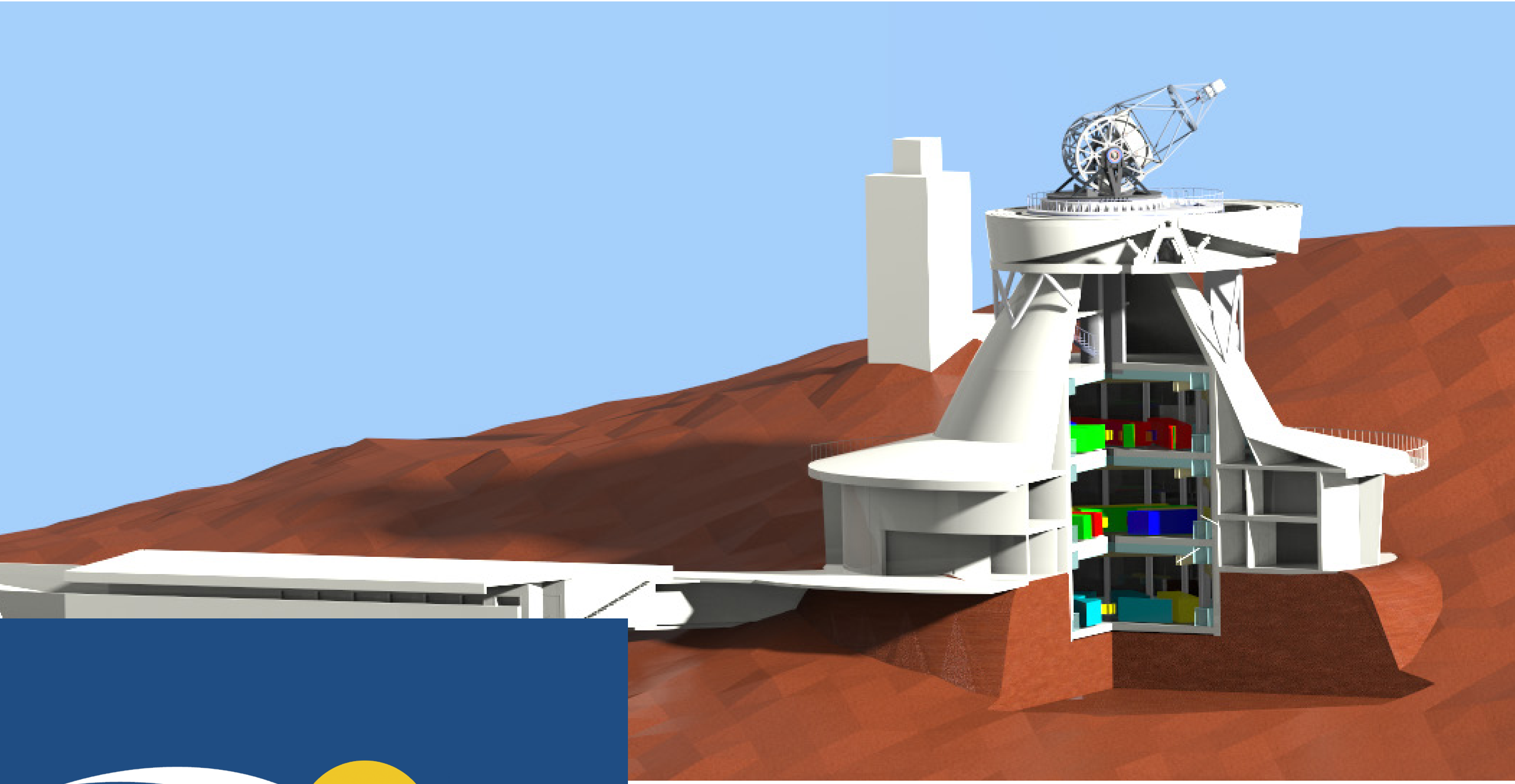

EST NEWS 11

THE EUROPEAN SOLAR TELESCOPE NEWSLETTER

DECEMBER 2022

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COORDINATOR'S CORNER

This is a special issue of the EST Newsletter. The project is finishing its Preparatory Phase as a necessary step to start construction. During the last 5 years, a strong interaction has been held between the Project Office, the Science Advisory Group, the Review Panel and other dedicated working groups, the Instrument and Data Center Consortia, and private companies. The joint activities have led to the present scientific and technical status of the project. All subsystems were carefully designed, and the main results presented at the SPIE Astronomical Telescopes + Instrumentation meeting held in Canada this year. Different technological alternatives were devised and analysed and, in some cases, prototypes have been built and tested. These works will give way to a Preliminary Design Review, to be held in early summer 2023, leaving the project ready to start construction from an engineering point of view. Most significant is the publication of the EST paper in Astronomy and Astrophysics with almost 300 authors, revealing the strong support of the solar community to the project.

From an organizational point of view, EST made a significant step forward: its Board of Directors decided to create a Canarian Foundation with the participation of the EST partner institutions. Besides representing EST towards the outside world, this legal entity will have the major goals of negotiating with the funding agencies the national contributions for construction and creating the ERIC, the legal figure especially devised by the European Commission to manage the construction and operation of large research infrastructures like EST. The construction permit will also be requested during this interim phase, as the EST site is now consolidated at the Observatorio del Roque de los Muchachos on the island of La Palma.

This issue is complemented with the most relevant outreach activities carried out during the last months, as a critical part of keeping the society and stakeholders aware of the progress of the project.

M. Collados, PRE-EST coordinator

EST CANARIAN FOUNDATION APPROVED

The EST Board of Directors met in October 2022 and gave green light to the formation of the EST Canarian Foundation as an interim legal figure for EST.

Virtual meeting of the EST Board of Directors on October 5, 2022.

The EST Board of Directors (BoD) has met twice in June and October 2022 to discuss the option of creating an EST Canarian Foundation (EST-CF) as a bridge between the Preparatory Phase and the start of the construction. The current Preparatory Phase is ending soon (the Preliminary Design Review of the telescope subsystems and associated services is expected to be held in mid-2023), and an interim legal entity is to be established to provide the project with the adequate scenario and the legal framework to partners until readiness for an ERIC legal entity is achieved and to work towards the start of the EST Construction.

The immediate consequences of having an interim legal entity may be summarised as follows:

- All participating partners in the EST-CF have direct control on the progress of the project.
- A separate legal personality allows EST as a project to contract with third parties (public and private), to hire personnel, to open bank accounts, to receive funds/grants, etc.
- In contrast to an European Research Infrastructure Consortium (ERIC), participation is not limited to countries/ministries, but allows the consortium institutions to become members/owners of the legal entity in their own right.
- Similar to an ERIC, a flexible governance plan with minimum constraints is in place, allowing the project to design its governance, functionality and procedures in the way it deems fit.
- An easy transit to an ERIC legal entity in the future is facilitated, with as little changes to the governance as possible.
- Ability to accept participants from non-EU countries.

A Canarian Foundation, selected as the legal figure for this Interim Phase, fulfils the above requirements and offers a fairly fast and simple establishment process. In addition, there are two precedents well known to some BoD members: (1) the Galileo Galilei Foundation (for the promotion of astrophysical research through the management of Telescopio Nazionale Galileo, participated by INAF) and (2) the Starlight Foundation (for the promotion of astronomy, participated by IAC). With these arguments, a Canarian Foundation was presented to the BoD as an adequate alternative of legal entity for the Interim Phase.

In the two BoD meetings held this year, the documentation needed to setup the EST-CF legal figure was presented and discussed: the statutes, the first-year action plan and the terms for contributions. These documents shall accompany the Deed where the partners express their willingness to create the Foundation, with the corresponding representation, rights and obligations.

Several meetings with the legal

departments of the EST institutions followed during the summer, until an agreement was achieved. The formal approval of the whole documentation by the EST Board of Directors took place in the second BoD meeting on October 5, 2022.

As a next step, all the involved institutions will present the proposal to their corresponding Councils for final approval. In most cases, these bodies will have met by the end of 2022. Some institutions have already confirmed their readiness to join the Foundation from the moment they receive that approval. In some cases, institutions belonging to the same country are looking for alternatives for participation through a national consortium. This is the case of Italy (involving INAF and the Universities of Catania, Rome Tor Vergata and Calabria) and UK (involving several universities). In some other cases, the partner institutions have not consolidated yet their funding contributions and they are expected to be in the position to join the Foundation at a later moment in 2023. The following institutions are expected to sign the EST-CF as initial founders: IAC and CSIC (Spain), MPS and KIS (Germany), University of Oslo (Norway), University of Stockholm (Sweden), USI (Switzerland) and the Italian consortium.

WAY FORWARD FOR EST AFTER PRE-EST

Plans for the future, after the end of the EST Preparatory Phase, are outlined and discussed.

EST is finishing its Preparatory Phase. This phase has been possible thanks to the contribution by the European Commission (PRE-EST project under Grant Agreement Nr. 739500) and by the partners. We also have to mention, for its especial relevance, the Government of the Canary Islands, which contributed with the funding that allowed the creation and maintenance of the EST Project Office (PO), presently formed by more than 20 motivated engineers.

Especial thanks go as well to the IAC, which provided the top-level staff for an efficient project management and systems engineering, complementing it with experienced engineers who coordinated and supervised the development of the preliminary design of the different telescope subsystems (optics, mechanics, thermal, control, civil works, …) and followed up the works carried out by the companies that were awarded the various industrial contracts for the preliminary design. For some critical subsystems, prototypes were constructed to demonstrate that the performance was compliant with the specifications and requirements. This issue of the newsletter describes the most important progress achieved in the different areas.

Now, the project is getting prepared for an important milestone: the Preliminary Design Review (PDR) of the telescope subsystems in early summer 2023 by an external panel composed of international experts. The results of all the works carried out during the last years will go through a critical evaluation and assessment by the PO team in the coming months in order to prepare all the documentation for the PDR. This review will represent a considerable step forward for the project. A successful review will pave the way to the preparation of the calls for tender for construction, after considering all the comments, criticism and suggestions by the panel.

In parallel, close collaborations among the partners are on the way for the definition and design of the in-kind contributions: multi-conjugated adaptive optics, the various instruments and the EST Data Center. The EST-PO is in close contact with the consortia responsible for the definition of these key elements of the project. The conceptual design of such subsystems will also be presented at the PDR. Once the main conclusions of the PDR are well settled, the preliminary design of these in-kind contributions will be addressed.

Also, an EST Canarian Foundation (EST-CF) is in the process of creation with the participation of EST research centres. From that moment on, EST will not be represented by the individual institutions, but, on the contrary, it will be supported by a legal entity with own personality. The EST-CF has several main goals ahead: (i) prepare all the paperwork needed to be ready for the start of construction; including the documentation to issue the required calls for tender; (ii) get the construction permit from the local authorities (which requires an environmental impact study and a settled construction project); (iii) define the role of all the partners in the construction and negotiate with the corresponding national ministries and funding agencies the creation of the EST-ERIC, which has to be signed at country level. Construction itself will be addressed by this latter entity, for which the work to be developed during the Interim Phase is key.

EST is now reaching a maturity status that makes us very positive that construction may start in a short time from now. The strong efforts made by the EST partners to reach the present scenario must be acknowledged, as they have allowed to open new optimistic perspectives for the coming years.

EST PRESENTATION ON LA PALMA

The EST project organised an event to present the European Solar Telescope to the regional authorities of La Palma, the island where the telescope will be built.

The president of the Council of La Palma, opening the event on September 28, 2002. Credit: Víctor López/IAA-CSIC.

The European Solar Telescope was presented to the regional authorities of La Palma (Spain) on September 28, 2022. The event took place at the Espacio Cultural Caja Canarias, in Santa Cruz de La Palma, the capital of the island.

The act was led by the President of the Council of La Palma, Mr. Mariano Hernández Zapata. The President valued the construction of EST at Roque de Los Muchachos Observatory as a great opportunity for the island, which maintains its ambition to be a world-class place for astronomical observation. Mr. Hernández Zapata stressed that the construction of EST will have a significant impact on the socio-economic development of La Palma.

The construction budget for EST is estimated to be 220 million euros. A return for the Canary Islands of at least 20% of that budget is expected. Likewise, 80% of the maintenance and operation costs will be executed in the Canary Islands during the 40 years of the operation phase. Around 100 direct and indirect jobs will be created during the construction of EST, along with some 200 induced jobs. For the operation phase, it is foreseen that about 150 direct and indirect positions, plus about 300 induced jobs, will be needed.

The event was attended by representatives of the different public administrations of the island. Besides the president, other invitees included the vice-president of the Council of La Palma, Mr. Carlos Javier Cabrera Matos, the minister of the Council of La Palma, Mr. Juan Ramón Felipe San Antonio, the major of Santa Cruz de La Palma, Mr. Juan José Neris, the delegate of the Spanish Government on La Palma, Ms. Ana María de León Expósito, and La Palma senators Mr. Asier Antona Gómez and Mr. Borja Pérez Sicilia. The act was attended also by the EST Science Advisory Group, the PRE-EST Board and the EST Project Office members present on the island for the PRE-EST final meeting, as well as by several local and regional media.

Manuel Collados (IAC) and Luis Bellot (IAA-CSIC), representing EST, offered a brief description of the project and the main scientific goals of the European Solar Telescope. The event was completed with the screening of the EST documentary "Reaching for the Sun". The movie travels through 400 years of history of solar astronomy in Europe, from Galileo to the latest solar telescopes built across the continent. A path that leads to the next step of the journey: the European Solar Telescope.

EST PRELIMINARY DESIGN, PRESENTED AT SPIE ASTRONOMICAL TELESCOPES 2022

The event took place in Montreal (Canada) on July 17-22, 2022. The program included 24 contributions related to the EST and SOLARNET projects.

Presentation of the status of EST, by Carlos Quintero Noda (IAC). Credit: Luis Bellot/IAA-CSIC.

The SPIE Astronomical Telescopes + Instrumentation conference is one of the major events worldwide for technology developments in astronomy. This year's meeting was held in person for the first time since 2018. Over 2,000 technical papers were presented, focusing on the engineering and technical aspects of ground-based, airborne, and space-based telescopes and their instrumentation.

A large number of engineers and scientists from the European Solar Telescope and the SOLARNET project participated in the meeting. They presented 24 oral contributions and posters, in six different conferences, describing the main advances achieved in the preliminary design of the telescope, its instrumentation and techniques to be used to acquire and/or analyse the observations. A list of all the contributions can be found on the publication section of the EST website.

Members of the EST Project Office described the preliminary design of the different subsystems, including the primary mirror, the adaptive secondary mirror, the structure, pier, and enclosure, the adaptive optics system, the polarimetric properties of the telescope, and the light distribution system.

Together with the EST Project Office, the companies awarded the contracts for the preliminary design also played a key role in the EST contributions to the conference program. SENER presented the results of its work on the EST primary mirror design. HEIG-VD introduced the development of the active optics actuators for the EST primary mirror. TNO described the status of the adaptive secondary mirror, and IDOM presented the latest design of the EST structure.

Beyond the technical presentations, the meeting hosted a three-day exhibition where nearly 100 companies showcased their products and services. IDOM displayed a scale model of EST at its booth as an example of the technological developments of the company. The model shows the updated design of the EST structure and dome, adapted to the final location at El Roque de Los Muchachos Observatory on La Palma.

SOLARNET contributions

At the same time, technical results from the SOLARNET H2020 project were presented in Montreal. Several contributions dealt with the upgrade of the Gregor Infrared Spectropolarimeter IFU as a testbed for the EST image-slicer spectropolarimeters, a new technique to achieve high-precision absolute polarimetry in solar telescopes, and inversion codes for the real-time analysis of high-spatial and temporal resolution spectropolarimetric observations.

THE EUROPEAN SOLAR TELESCOPE, AT THE BIG SCIENCE BUSINESS FORUM 2022

The event took place in Granada (Spain) from October 3-6, 2022. EST members presented the current status of the project and the upcoming opportunities for industrial companies.

EST booth at the BSBF 2022 meeting. Credit: Víctor López/IAA-CSIC.

The Big Science Business Forum (BSBF) is an international business-oriented congress focused on technology that was held in Granada (Spain) from October 3-6, 2022. It was the second edition of this event, and it brought together the main European research infrastructures and featured companies from the industry sector.

The first edition of this congress took place in Copenhagen in 2018, and the second one was scheduled to be celebrated in 2020. However, it had to be postponed due to the COVID situation. Finally, BSBF could be held in 2022, organised by the Centre for Industrial Technology Development of the Spanish Ministry of Science and Innovation.

More than 1100 participants and 150 speakers gathered at the Granada Convention Centre, where 190 technological companies and big science projects exhibited. BSBF addressed a wide range of topics about big science as a business area, like high precision and large mechanical components, information and communication technologies, or career opportunities and pathways in the science market.

The European Solar Telescope participated in the event as an Affiliated Big Science Organisation. A group of selected international organisations devoted to advanced infrastructures were invited to present their development plans for the coming years. EST systems engineer Miguel Núñez participated in a session with other featured big scientific infrastructures like the Cherenkov Telescope Array Observatory (CTAO), the Barcelona Supercomputing Centre (BSC-CNS), the ALBA synchrotron, or the Elettra Sincrotrone, to name a few. Núñez shared with the audience the current status of the European Solar Telescope project, highlighting the opportunities for the industry in the coming years, especially when the construction phase begins.

During the three days of the congress, staff from the EST Project Office and the EST Communication Office set up a dedicated booth in the exhibitors' area to present the latest developments in the telescope preliminary design as well as upcoming procurements of potential interest for European companies.

EST raised great interest among relevant companies from different technology fields, from optics manufacturers to big data centre managers. Around fifteen B2B meetings were scheduled with the EST representatives during the event, and up to 40 informal meetings and presentations took place at the EST booth.

The BSBF is held every two years. The next edition will take place in 2024, and the city designated to host the event was Trieste (Italy). EST will participate in that edition, too.

EST systems engineer, Miguel Núñez, presenting the project at the BSBF 2022.

PRE-EST SUCCESSFULLY COMPLETED

After almost 5 years of activity, the PRE-EST H2020 project came to an end on September 30, 2022.

The Preparatory Phase of the European Solar Telescope (PRE-EST) finished on on September 30, 2022, with a wrap-up meeting on La Palma, the island where EST will be built.

PRE-EST started on 1 April 2017. Funded by the European Commission (EC) through the Horizon 2020 Programme under Grant Agreeement Number 739500, the project objectives were:

- to update the EST Science Requirements Document
- to consolidate the Preliminary Design of the telescope,
- to identify the most appropriate legal framework for the construction and operation of EST,
- to propose a governance scheme for EST,
- to study the legal and financial implications of EST,
- to prepare the statutes of the legal figure of EST
- to start negotiations with national ministries to secure funding for EST
- to communicate the value of EST to the scientific community, industry, policy makers and the general public.

These tasks were organised around six different work packages. The PRE-EST consortium, consisting of 23 research institutions from 16 different European countries, managed to achieve all the goals after almost five years of dedicated work.

During this time, the project has passed two reviews by the European Commision, assisted by external reviewers, and has gone through four different reporting exercises. All of them have been completed satisfactorily.

Top: PRE-EST kick-off meeting held in Madrid in April 2017. Bottom: PRE-EST final meeting held on La Palma in September 2022.

The project has achieved the 22 milestones specified in the contract with the EC. Also, it has produced a total of 65 deliverables summarising the scientific, technological, legal, financial, and communication activities carried out during the project lifetime.

Some of these deliverables represent years of work, like for example the EST Science Requirements Document, the evaluation of potential sites for construction, the EST Preliminary Design and Construction Proposal, the EST Governance Proposal, the statutes of the EST European Research Infrastructure Consortium (ERIC), signature-ready Draft Documents for Construction, and the EST Communication Plan for the Construction Phase.

These documents will guide the work of the consortium in the coming years. The next milestone to accomplish is the global EST Preliminary Design Review, scheduled for early summer 2023.

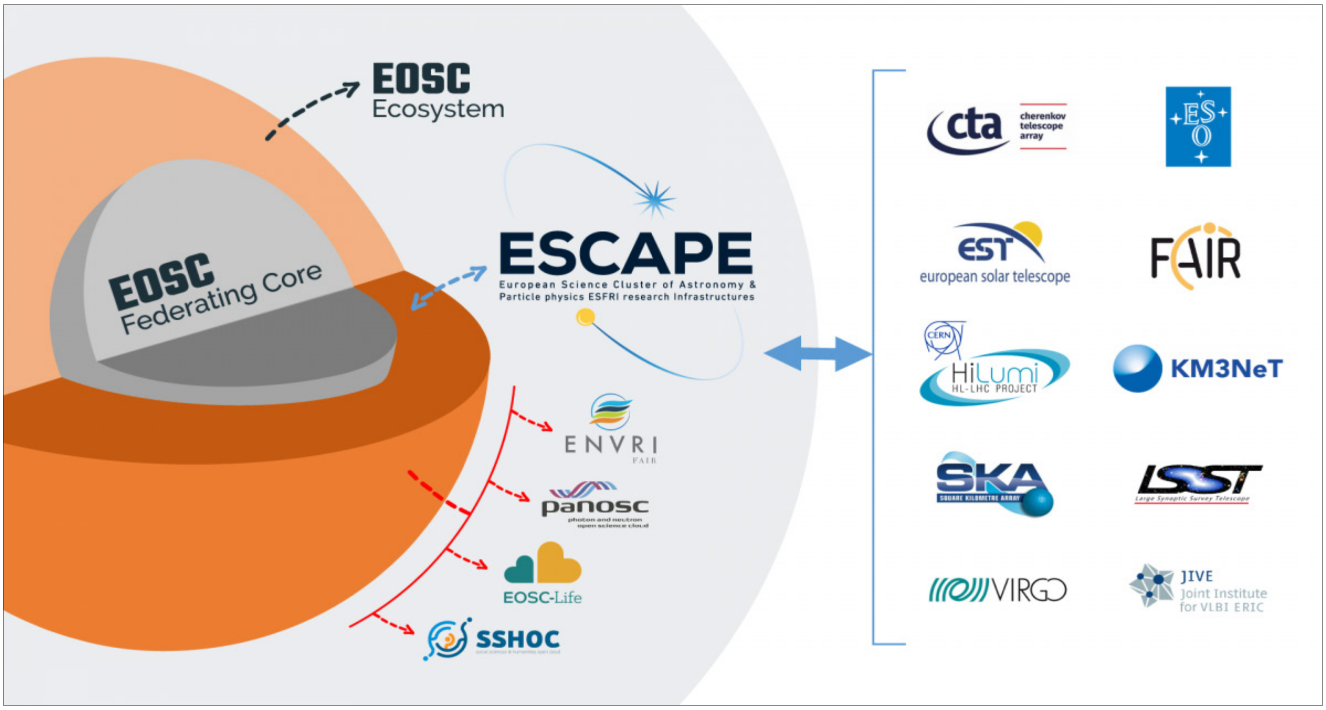
During its lifetime, PRE-EST has participated actively in and offered its communication channels to other H2020 projects such as SOLARNET and ESCAPE.

The legacy of PRE-EST is vast: an active Science Advisory Group, a Board of Directors, a consolidated Project Office, a network of European institutions pushing together to build EST, a solid preliminary telescope design, dynamic communication channels with an established audience, ongoing contacts with national ministries and funding agencies, and the challenge of promoting EST to an ESFRI Landmark project in the near future.

These tools will no doubt help the upcoming EST Canarian Foundation to secure funding for EST and proceed to the construction phase in the coming years.

EST IN ESCAPE H2020 AND BEYOND

The ESCAPE project is ending soon, but plans to continue the collaboration are underway



Relations between EOSC, ESCAPE and ESFRI Infrastructures (extracted from https://projectescape.eu/about-us).

ESCAPE, the European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures, initiated in 2019, has brought together a cluster of ESFRI projects and other world-class research organisations with the aim of implementing a section of a European Open Science Cloud (EOSC) to foster Open Science in astrophysics and particle physics.

The ESFRI projects within the cluster, like EST, share aligned challenges of data-driven research, with demonstrated capabilities in addressing various stages of data workflow, and are concerned with fundamental research through complementary approaches.

ESCAPE services

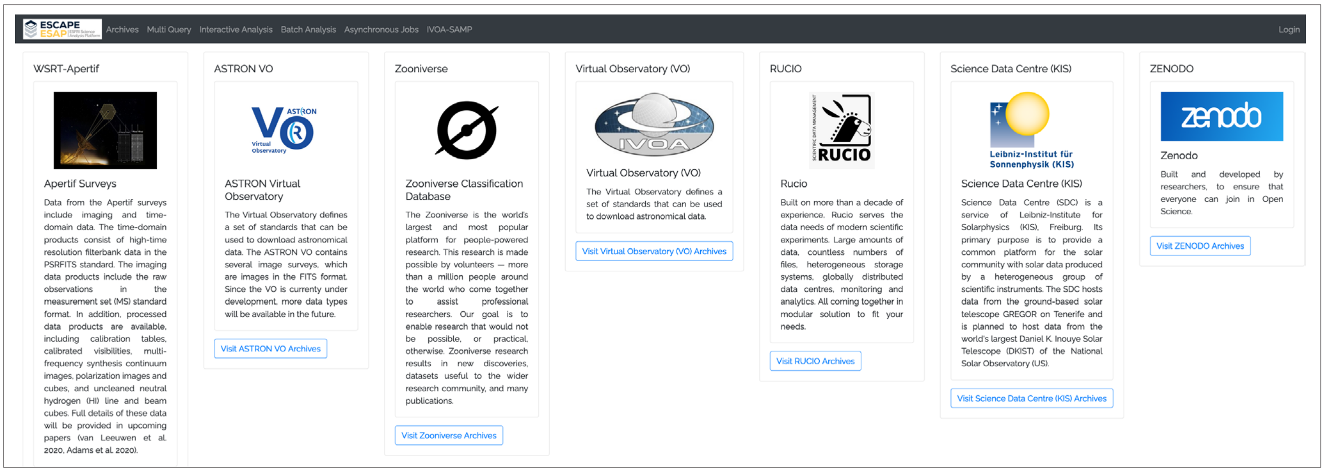
ESCAPE aims to produce versatile solutions, with great potential for discovery, to support the implementation of EOSC thanks to open data management, cross-border and multi-disciplinary open environment, according to FAIR (Findable, Accessible, Interoperable and Reusable) principles. The ESCAPE foundations lay on the capacity building of the H2020 ASTERICS (2014-2018) project work towards enabling interoperability between the facilities, minimising fragmentation, encouraging cross-fertilisation and developing joint multiwavelength/multi-messenger capabilities in astronomy, astrophysics and particle astrophysics communities. This is pursued through the five main ESCAPE services: the Virtual Observatory (VO), the Open-source Scientific Software and Service Repository (OSSR), Citizen Science (CS), The ESFRI Science Analysis Platform (ESAP) and the Data Infrastructure for Open Science.

EST contributions to ESCAPE H2020

EST is represented in ESCAPE by four institutions within the EST community: the Leibniz Institute for Solar Physics (KIS), the Royal Observatory of Belgium (ROB), the Leibniz Institute for Astrophysics (AIP) and the Tor Vergata University (UniToV), contributing to the ESAP, VO and OSSR Services.

The Leibniz Institute for Solar Physics has provided the broad astronomical and particle physics community with access to high-resolution solar data from the GREGOR solar telescope via the KIS Science Data Centre archive now included in the ESFRI Science Analysis Platform – ESAP Service.

The Royal Observatory of Belgium together with the Leibniz Institute for Solar Physics and in collaboration with the Strasbourg astronomical Data Center (CDS) and the German Astronomical Virtual Observatory (GAVO) have provided access to solar data from ground- and space-based observatories with the integration of these data into the VO Service



Services offered by the ESCAPE ESFRI Science Analysis Platform (ESAP).

by making the data compliant with the International Virtual Observatory Alliance (IVOA) metadata standards. This contribution has profited from the efforts carried out within the framework of SOLARNET FP7 and SOLARNET H2020 to create the SOLARNET Virtual Observatory (https://solarnet.oma.be) for solar data.

The prediction of solar wind conditions and the arrival times of Coronal Mass Ejections (CMEs) to the Earth are crucial elements in space weather. To improve the predictions by combining a phenomenological model with additional data sources and Machine Learning (ML) approaches, Tor Vergata University has developed within ESCAPE OSSR a database of CMEs features. This database has been shared with Centrum Wiskunde & Informatica (CWI), another ESCAPE partner, for the development of ML algorithms to highlight and extract relevant information on these highly energetic events.

The Leibniz Institute for Astrophysics Potsdam also contributes to the OSSR with data processing pipelines for high-resolution imaging and spectroscopy and a framework based on ML techniques for the classification of solar and stellar spectra. A prototype classification engine was developed for simulated spectra, which paves the way for spectral classification of data from GREGOR and the Vacuum Tower Telescope, among others.

Announcement of the Open Collaboration Agreement by G. Lamanna (ESCAPE Project Coordinator).

All these contributions are paving the road for the integration of the EST data into the ESFRI cluster now consolidated within the ESCAPE and as part of the European Open Science Cloud (EOSC).

ESCAPE to the future

In January 2023, ESCAPE H2020 is coming to an end. In a final "ESCAPE to the Future" all-hands event that took place in Brussels on October 25-26, the cluster member shared their results and achievements, and discussed the future of the ESCAPE Collaboration.

After the successful experience of ESCAPE H2020, the nine core ESCAPE Research Infrastructure partners including EST have signed a new Open Collaboration Agreement, which consolidates their cross-border action for the benefit of Open Science, the implementation of the EOSC and the establishment of new sustainable cooperative schemes within Horizon Europe for the benefit of the European Strategy for data and excellence science. The agreement is also open to further research infrastructures to join. This agreement is expected to maintain the collaborative and human experience represented by the Science Cluster and strengthen the role and impact of astronomy and nuclear/particle physics in the field of open science and, more broadly, in the European Research Area. More information on this initiative is available on the ESCAPE website at https://projectescape.eu/events.

SCIENCE ADVISORY GROUP ACTIVITIES

The EST Project Office presented the EST preliminary design to the SAG on September 27, 2022.

SAG meeting in Los Cancajos (La Palma, Spain), on September 27, 2022.

On September 27, 2022, the EST Science Advisory Group (SAG) met on La Palma to hear how their scientific input was converted into the EST preliminary design.

The SAG was formed in November 2017 and has worked for almost 5 years. In 2017, the SAG started with revising the Science Requirement Document (SRD), developed during the Conceptual Design Study from 2008 to 2011. The revised SRD was finalised in 2019 and contained programmes of multi-wavelength spectro-polarimetric observations designed to measure and understand fundamental magneto-radiative plasma processes, which dynamically couple the various layers of the outer solar atmosphere.

The following year was devoted to translate the scientific requirements into technical specifications for EST. This is a crucial process to guarantee that the telescope and its instrumentation can fulfil the planned scientific objectives. For that reason a review panel of instrumentation experts was formed. As a result, the communication between scientists and EST Project Office was facilitated, and the technical specification were worked out and finalised in the course of 2020.

In 2020, a fundamental change of the optical concept was undertaken. The dynamic solar atmosphere requires to accomplish measurements on time scales as short as seconds. As such measurements also require high spatial and spectral resolution at high polarimetric accuracy, the telescope should be as photon efficient as possible. In those years, new technologies were developed that opened the possibility to reduce the number of telescope mirrors and thereby increase the photon flux substantially: adaptive secondary mirrors became feasible, and it was decided to investigate an optical concept that integrates all deformable mirrors of the MCAO system into the telescope. This concept drastically improves the photon efficiency, since the transfer optics that comprised 7 mirrors in the preliminary design could be dismissed completely. Instead of 14 mirrors, the new EST design only needs 6 mirrors and a doublet lens, assuring the highest possible photon flux. Another consequence of the new design is that fewer mirrors improve the optical quality and substantially facilitate the optical alignment. The only potential drawback was that the transfer optics would have compensated for the image rotation which cannot be avoided in the alt-az mounting of the telescope. Therefore it was necessary to investigate the amount of image rotation, to make sure that it would not harm the science data.

Once the technical specifications of the telescope were finalised, the SAG focused on the light distribution and a concept of the post-focus instrumentation. The existing concept from 2011 was outdated not only technically, but also in terms of scientific objectives. It became clear that the evolution time scales in photosphere and chromosphere are shorter than anticipated during the preliminary design phase. Hence, the high photon flux had highest priority and the aim is that each individual instrument operate such that it receives all photons of a particular wavelength. For this reason, beam splitters that split the intensity were abandoned and only dichroic beam splitters are used. In the new concept, dichroic beam splitters allow to observe in four separated optical arms: 380-500 nm, 500-680 nm, 680-1000 nm, 1000-2300 nm. Each arm holds an integral field unit that performs spectro-polarimetric measurements. Additionally, tunable filter spectropolarimeters are foreseen in three of the arms. They will operate on a circular field of view with a diameter of 60 arcsec. The circular field of view is important not to loose a particular region of interest due to image rotation. This light distribution concept was approved by the SAG in May 2021, and since then the instrument teams are developing conceptual designs.

The EST Project Office engineers presented and explained the details of the new design at the SAG meeting on La Palma, and informed the SAG about the results of the calls for tenders for the various sub-systems of the telescope. The SAG members were extremely impressed about the convincing design and acknowledged the vast amount of work delivered by the EST Project Office.

EST ASTRONOMY & ASTROPHYSICS ARTICLE

The recent developments related to the European Solar Telescope have been described in a comprehensive article for Astronomy and Astrophysics.

The European Solar Telescope is a complex, multidisciplinary project. It was conceived in 2006 and has been developed since then. The progress in multiple areas, from the optical design to the instrument suite to the site selection, has been continuous thanks to the efforts of collaborators from many European countries. The EST progress was regularly reported in various publications over the years. However, those publications aimed to present new developments and described the ongoing activities instead of giving a complete, comprehensive overview of the project.

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Astronomy & Astrophysics

The European Solar Telescope

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Carballo-Martín[1], V. Carbone[36], E. S. Carlin[1,2], M. Carlsson[12,37], J. Castro López[38], L. Cavaller[38], F. Cavallini[39], G. Cauzzi[23,39], M. Cecconi[40], H. M. Chulani[1], R. Cirami[16], G. Consolini[41], I. Coretti[16], R. Cosentino[40], J. Cózar-Castellano[1], K. Dalmasse[42], S. Danilovic[6], M. De Juan Ovelar[43], D. Del Moro[30], T. del Pino Alemán[1,2], J. C. del Toro Iniesta[4], C. Denker[17], S. K. Dhara[30], P. Di Marcantonio[16], C. J. Díaz Baso[6], A. Diercke[23], E. Dineva[17], J. J. Díaz-García[1], H.-P. Doerr[34], G. Doyle[44], R. Erdelyi[45,46,47], I. Ermolli[48], A. Escobar Rodríguez[1], S. Esteban Pozuelo[1,2], M. Faurobert[49], T. Felipe[1,2], A. Feller[34], N. Feijoo Amoedo[1], B. Femenía Castellá[1,2], J. Fernandes[50], I. Ferro Rodríguez[1], I. Figueroa[51], L. Fletcher[52,12], A. Franco Ordovas[1], R. Gafeira[18], R. Gardenghi[14], B. Gelly[53], F. Giorgi[48], D. Gisler[24], L. Giovannelli[30], F. González[1], J. B. González[54], J. M. González-Cava[1], M. González García[4], P. Gömöry[7], F. Gracia[1], B. Grauf[34], V. Greco[55], C. Grivel[40], N. Guerreiro[24,25], S. L. Guglielmino[56], R. Hammerschlag[31,57], A. Hanslmeier[33], V. Hansteen[12,37], P. Heinzel[5], A. Hernández-Delgado[1], E. Hernández Suárez[1], S. L. Hidalgo[1], F. Hill[23], J. Hizberger[34], S. Hofmeister[17], A. Jägers[57], G. Janett[24,25], R. Jarolim[33], D. Jess[8], D. Jiménez Mejías[1], L. Jolissaint[21], R. Kamlah[17], J. Kapitán[58], J., Kašparová[5], C. U. Keller[31], T. Kentischer[3], D. Kiselman[6], L. Kleint[59], M. Klvana[5], I. Kontogiannis[17], N. Krishnappa[34], A. Kučera[7], N. Labrosse[52], A. Lagg[34,60], E. Landi Degl'Innocenti[61], M. Langlois[62], M. Lafon[42], D. Laforgue[53], C. Le Men[53], B. Lepori[63], F. Lepreti[36], B. Lindberg[6], P. B. Lilje[37], A. López Ariste[42], V. A. López Fernández[4], A. C. López Jiménez[4], R. López López[1], R. Manso Sainz[34], A. Marassi[16], J. Marco de la Rosa[1], J. Marino[23], J. Marrero[38], A. Martín[38], A. Martín Gálvez[1], Y. Martín Hernando[1], E. Masciadri[39], M. Martínez González[1,2], A. Matta-Gómez[1], A. Mato[1], M. Mathioudakis[8], S. Matthews[26], P. Mein[13], F. Merlos García[1], J. Moity[13], I. Montilla[1], M. Molinaro[16], G. Molodij[64], L. M. Montoya[1], M. Munari[56], M. Murabito[48], M. Núñez Cagigal[1], M. Oliviero[65], D. Orozco Suárez[4], A. Ortiz[12,37,66], C. Padilla-Hernández[1], E. Paéz Mañá[1], F. Paletou[42], J. Pancorbo[38], A. Pastor Cañedo[4], A. Pastor Yabar[6], A. W. Peat[52], F. Pedichini[48], N. Peixinho[18], J. Peñate[1], A. Pérez de Taoro[1], H. Peter[34], K. Petrovay[46], R. Piazzesi[48], E. Pietropaolo[67], O. Pleier[34], S. Poedts[68,69], W. Pötzi[33], T. Podladchikova[70], G. Prieto[38], J. Quintero Nehrkorn[1], R. Ramelli[24], Y. Ramos Sapena[1], J. L. Rasilla[1], K. Reardon[23], R. Rebolo[1,2], S. Regalado Olivares[1], M. Reyes García-Talavera[1], T. L. Riethmüller[34], T. Rimmele[23], H. Rodríguez Delgado[1], N. Rodríguez González[1], J. A. Rodríguez-Losada[1], L. F. Rodríguez Ramos[1], P. Romano[56], M. Roth[3,71], L. Rouppe van der Voort[12,37], P. Rudawy[29], C. Ruiz de Galarreta[1], J. Rybák[7], A. Salvade[14], J. Sánchez-Capuchino[1], M. L. Sánchez Rodríguez[1], M. Sangiorgi[1], F. Sayède[15], G. Scharmer[6], T. Scheiffelen[3], W. Schmidt[3], B. Schmieder[13,68,52], C. Scirè[56], S. Scuderi[72], B. Siegel[38], M. Sigwarth[3], P. J. A. Simões[73,52], F. Snik[31], G. Sliepen[6], M. Sobotka[5], H. Socas-Navarro[1,2], P. Sola La Serna[1,2], S. K. Solanki[34,74], M. Soler Trujillo[1], D. Soltau[3], A. Sordini[55], A. Sosa Méndez[1], M. Stangalini[75], O. Steiner[24,3], J. O. Stenflo[76], J. Štěpán[5], K. G., Strassmeier[17], D. Sudar[32], Y. Suematsu[77], P. Sütterlin[6], M. Tallon[62], M. Temmer[33], F. Tenegi[1], A. Tritschler[23], J. Trujillo Bueno[1,2,78], A. Turchi[39], D. Utz[33], G. van Harten[31], M. van Noort[34], T. van Werkhoven[31], R. Vansintjan[27], J. J. Vaz Cedillo[38], N. Vega Reyes[1], M. Verma[17], A. M. Veronig[33], G. Viavattene[48], N. Vitas[1,2], A. Vögler[34], O. von der Lühe[3], R. Volkmer[3], T. A. Waldmann[3], D. Walton[26], A. Wisniewska[17], J. Zeman[5], F. Zeuner[24], L. Q. Zhang[79,80], F. Zuccarello[81,56], and M. Collados[1,2]

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We decided then that the time was ripe to gather all this progress in a single work everyone could access to know more about the project. The main reason for deciding it was the right time is that the end of the Preliminary Design phase that started in 2017, just after EST became part of the ESFRI Roadmap, was approaching. During this period, the team of researchers and engineers dedicating most of their efforts to the project increased substantially, which helped speed up the progress in multiple areas concerning the telescope design. Also, the science community contributed to generating a new version of the Science Requirements Documents, and external partners dedicated a large chunk of their workforce to the design of external contributions like the instruments, the Multi-Conjugated Adaptative Optics, or the Science Data Centre of EST. Putting those ingredients together, it was clear that the EST project was bound to quickly advance in all areas and mature immensely to deliver an optimised design, precise cost book and plans for the next step, i.e., the construction phase, by the end of 2022.

For those reasons, we gathered the most up-to-date information and prepared an article covering all aspects of the project, including the top-level EST science goals, the site, the optical design, the Multi-Conjugated Adaptive Optics system, and the instrument suite. This publication aims to serve as the EST reference until the end of the construction and commissioning phase, when it will be replaced by a similar article describing the final design and performance of the telescope and instruments and first-light observations.

We want to emphasise that EST is a large solar telescope, hence designing it is an enormous task that can only be done by a large team of scientists, engineers, and managerial and administrative staff. Therefore, this publication is co-authored by everyone who contributed to the project since 2006, reaching a total of 281 co-authors.

The article was published in September 2022 in Astronomy and Astrophysics, one of the leading European astronomical journals. Thus, we are thrilled this peer-reviewed report is finally available to everyone, so both the solar and the broader astronomical community can follow our progress and developments. The paper is available in open access mode and can be downloaded here.

TELESCOPE STRUCTURE, PIER AND ENCLOSURE PRELIMINARY DESIGN

In July 2022, the Telescope Structure, Pier and Enclosure Preliminary Design Review was passed.

The Preliminary Design Review (PDR) was held at the IACTEC headquarters and was attended by the EST Project Office, the external reviewers and IDOM.

The goal of the PDR was to ensure that the design is robust enough. The verifications of the specification have been made by design, analysis or test. In addition, the preliminary design has defined the interfaces between each subsystem with the others ones. After the PDR, IDOM has provided some final changes in the models and documentation, and has also delivered the wind test prototypes.

IDOM has made a detailed model of the Telescope Structure and the Enclosure. The model has a scale 1:35 and shows the new EST design, being a powerful tool for communication purposes.

Telescope Structure. The Telescope Structure has been defined as a gantry configuration with axial hydrostatic bearings and a central radial bearing in the azimuth axis and rolling bearings in the elevation axis. The motion of the elevation an azimuth axis is achieved by direct drive motors.

The Telescope Structure provides enough stiffness to minimise the optical unit deflection and complies with the eigenfrequency required.

The Elevation Structure supports the Secondary Mirror and Heat Rejecter through a lightweight spider. The Primary Mirror is attached to the Elevation Structure by eight mechanical interfaces. A rigid trunnion is provided at the centre of each lateral frame to accommodate two antifriction bearings. Two radial water-cooled direct drive motors are installed at the periphery of the frames, providing a position servosystem bandwidth of 8 Hz.

The elevation axis features two compact and lightweight passive cable wraps, which minimises the air obstruction through the telescope structure.

In addition, the Elevation Structure provides a foldable textile cover to protect the primary mirror from undesired solar radiation, projected objects and dust.

The Azimuth Structure transmits the vertical loads from the elevation axis to six axial hydrostatic bearings ensuring high stiffness and low friction. The azimuth platform transmits the radial loads to a central rolling bearing. The motion of the Azimuth Structure is provided by two direct drives.

The Telescope Structure achieves a pointing error of 2.28 arcsec (2.70 arcsec required) and a tracking error of 0.76 arcsec (0.90 arcsec required), correcting different sources of error such as gravity, manufacturing errors, assembly errors, thermal errors, wind errors, and guiding accuracy and vibrations, without feedback from the acquisition and guiding system.

To ensure that the Telescope Structure can always be moved to the parking position, redundant drive systems have been implemented; in the elevation axis, an auxiliary system for the elevation axis integrates the actuator, a fail-safe brake and the locking pin system in a compact embodiment; in the azimuth axis, an auxiliary guiding system is conceived for each hydrostatic pad, which consists of a PTFE (Polytetrafluoroethylene) wheel hydraulically actuated by an external/manual pumping system.

The thermal control of the Telescope Structure is based mainly on passive solutions like improving the natural airflow and using high reflective (white) paint. In the most restrictive cases, plate coils will be used to achieve the specification of ±1°C compared to ambient air.

Enclosure. The enclosure is a rigid retractable dome (similar to VTT) that allows the observations in open operation to improve the natural air flushing and achieve the best seeing performances.

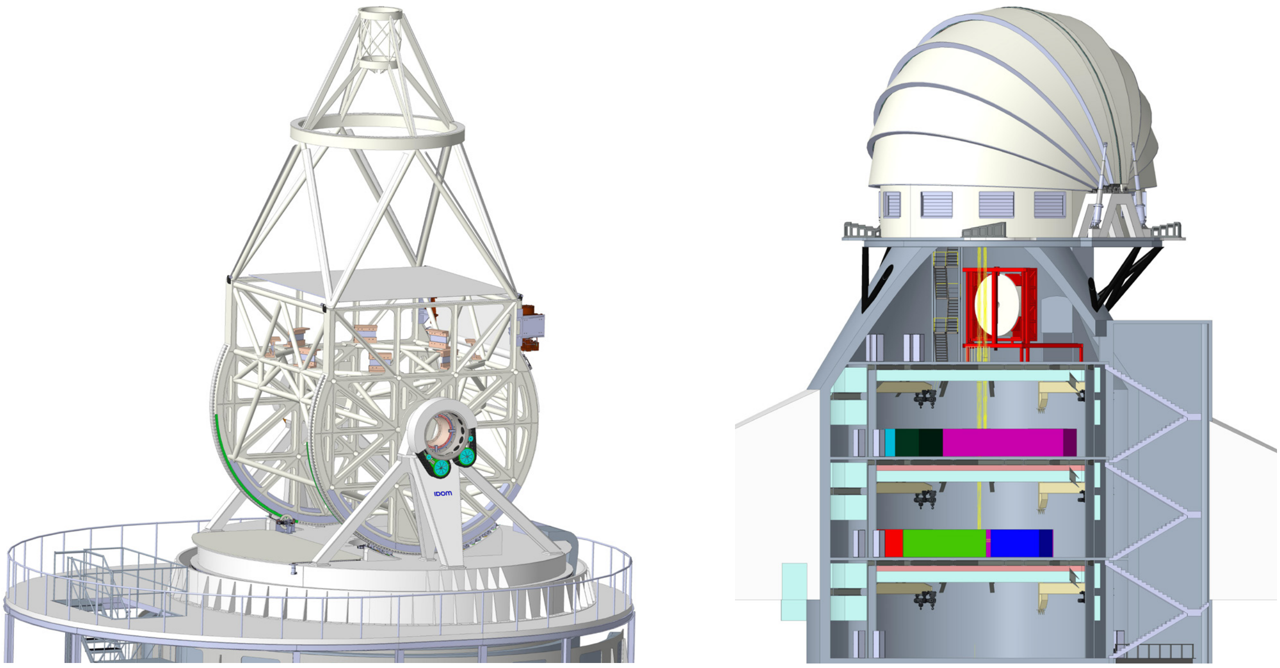
The main purpose of the enclosure is to protect the Telescope Structure from the environmental conditions when the telescope is not in operation.

To minimise the platform size, an elliptic enclosure has been developed. This solution allows the Telescope Structure to performe short movements while the Enclosure is closed and is compatible with the main maintenance operations to be performed in closed enclosure configuration, the main ones being the M1 and M2 maintenance manoeuvres.

When the enclosure is folded, its segments are fully placed below the telescope platform, thus reducing the air flow disturbance over the optical elements.

The enclosure will be actuated with four telescopic hydraulic actuators. The actuators will be connected to the two outer segments and when the enclosure starts to open, each segment will carry the next one by means of a contact region between them.

Some ventilation louvers are installed on the fixed structure to promote the natural airflow inside the telescope chamber when the enclosure is closed to control the telescope temperature passively respect to the environment. An effective sealing and drainage system prevents



Left: Preliminary design of the Telescope Structure. Right: Detail of the Pier in the preliminary design. M1 can be seen in the upper floor of the Coudé Room, placed vertically in the M1 Turning Tool. Credit: IDOM.

water leakage. A central latching system ensures the structural and sealing continuity in closed configuration. The design prevents snow and ice accumulation on the enclosure platform.

To ensure that the enclosure close in case of failure of the hydraulic system, a redundant system has been included.

The thermal control implemented in the enclosure is based on plate coil solutions in the external segments, which will be directly exposed to the sun radiation during observations.

Pier. The pier is a reinforced concrete structure with a platform supported with steel profiles that supports the telescope and enclosure. The pier supports the telescope structure, the enclosure and all the auxiliary equipment by means of the maintenance platform and the Coudé Room which houses the EST instruments. Also, the Pier provides access from the ground floor to the Coudé Rooms and the Enclosure floor.

The main structure of the pier is a reinforced concrete structure with 0.7 m thick structural walls which support the loads of the telescope, telescope platform, enclosure and the pier itself. The Pier thermally insulates the interior and Coudé Rooms. The pier has cylindrical shape on the bottom in order to make space for the Coudé Room. The outer diameter of the cylindrical section is 25.3 m. Above the Coudé Room, the pier takes a truncated cone shape to minimise the disturbance over the air flow to end in a cylindrical shape again to maximise the available space inside the enclosure volume, providing a crowning beam of 8.4 m in diameter. This shape is the most optimum to carry the telescope loads to the exterior of the pier. The main structure has a total height of 32 m and a concrete volume of 2525 m^3.

Operation manoeuvres. The Assembly, Integration and Verification (AIV) of the Primary Mirror, Secondary Mirror and Instrument Assembly have been the driver manoeuvres in the preliminary design.

For the Primary Mirror extraction, the telescope has two cranes which fix the M1 Handling Tool in the Telescope Structure. Afterwards, M1 is lowered vertically through the Pier up to the upper floor of the Coudé Room, where M1 reaches the M1 Turning Tool in vertical position (see figure, right panel). Then, M1 is rotated into horizontal position and transported to the ground floor with the M1 lifting platform. M2 is integrated by the telescope cranes and moved to the Enclosure Lift. Once in the Pier, M2 is moved to the M1 lifting platform and transported to the ground floor from there. The instruments will be pre-integrated in the optics laboratory, and after that they will be transported to the Coudé Rooms by the M1 lifting platform.

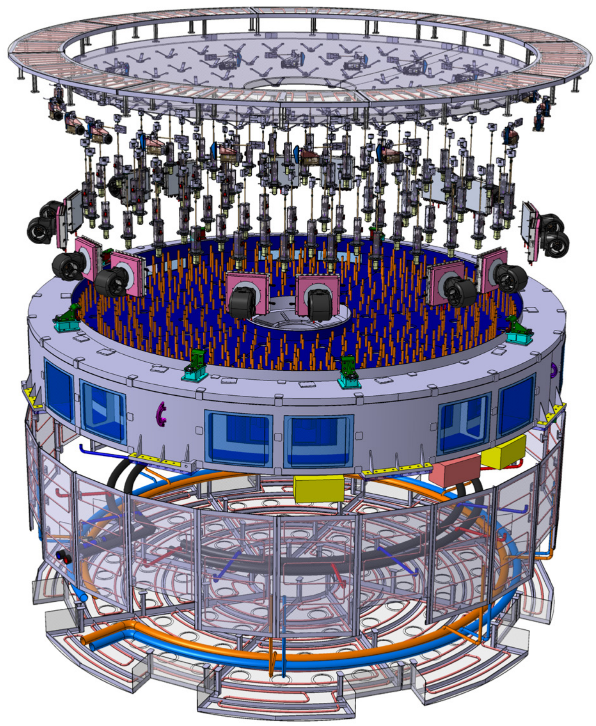
Conclusions. With the PDR of the Telescope Structure, Enclosure and Pier design passed, the three subsystems are ready to go through the global PDR in 2023. They are technically and economically feasible. The requirements have been accomplished and verified with several analyses and wind tunnel tests. In the next phases, the Pier will be part of the Civil Works subsystem that will unify Buildings, Pier and Civil Works.

We conclude we are well prepared to pass EST PDR by early summer 2023, continuing the development towards the construction phase.

M1 ASSEMBLY PRELIMINARY DESIGN

The status of the preliminary design of the EST M1 Assembly is presented

SENER-Aeroespacial S.A. won and executed the contract for the Preliminary Design of the M1 Assembly between March 2021 and September 2022. The two main objectives of this contract were to develop the preliminary design ensuring both technical and economic feasibility, and to generate a set of documents which will be the basis for the future tender's documentation of the "Detailed Design and Construction" (Specifications, ICDs, RAMS, Opera-tional and Construction plan).



Exploded view of the M1 Assembly. Credit: SENER Aeroespacial.

This contract was divided in 3 phases. Phase 1 (March 2021 to June 2021) was devoted to carry out comparative studies and to select the baseline design. During Phase 2 (July 2021 to April 2022), the baseline design was developed up to preliminary design level and the prototypes design was started. In addition, interfaces with Telescope Structure were identified and agreed. Finally, during Phase 3 (May 2022 to September 2022) the prototype production was completed and tests were executed. Results from tests were implemented in the design. Also, documentation for "Detailed Design and Construction" was generated.

The two design main drivers were:

- The M1 surface figure error shall better than 60 nm rms for quasi-static loads (can be corrected with M1 active optics) and better than 150 nm rms for dynamic loads (mainly produced by 16 m/s wind, cannot be corrected with M1 active optics).
- The M1 surface shall be maintained at +0.5/-2°C with respect to the ambient temperature. A heat load of about 2.3 KW due to solar radiation is absorbed by the mirror in the worst case scenario.

Other important drivers were that the M1 shall have a 4.2 m diametre and that the use of liquids shall be minimised.

Phase 1. Comparative Studies

A baseline design concept was proposed after carrying out a set of comparative studies of the M1 Assembly main components. In general, the objective was to found the solution with the best balance between performance, costs and risks.

Mirror type and number of supports. For different number of supports and mirror thickness, both solid meniscus (with and without support tripods) and lightweight (standard, honeycomb and stiffened) mirrors were evaluated. The best compromise between thermal inertia, behaviour against wind buffeting, risk and costs was obtained for the case of a solid meniscus mirror 70 mm thick with 4 rings of tripods connected to 80 axial actuators.

Support system. Actuators based on hydraulic and pneumatic (3 and 6 zones) and electro-mechanic (isostatic, hyper-static, hybrid) technologies were the main options evaluated. The best compromise between image stability, behaviour against wind, risks and costs was obtained for the case of hyper-static support based on electro-mechanical actuators.

Number of mechanical interfaces with the Telescope Structure. Cases with 3 to 12 mechanical interfaces were evaluated. The best compromise between M1 mass, induced deformation of the M1 Mirror surface and Telescope Structure design restrictions was obtained for the case of 8 mechanical interfaces.

Thermal control system. Plate coils (conduction), air jet impingement (forced convection) and radiation plates (radiation) were the options evaluated. The best compromise between AIV complexity, cooling performance, acceptable coolant temperature and risk was obtained for the case of air jet impingement with fans integrated on the cell.

Phase 2. Preliminary Design

The baseline concept defined in the previous phase was developed up to preliminary design level. Specific components were selected, axial and lateral actuators were designed at a very detailed level, and a complete set of analysis (FEM, CFD, analytical, error budgets...) were performed in order to demonstrate that all requirements are achieved.

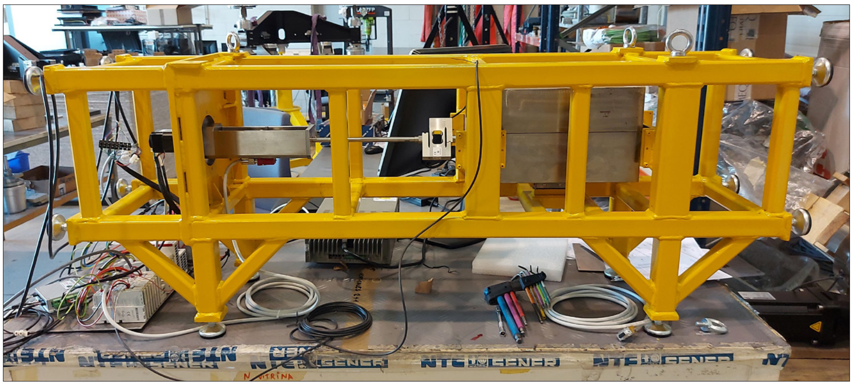
The main characteristics of the resulting preliminary design are:

- The mirror is a solid meniscus with 70 mm thickness supported by 4 rings of tripods. Its shape is an annulus of 4.25 m external diameter and 1 m internal diameter.

- There are 80 axial actuators with 5N/µm stiffness, stroke 10mm, force range +650N/-350N, force repeatability <±0.2N and position resolution <0.1µm. There are 20 lateral actuators in tangential configuration with the same characteristics than axial actuators, but with 1:4 lever in order to increase the force range.

- The mirror thermal control is based on air jet impingement applied to the backside of the mirror with a speed of 10 m/s at 13.5 ºC below ambient temperature. Sixteen sets of fans plus heat exchangers are in charge of air-cooling and recirculation. In addition, a passively cooled external cover was implemented in order to maintain the external surfaces of the M1 Assembly (except the mirror surface) at ±2 ºC.

M1 thermal control prototype. Credit: SENER Aeroespacial.



M1 actuator prototype. Credit: SENER Aeroespacial.

Phase 3. Prototypes

A prototype of actuator was used to verify that it achieves the required performance. The main requirements evaluated and verified were, both for positioning and for applied force, the total range, minimum step size, repeatability and closed loop performance.

In addition, a prototype of the thermal control was developed. It is a simplified 22.5º sector of the M1 Assembly at 1:1 scale. It was used to test and verify in real conditions (with Sun) its ability to maintain the mirror surface temperature in the range +0.5ºC to -2ºC. This prototype was also used to validate the airflow characteristics and the FEM and CFD analyses.

Conclusions

A technically and economically feasible preliminary design has been developed. Analyses were performed in order to ensure that all requirements were accomplished, and tests on prototypes were carried out to verify the most critical requirements. Also documents that will form the basis for the future "Detailed Design and Construction" tender were generated. In conclusion, the M1 Assembly Preliminary Design was successfully completed and is ready for EST PDR by early summer 2023.

M2 PROTOTYPE TESTS

A 19 actuator prototype of the EST adaptive secondary mirror has been constructed and tested.

One of the main design drivers resulting from the EST Science Requirement Document is to optimise the photon throughput. In order to achieve it, the optical surfaces efficiency must be very high and the number of them must be reduced as much as possible. In 2011, the EST optical design included 14 mirrors while the current optical design includes 6 or 7 mirrors, depending on the spectral branch, and two sets of lenses within the Pier Optical Path (POP). In both cases the light distribution within the instrument Coudé rooms has not been accounted for. The reduction in the number of optical surfaces was achieved thanks to several factors, one of them was that the secondary mirror has now a triple functionality as secondary mirror, deformable mirror and tip-tilt mirror.

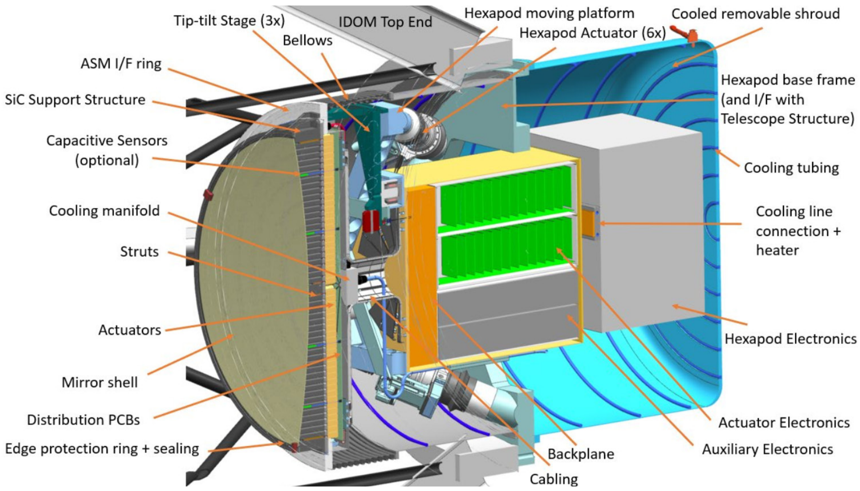


Figure 1. EST Adaptive secondary mirror section. Credit: TNO.

Adaptive Secondary Mirrors (ASM) are currently a technological growing tendency in giant night-time telescopes such as VLT, LBT, GMT and EELT, but the requirements for the EST ASM are quite challenging due to the harder atmospheric conditions in day-time on average and the need to correct at a wavelength of 500 nm. This leads to a very tight distance between actuators of 16.5 mm, with about 1900 actuators. The preliminary design of the EST ASM was awarded to the Dutch company TNO. Its design (Figure 1) is based on an innovative actuators technology, (Figure 2, left). The mirror includes a small number of position sensors, assuming that it will always be used in closed loop with a wavefront sensor.

Figure 2. One actuator (left) and 19 actuator-mirror prototype for EST M2 (right).

Being a new challenging design, TNO produced a prototype with 19 actuators (Figure 2, right) to assess that its construction was feasible and to measure the performance achieved.

In the last week of November, two members of EST Project Office visited the TNO laboratory to witness a set of selected tests over the prototype and to be trained in its use. The results achieved so far are promising, and the test campaign continues in December. It has already been verified that the bandwidth is larger than 350Hz, the stroke range larger than 28 microns, the rise time shorter than 1 ms for very small steps of 0.8 microns, and the mechanical resolution is better than 5 nm.

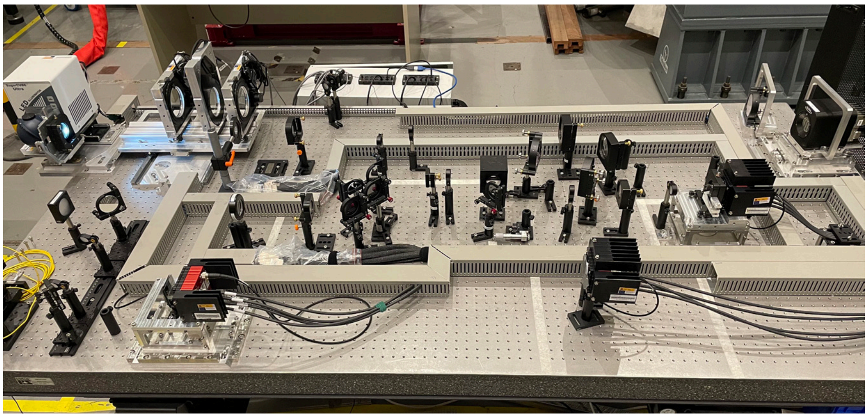
On the contrary, the hysteresis and the actuators efficiency is slightly out of requirement, but none of them should be a non-compliance showstopper. Some other tests have not been finished yet, such as the mirror surface stability or the fast tip-tilt repeatability. The last one is critical because the EST image stability depends on it.

In conclusion, the results obtained so far are promising and the test campaign on the prototype continues.

EST ADAPTIVE OPTICS

The status of the preliminary design of the EST Adaptive Optics system is presented.

EST will be equipped with several deformable mirrors (DM) to correct atmospheric turbulence at different altitudes, achieving a corrected FOV of one arcminute. The initial design consisted of 14 reflecting surfaces. To increase the throughput, the design has been updated to have 7 reflective surfaces of which 5 are deformable mirrors. The most innovative element of this design is a 800mm secondary adaptive mirror composed of 1950 actuators. Another key feature of the design is the configuration of the attitude DMs which define the azimuth and elevation axes of the telescope.



EST adaptive optics test bed at IAC. Credit: Carlos Quintero Noda/IAC.

During the preliminary design study, the AO activities carried out by the project focused on the EST multi-conjugate adaptive optics (MCAO), end-to-end simulations, and the development of a test bed in the laboratory.

A complete error budget for single conjugate AO (SCAO) configurations was elaborated by summing in quadrature the contributions from different error sources: fitting error, aliasing error, AO bandwidth/temporal error, wavefront sensor measurement error, residual tip-tilt, non-common path aberration error, chromatic error, and scintillation effects. Some errors were modelled with high fidelity (such as the temporal error), using the knowledge acquired on the AO dynamics and models of atmospheric turbulence, wind shake and vibrations into a FEM model of the telescope structure. Other sources of error are based directly on analytical expressions found in the AO literature. This SCAO on-axis error budget is a preliminary stage towards a more elaborated budget for the full MCAO strategy.

To support the activities for the final design of the MCAO, the EST project designed, built and integrated a breadboard to validate WFS strategies and reconstruction techniques of interest for solar MCAO.

The test bed consists of an illumination system with point-like and extended sources coupled with a configurable turbulence simulator of 5 phase screens (to test numerous combinations of atmospheric turbulence distributions and strength and wind speed vertical distributions), a wavefront corrector consisting of three DMs manufactured by ALPAO (one is conjugated to the pupil plane with 33x33 actuators, and 2 DMs with 24x24 actuators are conjugated to altitude layers), two wavefront sensors (one Shack-Hartmann correlation WFS with 33x33 subapertures of 10 arcsec FoV and another Shack-Hartman correlation WFS with two sets of lenslet array, one of 33x33 and another of 17x17 with 70 arcsec FoV), a science camera to evaluate the performance of the whole system, and a control system including a high performance computer and a real time software controller (DARC) developed by the University of Durham and adapted to the EST MCAO bench by the IAC in collaboration with researchers from Durham. The alignment of the elements installed on the optical table and verification of the whole system is complete. Numerous control and calibration strategies have been already proven with point-like SCAO thus enabling to settle some technical issues before MCAO integration. The test bench is currently fully operative for SCAO and GLAO and ready to be upgraded to MCAO.

During the EST initial design phases, different AO simulators have been evaluated and used to study key parameters of the future solar MCAO system, including FRIM, PropAO and DASP. Most relevant results obtained with simulations include the analysis of the AO performance as a function of the turbulences profiles, number of DMs and altitude conjugations of DMs and the impact of the order of correction of turbulent layers.

In collaboration with the Universidad de Oviedo, new techniques of wavefront reconstruction based on machine learning have been investigated. Two approaches have been simulated, first the reconstruction of the wavefront error for SCAO from solar images avoiding correlations calculations between subapertures, and second the tomography reconstruction from turbulence wavefronts for different number of layers and DMs.

EST OPTICAL DESIGN

The current EST optical design, wavefront sensing and polarisation models are presented.

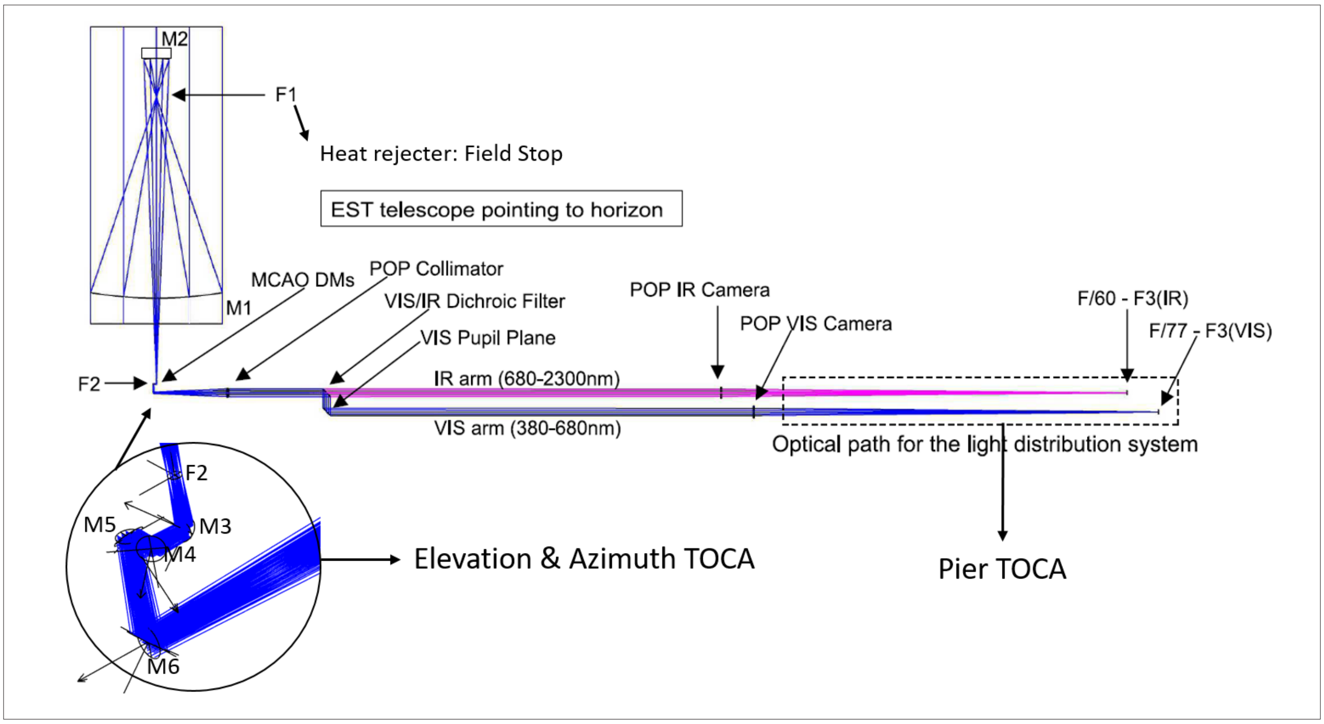


Figure 1. Current EST optical design with the three subassemblies: M1, M2, and TOCA.

The European Solar Telescope (EST) is part of the next generation of large aperture solar telescopes, and will be located at the Roque de los Muchachos Observatory on La Palma (Spain). EST will perform precise polarimetry with high spatial and temporal resolution at many wavelengths simultaneously.

EST has an on-axis Gregory configuration that ultimately results in a telecentric system having different f-numbers for the IR arm and for the VIS arm at the Coudé focus. As shown in Figure 1, EST is divided into three different subassemblies which are described below.

- Focus F1 is the F/1.5 focus generated by the almost parabolic 4.2 m diametre annular M1. A heat rejecter (HR) that also works as a field stop is located at F1 to limit the field of view (FOV). Focus F2, where a second field stop will be located to limit the FOV to 127 arcsec, is generated by the on-axis ellipsoid secondary mirror, M2, providing an F/12.57 focus. M2 has a diameter of 800 mm. This allows assembling M2 as an Adaptative Secundary Mirror (ASM), providing adaptive optics compensation of the ground layer turbulence. Besides, the ASM will be mounted on a hexapod with 5 degrees of freedom (piston, δx, δy and slow tip-tilt) to perform active optics tasks.

- The Transfer Optics and Calibration Assembly (TOCA) is intended to perform the following key functionalities: generate the elevation and azimuth axes, achieve Multi-Conjugate Adaptive Optics (MCAO) correction, calibrate the ASM, deliver the secondary focus F2 to the Pier Optical Path (POP), perform polarimetric calibration of the optical path, control the local seeing degradation, enable the positioning and alignment of the POP and F3, ensure the structural housing and assembly of the different optical elements and subsystems inside the TOCA.

- The Pier Optical Path (POP) is the telescope subsystem aimed to relay the light from F2 to F3 to deliver the beam to the different Coudé rooms. Its design is still under internal development. Currently it consists of paraxial lenses.

A main non-rotating station at the Coudé focus contains three types of instruments, each consisting of different channels to observe different wavelengths: integral field spectropolarimeters and tunable imaging spectropolarimeters. The instruments are arranged on two floors with a controlled environment, each with its own Coudé focus provided by a light distribution system which divides

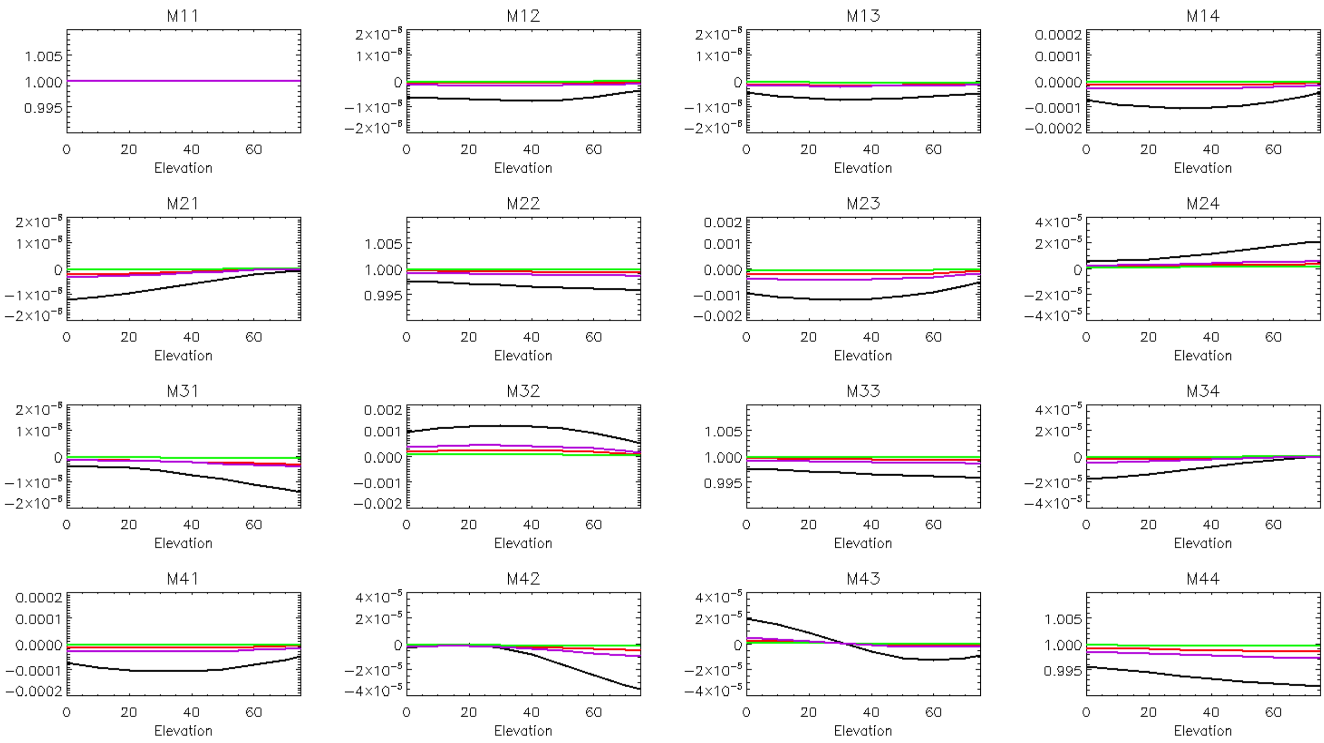


Figure 2. Normalised Mueller matrix for different wavelengths (black: 400 nm, purple: 630 nm, red: 850 nm, green: 1565 nm) as a function of the telescope elevation (0º, 30º, 60º, 90º), for a 60" off-axis line of sight.

Table 1. Most salient specifications for the EST SCAO WFS and its detector.

WFS concept	Correlating SH
Subaperture size (on the entrance pupil)	8< d < 85 cm
Linear Nb. Of subapertures	> 50
Field of View	10"
Operating Wavelength (nm)	$\lambda_{WFS} \in [500,510]$
WFS bandwidth (along pupil diameter)	$\Delta\lambda_{WFS} \leq 10$
Lenslet geometry	square
Linear number of pixels per subaperture	even, ≥ 18
Guard pixels per subaperture	≥ 1
Plate scale ("/pixel)	≤ Nyquist at λ_{WFS}
WFS total Throughput	> 65%

Detector Type	CMOS/ CCD
Detector size (pixels)	> 1024 x 1024
Frame rate	≥ 2000 fps
Pixel well	≥ 40000 e^-
Digitation	12-bit (TBC)
Shutter	Global
Frame integration time	≤ 0.5 msec

the incident beam into visible wavelengths in the 380-680 nm range and red/infrared wavelengths in the 680-2300 nm range.

Studies about mirror substrates and coatings as well as more detailed studies of straylight are being carried out.

Active Optics

EST will be equipped with Active Optics (AcO) to ensure a seeing limited performance over the FOV, requiring the correction of quasi-static wavefront errors generated by thermal variations, gravity loads, quasi-static wind perturbations and figure errors. These sources of degradation will also lead to pupil displacements and pointing errors that should be controlled by the AcO system before the correction of the slowly varying aberrations.

Currently, the preliminary AcO strategy is under internal development. It includes M3 as a pupil positioner, the telescope guiding system to control the pointing error and the hexapod to perform on-axis wavefront error corrections. At this stage of the active optics design, only rigid body motions are considered. In a next step, M1 figure errors will be included, and M1 will act as the active compensator for those errors.

EST High Order Wavefront Sensor

A correlating Shack-Hartmann sensor inspired on the wavefront sensor of the GREGOR adaptive optics system has been selected for EST. We have studied the relevant trade-offs to propose the characteristics shown in Table 1.

At this stage of the wavefront sensor design, the most critical aspect is the camera sensor. We have started to look for commercial camera providers offering devices close to meeting our requirements but which may need some additional work. The current optical design of the EST high-order wavefront sensor exhibits good behaviour, with spot diagrams well within the Airy disks for each lenslet. The design is still flexible to accommodate a re-imaging optics if we conclude that it is necessary during the design phase

Polarisation modeling

The polarisation state of the incoming light is modified by the coatings and the incident angle, differently for different wavelengths. The EST design includes six reflections. M1 and M2 do not introduce polarisation for an on-axis object due to their rotational symmetry. The next four mirrors (M3-M6) are arranged in pairs, with incidence-reflection planes perpendicular to each other to compensate for the instrumental polarisation induced by each individual mirror. A numerical model has been developed to calculate the instrumental polarisation induced by the telescope. Figure 2 shows the Mueller matrix at different wavelengths as a function of the elevation angle, for a 60" off-axis ray. In all cases, the Mueller matrix of the telescope is diagonal, with negligible values of the off-diagonal elements.

A laboratory setup has been designed to measure experimentally the polarisation introduced by the deformable mirror in the laboratory.

Error budget

Current image quality budgets for all wavefront control modes and observatory configurations for EST have been implemented. Initial error budgets have been generated from a top-down scheme for different wavefront control modes and a further break down is distributed across subsystems. To identify critical areas of concern, a top-down/bottom-up cross-check is performed to track errors. A conflict resolution strategy is devised to feedback budget schemes and subsystem allocations to ultimately meet the top-level EST requirements. With the information currently available from bottom-up, EST is able to meet the image quality criteria imposed by the science requirements.

CFD AND THERMAL ANALYSES

A report of the CFD and thermal analyses carried out for the Preliminary Design is given.

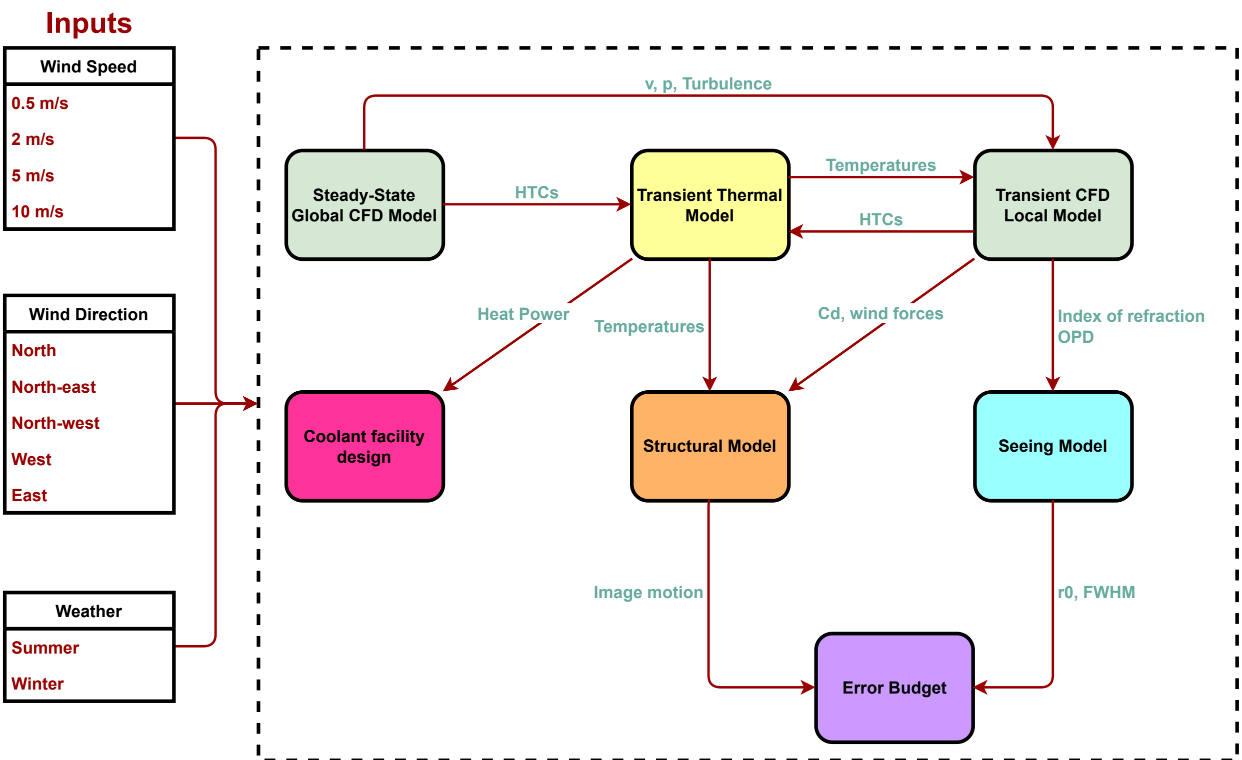


Figure 1. Global analysis approach currently adopted by the EST-PO. Credit: Mahy Soler/EST.

The design of a large solar telescope faces numerous challenges that have to be addressed in all stages. One of them is the thermal design. EST will be subject to a considerable amount of heat coming from the sun. This heat will increase its temperature, which has a direct effect on the telescope's performance. Moreover, deviations in the telescope's temperature from ambient air may produce thermal plumes. These contribute to the so-called local seeing, which is

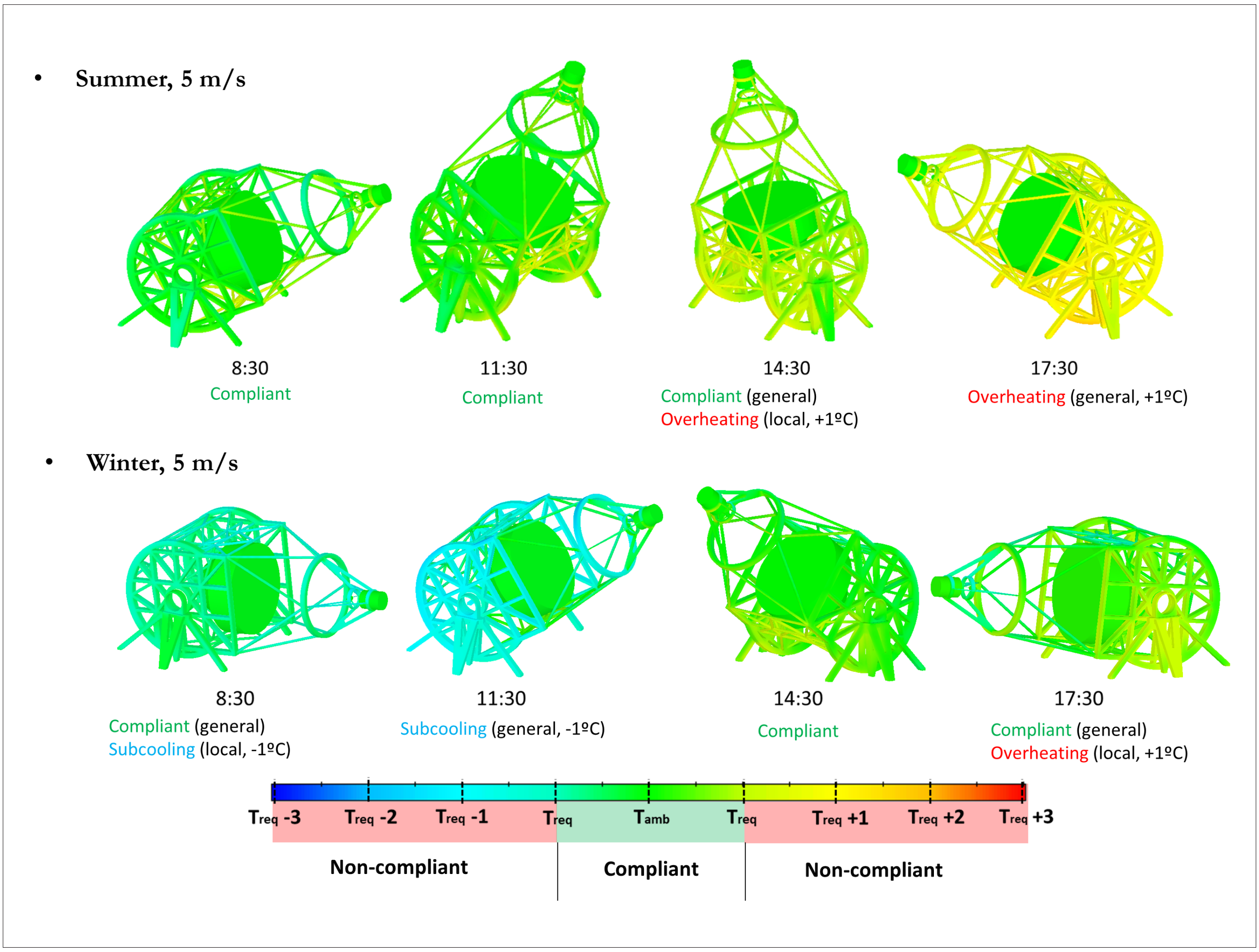


Figure 2. Telescope Structure surface temperature for a wind speed of 5 m/s in summer and winter conditions. Credit: IDOM.

a degradation of the image quality. All these effects can be estimated from numerical techniques such as thermal finite element analyses (FEA) and computational fluid dynamics (CFD).

The EST Project Office (PO) is currently adopting a global strategy that gathers cutting-edge technologies in structural, thermal, fluid and optical analysis. Figure 1 shows the current analysis workflow implemented by the EST-PO. This workflow summarises the main ouputs of these models and how many of these are used as inputs in subsequent models. This allows not only to solve the specific problem for which the model was created but also to offer further insights on higher level requirements.

Thermal modeling. During the Preliminary Design Phase, several analyses were performed to accurately estimate the thermal performance of the Telescope Structure, Pier and Enclosure. These were transient analyses (24-hour periods) that included many details, such as the telescope orientation and the sun's position or the most relevant environmental data (air temperature, sky temperature, sun's irradiance…).

Figure 2 shows results for the Telescope Structure for the worst-case scenario in the winter and summer seasons. These analyses allowed the EST Project Office to detect potential overheating/subcooling zones in the telescope and to design the coolant lines needed to comply with thermal requirements.

CFD modeling. Computational fluid dynamics models were used to predict the airflow structure around the Telescope Structure. The model that was developed includes many ingredients such as the terrain near the EST site, the Pier, the Enclosure, and the Telescope Structure.

The main goal of this model was to solve the mechanical and thermal turbulence near the telescope where the main optical elements are held. This is used to estimate how changes in the refraction index (due to air turbulence) may degrade the image quality. This methodology is crucial to evaluate design options and their effects on the final performance of the telescope. Furthermore, the model was also used to estimate the forces exerted by the wind on the Telescope Structure, which were later validated through a wind tunnel test campaign performed at Wacker Ingenieure (Birkenfeld, Germany).

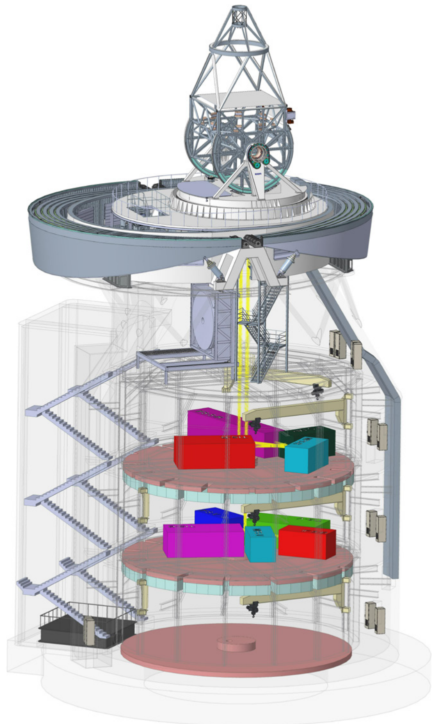
EST INSTRUMENTATION SUITE

The report on the Preliminary Design of the EST scientific instruments has been delivered.

The D6.14 Report on Preliminary Design for the Scientific Instruments, requested by the PRE-EST H2020 project, has been delivered on time.

This major milestone has been led by the EST Project Office (EST-PO) and the Leibniz-Institut für Sonnenphysik (KIS) for the Data Centre contribution. It has been achieved thanks to the help of the Science Instrumentation Suite (SIS) Consortium leading institutions.

The deliverable describes the design evolution and status of the SIS, based on the developer's input for each of the three different foreseen instrument's modules: Tunable Imaging Spectropolarimeters coupled to Fixed Band Imagers (TIS/FBIs), and Integral Field Polarimeters based on slicers (IFS-S) or microlens arrays (IFS-M). It also describes how interfaces with the telescope are managed. Finally the report provides insight into how the EST-PO and SIS consortia should work together in order to deliver accurate inputs for the next EST major milestone: the EST Preliminary Design Review (PDR).



General view of the EST Instrumentation suite.

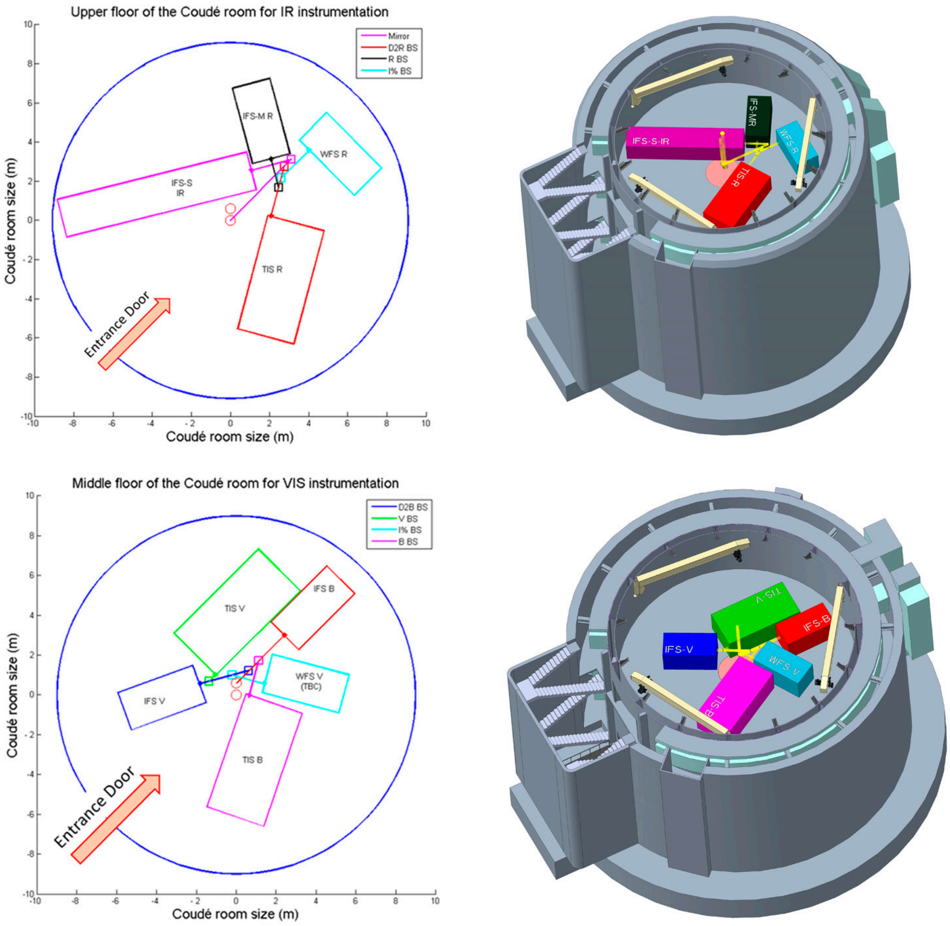
The present status of the SIS design corresponds to a conceptual phase, but interfaces and high level general technical requirements with a PDR maturity level have been addressed. Thus a first issue of the General Design and Interfaces Requirements (GDIR) has been produced, to ensure that the level of definition of the instruments will be sufficient to have a successful telescope PDR.

The iterations on the GDIR will drive the instrument's architecture from now until the EST PDR, when all the high level external interfaces shall be frozen. There is still some work ahead to reach PDR, but the different instrument teams and the EST-PO are motivated and moving forward. Each SIS high level architecture concept has been baselined after the main trade-offs identifying the needed technologies and pushing forward the best possible design solutions have been conducted.

Interface updates

The Pier Optical Path (POP) is the EST Optical Subsystem that will transfer the Science Focal Plane from F2 to the two Coudé Rooms where the SIS will be hosted. The Coudé Rooms are distributed in three different floors inside the Telescope's Pier in order to operate and host the different instruments of the EST observatory. The middle and upper floors will be used by the first generation visible (VIS) and infrared (IR) instruments, respectively. An underground (bottom) floor is foreseen so future visitor instruments can also be installed. The VIS and IR Coudé Rooms will provide the following functionalities for the SIS:

- 18.2 m diameter surface area per Coudé Room, made of concrete slab (non-rotating platform).
- A Coudé Light Distribution (CLD) system to allow SIS simultaneous operations.
- A lifting platform, to provide access to the different Coudé Rooms.
- Lifting cranes and other auxiliary equipment on each Coudé Room, to facilitate the instrument integration and installation activities inside the rooms.
- An ISO7 cleanliness working environment.
- Auxiliary equipment and tools for instrument alignment and calibration.
- Interfaces for Power, Grounding, and Cooling Liquids.



Distribution of EST instruments in the IR Coudé Room (top) and the VIS Coudé Room (bottom).

The physical distribution of the different instruments in the Coudé Rooms has been iterated between EST-PO and the instruments' teams during the last months (see Figure).

It has been agreed that the instruments will not strictly match the f-number and plate scale values of the delivered Science Focal Plane. Each instrument will instead design a pre-scaling relay system so they can internally modify their plate scale and create the different intermediate pupil and image planes as well as the aperture diameters that shall be required at the different locations of their system.

The f-number that the POP will deliver to the instruments is driven by the instrument's distribution inside the Coudé Rooms that depends in turn on the surface (envelope) that each instrument occupies. It is also related to the degree of telecentrism that will be needed by the instruments. Finally, the f-number is ultimately limited by the telescope's pier structure mechanical envelope (i.e the height of the Pier and the height and distances between the different Coudé Rooms) or the cost and the manufacturability of large diameter optics made of materials that can reduce chromatic aberrations due to the wide spectral range that is covered (380-680 nm for the VIS Coudé Room and 680-2200 nm for the IR Coudé Room).

The current design values of the f-number to be delivered are between 59-77. These values will be assessed and agreed before the EST PDR.

The EST Science Instrumentation Suite Consortium members are:

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, Queens University Belfast, University of Catania, University of Rome "Tor Vergata", and Institute of Solar Physics of Stockholm University.

Integral Field Spectropolarimeters. Institute of Solar Physics of Stockholm University (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.

EST FACILITIES AND CIVIL WORKS

The updated EST building design and next steps towards the construction permit are described.

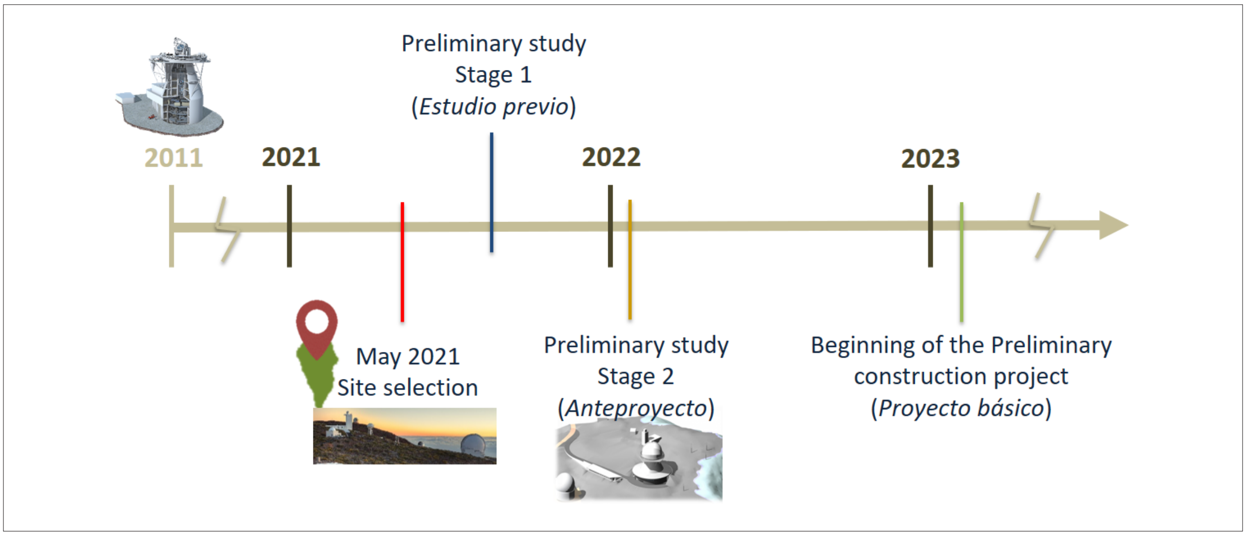


Figure 1. Civil works design timeline.

The ambition to construct the European solar telescope responds to the needs of the scientific community, that wants to study the sun but current technology turns out insufficient.

From the moment that the need of a new observation tool is identified and, of course, funding is available, the engines of a full machinery are set in motion and the telescope begins it design.

The design process starts with the optical elements and the definition of the characteristics of the instruments that will serve the scientific purposes. Afterwards, the mechanical elements step in to provide the optics with a suitable structure and precise movement and at the same time, the control system is developed to pull the strings of all those elements.

However, something as important as these systems is missing… the facilities and civil works. No ground-based telescope will function without an infrastructure built to support and supply the optics, mechanics and control systems with the elements they need to function.

The civil works required to develop an infrastructure at the Roque de Los Muchachos Observatory are fundamental for the operation and maintenance of EST, subordinated not only to the scientific, operational and management requirements, but also to the site conditions.

All these requirements set the guidelines to construct an infrastructure hat serves science but also blends in harmony with the surrounding environment and telescopes. Reaching a compromise among all requirements has been, is and will be the main challenge of civil works design.

The facilities and civil works design has been divided in four phases (see Figure 1): conceptual design (in Spanish, *Diseño Conceptual*), preliminary study (*Estudio Previo y Anteproyecto*), preliminary construction project (*Proyecto básico*), and detailed construction design (*Proyecto de ejecución*).

The conceptual design was submitted in 2011. The buildings were designed to be constructed in a generic flat surface. Then, in May 2021 an important milestone in the EST preparatory phase was achieved: the selection of the site for the construction of the EST telescope at the Observatorio del Roque de Los Muchachos on La Palma. Since that moment, efforts have been made to adapt the conceptual design to the site minimising the environmental impact, with the consequent changes in the shape of the buildings.

Looking back at the design study phase, the building was planned to be a rectangular-shaped structure with four floors attached to the ier. In the preparatory phase, the shape of the main building has changed from rectangular to circular, to adapt it to the shape of the site (see Figure 2).

It is worth mentioning that, due to the stringent scientific requirements on tracking and pointing accuracy and the negative influence that vibrations can cause in the functioning of the telescope, the preliminary design of the pier has been performed in the same

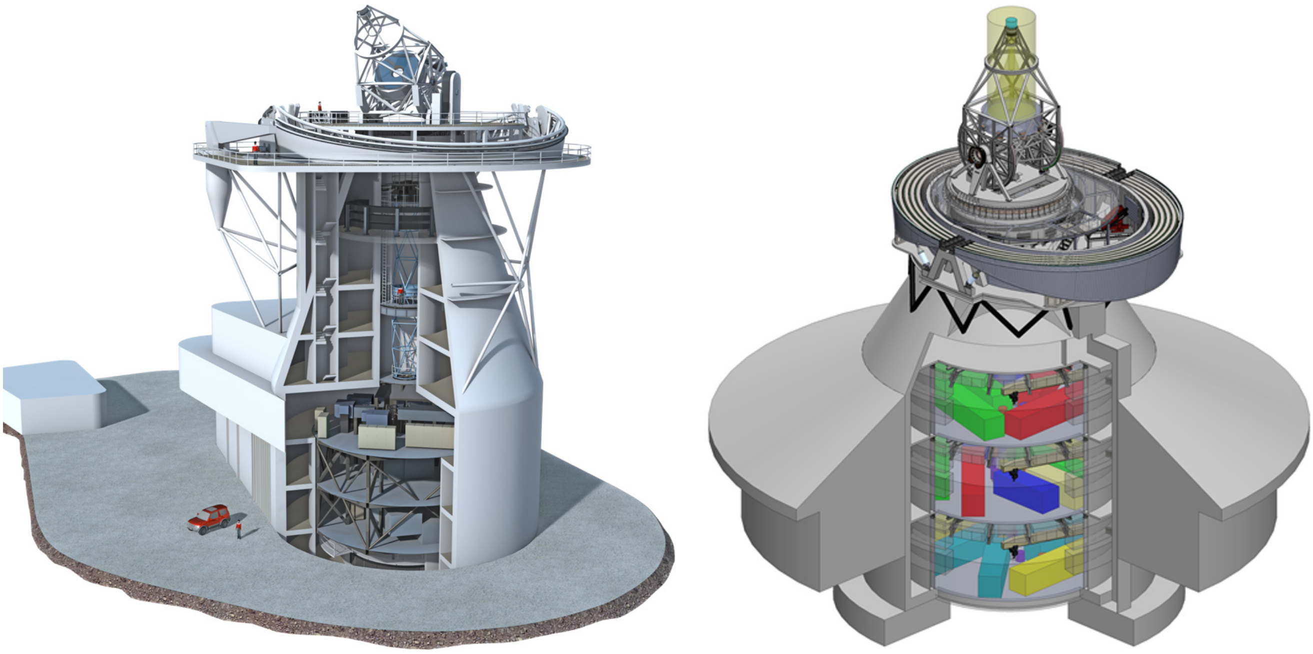


Figure 2. Evolution of EST building design. Left: conceptual design (2011). Right: preliminary design (2022).

contract as the telescope structure and the enclosure. From now on, the pier and the rest of the buildings and civil works will be treated as a whole, to prepare the necessary documents to obtain the construction permit.

The path to the current design has gone through various phases in which numerous studies have been performed to validate the suitability of the location and the alignment of the EST Observatory design with the requirements.

During the preliminary study stage 1 (*Estudio previo*), a preliminary study of the geological and geotechnical characteristics of the area of interest was performed to determine its suitability for the installation of EST. A wind study was accomplished to see the optical performance of the telescope, at the selected site, and the best location for the main building and the auxiliary building. At the same time, the influence on the nearby telescopes was studied. In addition, environmental restraints were contemplated in order to determine the suitability of the site taking in account that the site is within the La Caldera de Taburiente National Park, hence protected.

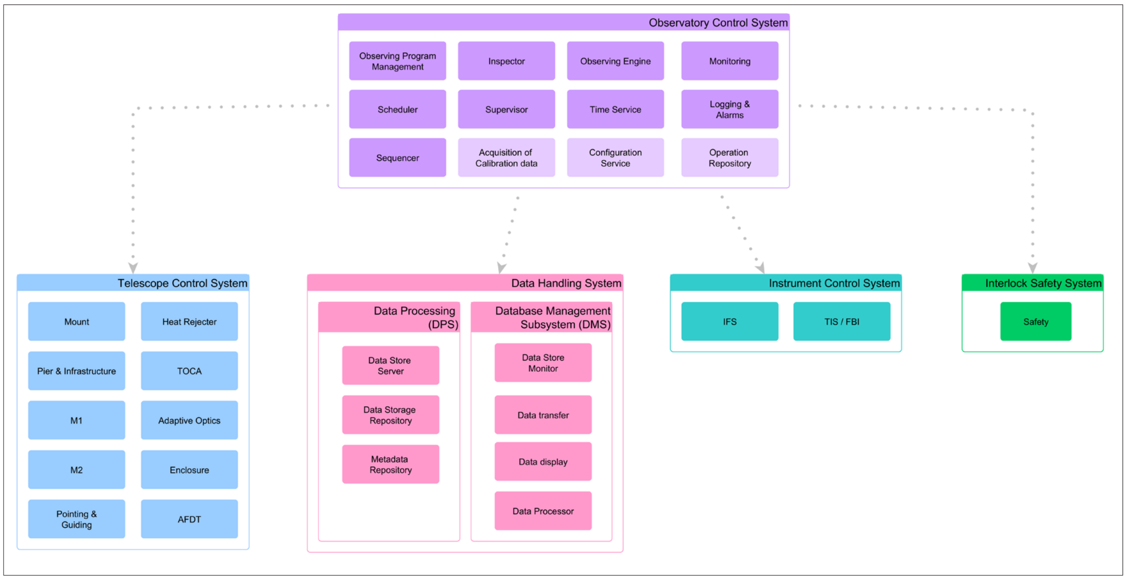
Throughout the preliminary study stage 2 (in Spanish *Anteproyecto*), the biggest change took place. It was determined that the conceptual design buildings placed on the selected site would involve a large amount of earthwork to obtain a flat building surface, which is not in consonance with the environment. Therefore, new designs were explored until the final one was selected.

Apart from different building configurations, other studies were performed and accomplished. A preliminary archaeological study uncovered five stone archaeological engravings and the location of existing scattered materials. The archaeological elements found, located in the external area, are not an impediment for the construction of EST, although special attention should be exercised during construction to preserve them, as well as future engravings that might appear. A topographic survey with contour lines every metre was performed and checked by overlaying it with other topographic surveys of the same site. Geotechnical conclusions were extracted from previous studies; the upshot was favourable to the construction of EST at the site. Finally, the Roque de los Muchachos Observatory is in Red Natura 2000, and an specific environmental impact statement will need to be developed according to law 21/2013 of environmental assessment (in Spanish ley 21/2013 de evaluación ambiental).

The call for tenders for the preliminary construction project (in Spanish *Proyecto básico*) will be announced soon. During this phase, different samples from the site will be taken for a geotechnical evaluation and all the necessary studies and design documents for processing the environmental impact statement will be produced. This will give the EST project time to complete the design of the main elements of the telescope and secure the funding for the construction phase while the environmental permits are obtained. Hopefully, all those steps will be completed at the same time to start the construction of EST.

EST CONTROL SYSTEM

An overview of the current concept of the EST Control System is given.



EST Control System breakdown.

The control system of EST will make it possible to observe the sun by coordinating and monitoring all the elements that make up the telescope. To get an idea of the complexity that the EST control system can reach, we just have to consider the variety of elements to be controlled, from the simple motor driving the primary mirror cover to the complex deformable secondary mirror with 1950 actuators. The main systems to be controlled are:

- Telescope structure. We have to control the axes of the telescope structure in order to point at the sun.
- The primary mirror will have 100 actuators to deform its surface.
- The secondary mirror is an Adaptive Secondary Mirror with adaptive optics capabilities. A total of 1950 actuators will deform its surface.
- The enclosure will protect the telescope from inclement weather.
- The thermal control system is designed to maintain the telescope temperature within ±1°C of the ambient temperature.
- Seven instruments will be run simultaneously. They will be able to work independently, synchronised, or with synchronised detectors.
- The pointing and guiding system will coordinate the AO system, M1, M2 and the structure of the telescope to be able to track the sun.

In short, we will have to control more than 2050 actuators in deformable mirrors and more than 60 motors, monitoring 260+ sensors.

The EST control system will be a distributed system consisting of 5 systems, as shown in the Figure:

- Observatory Control System (OCS), responsible for interacting with users and coordinating other systems.
- Telescope Control System (TCS). It comprises the control subsystems of the telescope elements.
- Data Handling System (DHS), responsible for handling science data and telemetry.
- Instrument Control System (ICS), responsible for managing the instruments and the synchronisation between them.
- Interlock and Safety System (ISS). It ensures the reception, storage and propagation of alarms and log message to the entire system.

The EST Project Office is currently developing the Preliminary Software Design and Control document, which will contain the specifications of the future EST control system.

One of the key elements in the control system will be the integration of the instruments. It is currently estimated that the instruments will generate 30 PB of data per day. This amount of information is a challenge, requiring a large capacity data storage system and a very efficient reduction pipeline. In collaboration with the Leibniz-Institut für Sonnenphysik (KIS), the best strategies to solve this problem are being defined, as well as the flow of data from the telescope on La Palma to the Data Centre in Freiburg.

The challenges for the EST control system are numerous and complex, but certainly also very exciting.

COMMUNICATION ACTIVITIES

Despite the work overload associated with the end of the PRE-EST project, the EST partners have made an effort to maintain communication and outreach activities in these months.

Presentation of the documentary "Reaching for the Sun" on La Palma (Spain). Credit: V. A. López/IAA-CSIC.

After the first presentations of "Reaching for the Sun" in Madrid (Spain) and Bratislava (Slovakia), the EST documentary has been screened several more times. The film, which addresses 400 years of solar physics research in Europe, was displayed on July 9 in Göttingen (Germany) as part of the activities organised by MPS for the Night of Science 2022. It has also been part of the public activities carried out during the final PRE-EST meeting. On the one hand, "Reaching for the Sun" was screened on September 28 in Santa Cruz de La Palma during the presentation of the EST project to authorities from the regional government of La Palma, led by the president of the Cabildo de la Palma, Mr. Mariano Hernández Zapata. On the other hand, the Benahoarita Archaeological Museum, in Los Llanos de Aridane, hosted a premiere of the documentary for the general public.

In the coming months, we plan to sign an agreement to distribute "Reaching for the Sun" worlwide through television channels and video-on-demand platforms. The film will also be presented in international festivals to achieve the highest possible visibility.

EST has attended several international conferences and events. In July, the Public Awareness Research Infrastructures 2022 conference was held in Manchester (UK), organised by the SKAO, to exchange best practices and lessons learned in communicating science to the public. Víctor Aníbal López (IAA-CSIC) attended this workshop and presented a poster on the experience of the international infographic school competition "The Sun at a glance", organised by the EST consortium. On the other hand, the EST roll-ups and

European Researchers' Night in Catania (Italy). Credit: Francesca Zuccarello/UNICT.

informative materials about EST were displayed during the Hinode-15/IRIS-12 science meeting held in Prague (Czech Republic) from September 19 to 23. Finally, EST participated as an Associate Big Science Organisation in the Big Science Business Forum 2022 held in Granada from October 4-7, 2022. The project set up a booth in the exhibitor area. Moreover, the EST systems engineer, Miguel Núñez, gave a talk about EST. A dedicated article with information about the BSBF 2022 is available in this newsletter.

In addition, EST scientists have continued to deliver invited talks at different international meetings. Manuel Collados (IAC) spoke at the European Astronomical Society Annual Meeting (Valencia, Spain) on June 28 and at the IAA Severo Ochoa Meeting (Granada, Spain) on October 21. Francesca Zuccarello (UNICT) was invited to present EST at the XV Meeting of the Spanish Astronomical Society held in La Laguna (Spain) on September 8, and Carlos José Díaz (SU) gave another talk at the Hinode-15/IRIS-12 meeting (Prague, Czech Republic) on September 19.

During the last 6 months, the EST consortium organised several outreach activities. Also this year, EST was present at the European Researchers' Night on September 30, 2022. UNICT organised a workshop in Catania (Italy) to bring together the students who participated in the school competition "The Sun at a glance", while the Hungarian Solar Physics Foundation (HSPF) and the Eötvös Loránd University (ELTE) organised a solar observing session with amateur telescopes in Budapest.

In Hungary, the members of HSPF organised other outreach activities like the Solar and Astronomy Open Day in Balatonrendes (Hungary) on August 4 or the Week Under the Stars 2022 that also took place in Balatonrendes between August 5-14, 2022.

Furthermore, Dan Kiselman (ISP) gave an outreach talk as part of the Day and Night of Astronomy organised by the House of Science in Stockholm (Sweden) on September 23, 2022.

Poster about the EST school contest presented at PARI 2022 (Manchester, UK).

EST in the media

TASR, the news agency of the Slovak Republic, published an article about the European Solar Telescope on August 15. This agency provides news for all the Slovak media, so it was a high-impact publication in Slovakia, highlighting the Slovak contribution to EST and solar physics research in Europe.

In September 2022, the Spanish edition of the National Geographic magazine published a short interview with Luis Bellot (IAA-CSIC). In this article, he talked about the current challenges of solar physics research and the need for EST.

Besides, a press release was sent to the regional media of La Palma, on the occasion of the EST presentation on the island on October 28, 2022. Three local newspapers published articles based on it. The news also appeared in the bulletin of Radio Televisión Canaria, the public broadcasting company of the Canary Islands.

Solar observation in Budapest. Credit: Asztalos Balázs/ELTE.

EST VIDEO GAME LAUNCHED

"Solar Mission EST" is available on the EST website, Google Play and the App Store.

"Solar Mission EST" is now available for download on the EST website, Google Play and the App Store. For more than two years, the EST Communication Office has worked on this project whose main objective is to bring solar physics closer to young people.

Imagine that one morning your toaster starts throwing pieces of bread, your oven tries to kill you, and the night lamp wants to finish you off. Imagine all electronic devices going bananas. The origin of this situation is the solar magnetic field. The magnetic activity of the Sun is unprecedented and affects all systems on Earth. "Solar Mission EST" builds up around this fun premise. A team of brave solar physicists is humanity's last hope to stop the disturbances caused by the crazy solar activity. The team will have to complete the construction of EST, a state-of-the-art infrastructure that will allow them to find out what is happening in the Sun.

The story of the video game sets off from a real phenomenon: solar magnetic fields drive eruptions that have measurable consequences on Earth. However, the story is exaggerated to attract the attention of a young audience.

The game includes six scenarios inspired by real observatories. In each scenario, a solar astronomer will have to obtain a specific piece for EST, solving puzzles and mini-games related to solar physics. During the mission, crazy machines will try to prevent the player from achieving their objective. The game conveys information about the magnetic features and processes present in the Sun's atmosphere, such as sunspots, flares, or coronal loops. Also the techniques and instruments used to study our star are introduced.

Each scenario has a "special enemy" who cannot be defeated until the player obtains the piece for EST.

Lomnický Štít Observatory. Solar astronomer UV has to fight lamps hidden in wavelengths not visible to the human eye. He must find a UV camera for EST and finish off the lamps. The skill of producing solar magnetic tornadoes will help him accomplish his mission.

Einstein Tower. Flare finds out that polarised TVs are wreaking havoc at the Tower. She has to get a spectropolarimeter to decompose the light and fight the machines. She uses a cannon to shoot miniature coronal mass ejections.

Pic du Midi Observatory. Evil toasters plague the site. They can only be defeated by shooting at their guts, and Ms. Prominence will need appropriate filters for that. Her ability to create solar flares will be extremely useful to collect them.

GREGOR. Young Spot has to get rid of excess heating, partially produced by berserk ovens. To reach that goal he needs a heat rejecter. He uses a jetpack to create solar spicules.

Swedish Solar Telescope. Eclipse is in charge of getting the Adaptive Optics system for EST. She has to reach the SST through a cloud of enemies, including blurry microwaves. To see them clearly she needs AO, but she can take care of herself by creating small solar magnetic fields around her.

European Solar Telescope. Senior astronomer Spectro will be responsible for turning EST on to find out what is happening in the Sun. However, at that time solar activity will be even more intense, with surprising effects on Earth.

Throughout these scenarios, the characters will not only have to overcome their own challenges, but they will also have to cooperate with each other, much like in real scientific collaborations.

"Solar Mission EST" is aimed at children aged 8-12, but it is designed to be appealing to people of any age with an interest in science. The objective is to transmit, in an attractive way, some of the concepts used in solar physics, and how EST will contribute to a better understanding of the Sun. To reinforce the learning process, the player can access the game "Solarpedia" at any time. This resource is a collection of 74 short articles providing information on a variety of topics.

"Solar Mission EST" runs on mobile phones and tablets. There is also a PC version that can be downloaded from the EST website. The game has been developed in English, but a Spanish update is ready and will be released soon.

EVENTS

EST INVITED TALKS

A list of EST invited talks in national and international meetings is available on the EST website at http://est-east.eu/est-invited-talks

EST: THE MOST ADVANCED TELESCOPE FOR ACCURATE HIGH-RESOLUTION SPECTROPOLARIMETRY
Luis Bellot and Manuel Collados, in Solar Polarization Workshop 10, Kyoto (Japan)
7 November 2022

THE EUROPEAN SOLAR TELESCOPE
Francesca Zuccarello, in XV Scientific Meeting of Spanish Astronomical Society, Tenerife (Spain)
8 September 2022

THE EUROPEAN SOLAR TELESCOPE
Manuel Collados, in IAA-CSIC Severo Ochoa Meeting: Addressing Key Astrophysical Questions from Granada, Granada (Spain)
21 October 2022

APPLICATION OF MACHINE LEARNING AND NEURAL NETWORKS TO DATA PROCESSING IN SOLAR PHYSICS
Carlos Díaz Baso, in Hinode 15/IRIS 12 meeting, Prague (Czech Republic), 19 September 2022

OTHER EVENTS

ROCS, MUSE, IRIS (ROCMI) WORKSHOP
Svalbard (Norway), 27 Feb-3 Mar 2023

SPACE WEATHER WORKSHOP 2023
Boulder (USA), 17-21 April 2023

MACHINE LEARNING AND COMPUTER VISION IN HELIOPHYSICS
Sofia (Bulgaria), 19-21 April 2023

THEORY AND SIMULATION OF SOLAR SYSTEM PLASMAS - EGU ASSEMBLY
Vienna (Austria), 23-28 April 2023

ADVANCES IN UNDERSTANDING ALFVÉN WAVES IN THE SUN AND HELIOSPHERE
Berlin (Germany), 28 May-2June 2023

SOLAR WIND 16
Pacific Grove (USA), 12-16 June 2023

WAVES AND INSTABILITIES IN THE SOLAR ATMOSPHERE (WISA 2023)
Newcastle upon Tyne (UK), 20-23 June 2023

RAS NATIONAL ASTRONOMY MEETING
Cardiff (UK), 3-7 July 2023

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