until October 30, 2021 and submit infographics anytime before December 20, 2021.

To give the students visibility, the website will list all the participants, their schools and countries in a dedicated section. The results will be announced on the EST website and social media channels by January 28, 2022. The trips will take place around Easter 2022, COVID-19 permitting. A range of activities in Tenerife are being organised by the project to make the trip memorable. And who knows – maybe some of the winning students will eventually become solar physicists and use EST for their research!

IMPORTANT DATES

Registration opens:	Jun 01, 2021
Registration closes:	Oct 30, 2021
Submission deadline:	Dec 20, 2021
Results:	Jan 28, 2022
Visit to Tenerife:	Easter 2022

EST EXHIBITION: THE SUN OF A THOUSAND FACES

A multilingual, itinerant, easily transportable exhibition that can be shown in museums and science centres all over the continent has been designed by the EST Communication Office.

Science communication acts as a bridge between the scientific community and the general public. In the case of large scientific and technological projects like EST, science communication plays an even more important role, given the investment needed to make such infrastructures a reality. As stated in the EST Communication Plan, "the social contract is not complete until the results are communicated".

Designing an exhibition for the general public was one of the flagships of the EST Communication and Outreach Plan, meant to educate about the Sun and the need of a large solar telescope like EST to unveil all its secrets. This activity was scheduled for the second half of the EST Preparatory Phase, in order to use all the communication materials previously developed by the consortium.

Goals. The EST exhibition, entitled *The Sun of A Thousand Faces*, is meant to raise awareness of solar physics among European citizens while, at the same time, emphasising the pan-European character of the EST project and its relevance to answering many long-standing questions about our star.

We believe awareness-raising is the main objective and the others follow from it. Therefore, the EST exhibition has been conceived with an educational mindset: informative, stimulating, and visually appealing, it aims to explain the main features of the Sun to European citizens, as well as the coordinated efforts of the scientific community to unveil its still numerous secrets.

Technical requirements. The exhibition is expected to travel to different cities. For that reason, it has a relatively small size and an emphasis on modularity, to make transportation both easier and more affordable. Also, such a design allows the exhibition to be accommodated in a wide range of venues, from big museums to community science centres.

Foyer of MPS Göttingen with a Sun model and large Sun panels on the wall.

This leads to the following set of technical requirements:

- Small to medium size. The EST exhibition has been designed to be around 120-140 m^2 in size.
- Materials should be durable enough to withstand all transfers with minimal deterioration.
- However, that resistance must not be at the expense of aesthetics: the exhibition must be up to the standards of museums.
- Modularity: the exhibition furniture should be designed to be easily transportable, ideally in a small truck or medium-sized van. This will help reduce transportation costs between venues and countries.
- Several bilingual copies of the exhibition will be produced (Spanish/English, Italian/English, Norwegian/English, Czech/English, etc). However, depending on the available budget only one physical copy of the exhibition might be affordable. For that reason, the preferred solution is one that allows for changing the language bits without having to build everything anew.
- Interactivity: as far as possible, the exhibition should include interactive and actionable modules to encourage learning through play.

Thematic script. The exhibition is envisioned as a series of independent, self-contained thematic units. This organisation has two advantages: on the one hand, the visitor does not need to follow a pre-established path; on the other hand, it allows the exhibition to be adapted to smaller spaces by simply

Two examples of modules that could be used in the EST exhibition. They correspond to the UPWARDS H2020 Mars exhibition. Left: large-format panels. Right: dedicated module that could be replicated as a stand for the EST videogame.

eliminating one or more modules without compromising the understanding of the others.

The pedagogical mentality of the exhibition means that some of the scientific issues of EST have been purposefully left out, and those included will not be much detailed. This is a thoughtful decision: according to the experts and companies consulted, it is better to have less content but well explained, rather than a plethora of information. Learning is more effectively achieved in this way.

This educational mindset is also the reason why the planned exhibition does not revolve around the ground-breaking technological contributions of EST, but chooses to step back to more basic facts about the Sun in order to connect with non-expert audiences without overwhelming them. The main objective is more aligned with stimulating curiosity (i.e, intriguing audiences with everything still unknown about the Sun and hopefully planting the seed for future scientific vocations).

That philosophy also led us to include content not directly related to the scientific objectives of EST, like the efforts to use the Sun as a source of energy and its role in the regulation of climate. In this way, we believe the exhibition will give a more multifaceted view of the Sun, bringing it closer to the public's experience and highlighting the importance of studying it from different perspectives.

The modules will be preceded by a dedicated introductory module based on a video display, model of the Sun, or standard information panel, depending on the available budget.

Plans for implementation. The development of the exhibition started in September 2019 and the conceptual design was completed in March 2021. The exhibition is now ready to enter the final production stage. However, with the COVID-19 outbreak hitting Europe during most of 2020 and 2021, the EST Communication Office decided that the actual production and distribution will be undertaken as part of the communication activities of the consortium during the EST Construction Phase.

A public call for tenders will be launched to select the company that will take over the production of the exhibition. The biding companies will have to submit a first proposal based on the thematic script and the technical requirements already developed.

It remains to be decided whether the architectural design and the final arts should be part of the same call, although this is the option favoured by the experts, to produce the exhibition as a whole, within the agreed timeline, and without unnecessary interfaces.

Once the company in charge of the construction has been selected, the production phase will begin: refinement of the proposal and final form of texts and graphics. During this process, interaction between the selected company and the EST Communication Office will be essential to ensure that the product meets the highest quality standars and the requirements set forth in the contract.

The EST Communication Office —with the help of all consortium members— will work to ensure that the exhibition travels to as many venues as possible. Given that the programming of cultural bodies is usually decided well in advance, the planning of distribution should begin at the same time as production, if not before.

In fact, the EST Communication Office has already taken steps in this direction. A Spanish centre, the Casa de las Ciencias in Seville (belonging to the CSIC) has expressed interest in hosting the exhibition once it has been produced. Discussions have also been initiated with the Parque de las Ciencias in Granada (Spain) to assess their interest and availability. Finally, in Oslo, the Norwegian Museum of Science and Technology has expressed interest in the EST exhibition and first negotiations have been carried out.

MODERN SOLAR OBSERVATIONS AND EST

Instruments for observing the Sun have evolved tremendously from Galileo to the present day. EST will be part of that history, and will incorporate technological innovations that will allow scientists to study solar magnetic fields like never before. This progress is the result of collaboration between different teams and disciplines.

Key points: modern solar observation, EST, international cooperation in research

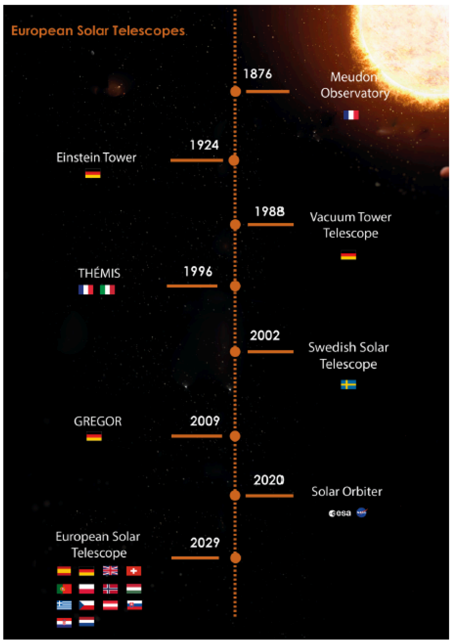
Reference materials:
solar telescopes and space missions (ESA), the Technology Of EST (EST)

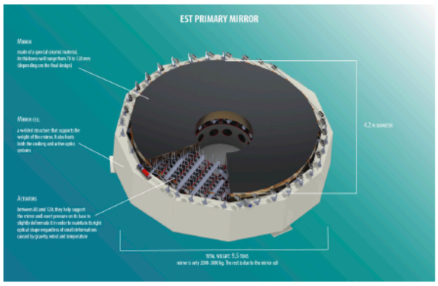
Exhibition proposal:
infographics of telescopes and solar missions (SST, GREGOR, Hinode, SDO, Solar Orbiter...), culminating with EST. In addition, an infographic based on a cross-sectional image of EST showing the main technological advances. This will be complemented by a videogame module (work with others and help build EST!)

Video: no

Interactivity: yes

Materials needed:
infographics and 1/2 screens (for EST videogame)





Left: timeline of solar telescopes in Europe.
Right: description of EST primary mirror (top) and stills from the EST videogame (bottom).

Conceptual design of the solar observation module.

Thematic script of the EST exhibition "The Sun of a Thousand Faces".

Part 1. Meeting the Sun

From solar nebula to white dwarf

Our star was born from clouds of gas and dust some 5 billion years ago. In about 5 billion years from now, the hydrogen will start to run out.

The Sun up close

The layers and composition of our star.

Sunspots, flares and ejections

Solar phenomena vary according to the solar cycle, every 11 years or so. Scientists look at them at different wavelengths to follow their evolution as they traverse the solar atmosphere.

Part 2. Studying the Sun

Solar magnetic fields

The solar phenomena are caused by magnetic fields, which scientists have yet to fully understand to untangle solar activity. The solar cycle and the solar dynamo are explained here. It also includes an interactive experiment to show magnetic field lines in different solar structures (sunspots, filaments).

Studying the solar magnetism

We cannot see magnetic fields (nor can we go to the Sun to measure them) so scientists study them by measuring their effects on the light we receive from the Sun. Polarimetry, spectroscopy and the Zeeman effect are explained here in simple terms.

Modern solar observations and EST

The European Solar Telescope will be presented as the last milestone in a series of European solar telescopes and missions (represented over a timeline). An infographic detailing the main technological advancements of EST will be included here, together with the EST model and the EST videogame.

Part 3. Living with the Sun

Space weather

The impact of very strong solar activity on Earth (auroras, geomagnetic storms) and satellites orbiting the Earth will be described here. The root cause of these phenomena —coronal mass ejections— will be described as well.

Life and energy

An overview of some of the many ways we use the energy generated inside the Sun: photosynthesis, solar energy and research towards nuclear fusion.

The role of the Sun in the Earth's climate

The Sun is only one of several factors influencing the climate. This module intends to explain the difference between climate and weather, how the Sun influences the climate (Milankovich cycle), and how it has mitigated the effects of CO_2 over the Earth's history.

EUROPEAN SOLAR PHYSICS NUGGETS

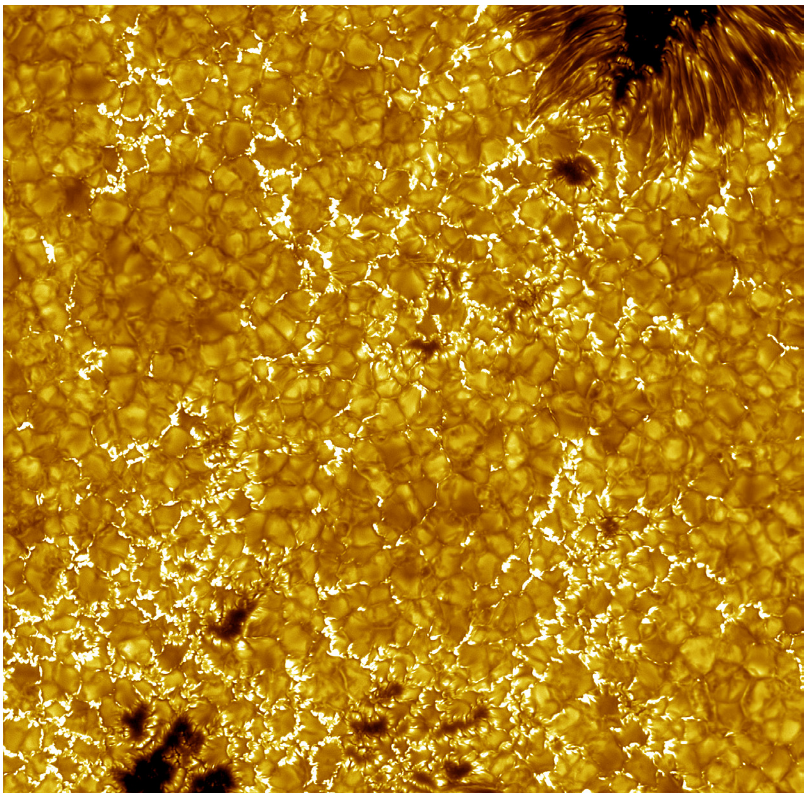
The SOLARNET and EST projects are teaming up to produce the European Solar Physics Nuggets, a new series of articles about the latest science results by European solar physicists

We, as researchers, are very good at sharing our science through published articles, although typically our work is highly specialised and only read and understood properly by a small number of people. The limitations of journal articles have been appreciated by sections of the solar physics community and, since at least the days of Yohkoh, there has been various series of so-called science 'nuggets'. These science nuggets are essentially a distilled version of published works, suitable for a non-specialist but scientifically literate audience; hence, enabling researchers to share the key ideas of their work with a broader audience.

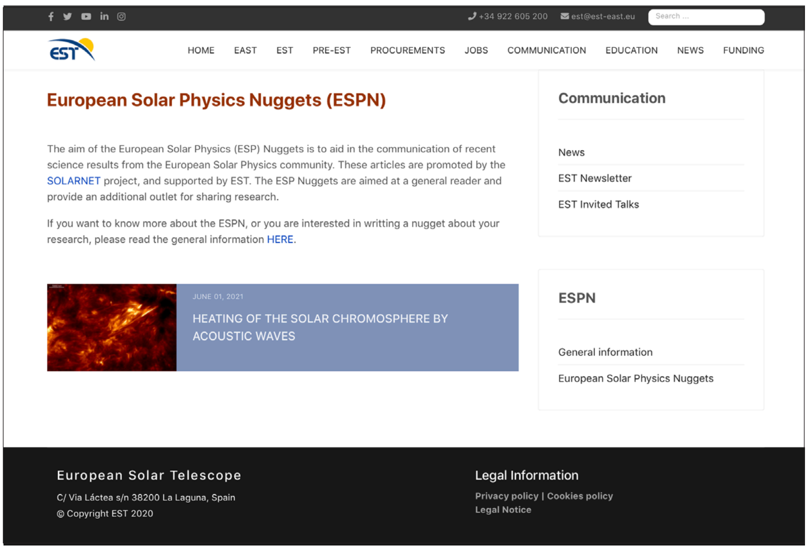
While various solar-themed nugget series exist, there is currently no version that enables the general European solar community to share its research. As part of the SOLARNET H2020 project, we are aiming to change this with the launch of the 'European Solar Physics Nuggets' (ESPN) series. We are initially aiming to publish the nuggets once every 8 weeks. They will be hosted on the European Solar Telescope website at https://est-east.eu/nuggets.

Submissions for nuggets will be accepted from all researchers based at a European institution. If you would like to contribute to the 'European Solar Physics Nuggets' series then please contact Richard Morton (Northumbria University, UK). More information on the contents and style of nuggets can be found on the EST website

The first nugget was published on the 1st June 2021 by Abbbasvand et al. on the "Heating of the solar chromosphere by acoustic waves", partly based on observations carried out through the SOLARNET access program.



Solar surface as seen by the Swedish 1-m Solar Telescope. An example of the type of images that will be presented in the ESPN series. Image credit: Vasco Henriques (ISP/Stockholm).



European Solar Physics Nuggets articles, curated by the SOLARNET H2020 project and hosted on the EST website at https://est-east.eu/nuggets.

EST NEWCOMERS

JOSÉ MANUEL GONZÁLEZ CAVA

AUTOMATION AND CONTROL ENGINEER

José Manuel obtained his PhD in Automatic Control Engineering in 2020. His PhD research was devoted to the application of closed-loop techniques for the automation of clinical variables in uncertain scenarios. In 2016 he received a Technological Development Grant to work in the application of closed-loop algorithms to the Gran Telescopio Canarias adaptive optics system. Since 2016 he worked at Universidad de La Laguna, where he combined his research activity with teaching responsibilities. He joined the EST team in 2020.

BRUNO FEMENÍA CASTELLÁ

ADAPTIVE OPTICS SPECIALIST

Bruno obtained his degree in Physics with Major in Astrophysics at University of La Laguna in 1993 and his PhD in Observational Cosmology at the IAC and University of La Laguna. After his PhD he moved into adaptive optics (AO) where he has been working ever since. He has worked in nighttime AO systems at the LBT, GTC and Keck telescopes. Bruno joined the EST team in 2020 to work within MICAL in the multi-conjugate adaptive optics (MCAO) breadboard from which important lessons will be learnt with direct implications in the design of the EST AO and MCAO systems.

MARTA BELÍO ASIN

OPTICAL ENGINEER

Marta has a degree in Optics and Optometry from the University of Zaragoza and a MSc in Optical and Imaging Technologies from the Complutense University of Madrid, where she gained skills within the field of optical engineering. Specialised in optical design, she did her Master's thesis last year on the development of an instrument which was to be integrated in a rover, a project for which she designed and analysed a camera for exploration purposes on Mars. Marta joined the EST team this year to work as an optical engineer.

SERGIO BONAQUE-GONZÁLEZ

OPTICAL ENGINEER

Sergio is an optical engineer who obtained a PhD in experimental physics at the University of La Laguna. He has four Master's degrees in astrophysics, basic research, statistics, and ophthalmic technologies. He has extensive experience in the private sector as an optical engineer and researcher. His main achievements include significant contributions to the development of a new technology for wavefront sensing and a real-time light-field camera, the invention of a temporal variant of curvature sensors, and the design of a novel method to correct vision by amplitude optimisation.

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

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

THE EUROPEAN SOLAR TELESCOPE
Dominik Utz, in *International Conference of Physics Students*, Köln (Germany), 23-25 July 219

THE SOLAR CHROMOSPHERE
Georgia Tsiropoula, in *14th Conference of the Hellenic Astronomical Society*, Volos (Greece), 7-11 July 2019

EST INSTRUMENTATION REQUIREMENTS. HOW WERE THEY DEFINED?
Manuel Collados, in *Preparing for the next generation of ground-based solar physics observations*, Guilford (UK), 23-25 July 2019

OTHER EVENTS

EUROPEAN ASTRONOMICAL SOCIETY MEETING 2021
Online, 28 June-2 July 2021

RHESSI-20 WORKSHOP
Online, 6-9 July 2021

4TH NCSP DKIST DATA-TRAINING WORKSHOP: AN INTRODUCTION TO CHROMOSPHERIC DIAGNOSTICS
Online, 19-23 July 2021

ASIA-OCEANIA GEOSCIENCE SOCIETY 18TH ANNUAL MEETING
Online, 1-6 August 2021

SOLARNET SUMMER SCHOOL HIGH-RESOLUTION SOLAR PHYSICS
Online, 30 August-3 September 2021

16TH EUROPEAN SOLAR PHYSICS MEETING
Online, 6-10 September 2021

HINODE-14/IRIS-11 JOINT SCIENCE MEETING
Washington DC (USA), 25-28 October 2021

17TH EUROPEAN SPACE WEATHER WEEK
Glasgow (UK), 25-29 October 2021

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