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List of Abbreviations

AFDT	Auxillary Full Disk Telescope
BBI	Broad Band Imager
EST	European Solar Telescope
FOV	Field of View
FPI	Fabry Perot Interferometer
IFU	Integral Field Unit
MCAO	Multi Conjugated Adaptive Optics
NBI	Narrow Band Imager
OP	Observing Program
PSF	Point Spread Function
SAG	Scientific Advisory Group
SNR	Signal to Noise Ratio
SP	SPectrograph
SRD	Science Requirement Document
TRD	Technical Requirement Document

Introduction

In this document we present a review of the scientific requirements of the Narrow Band Imagers (NBIs) for the European Solar Telescope (EST). NBIs are based on stabilised Fabry-Pérot interferometers and are among the focal plane instruments of EST. They will produce narrow-band images with the highest spectral, spatial and temporal resolution, with polarimetric capabilities.

Observations with this instrument should allow rapid imaging spectrometry, Stokes imaging polarimetry, accurate surface photometry and spectroheliograms that will result in Doppler velocity maps, transverse flows and imaging magnetograms that track evolutionary changes of solar activity.

The baseline documents used as a reference for this review are the "European Solar Telescope: Conceptual Design Study Report" (CDSR, version RPT-EST-0001 Issue:2.A), delivered in 2011 under the FP7 EST Design Study, and the Science Requirement Document (SRD) for EST (30 May 2019 version) prepared by the Science Advisory Group (SAG) under the H2020 PRE-EST project. Original text from the reports is reported in *italic* while relevant details about the NBIs are underlined in **bold**.

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NBIs requirements - EST Conceptual Design Study Report

We summarize here the NBI requirements defined in the CDSR which served also as starting point for the scientific requirements review achieved in the SRD.

Instrument	spectral range (nm)
NB1	390 - 500
NB2	500 - 620
NB3	620 - 860
NIR NB1	800 - 1100
NIR NB2	1500 - 1800

NBIs requirements were defined in the EST CDSR as follows:

- *Spectral Resolution: 150,000 at 525 nm, 630 nm (visible channels), 854 nm, 1565 nm (infrared channels), with goal at 1083 nm and TBD at 396 nm (CaH, K channel).*
- *Polarimetric SNR in 1 sec at 0.04" resolution and at 500 nm: 1000*
- *Instrument Transmission: >30 %*
- *Spectral S/N ratio: >100 (TBC)*
- *Max Ghost: <1 % (TBC)*
- *Max. Interetalon Ghost: < 0.5 % (TBC)*
- *FoV: 60 arcsec*
- *F-Ratio@Etalons: 200 (TBC)*
- *Max. Etalon mismatch: < 1% (TBC)*
- *Polarimetric accuracy: 3e-5*
- *Spectral Stability: 1% of spectral FWHM*
- *Strehl intensity: 90 % minimum*
- *FoV: ~ 1 arcmin (photometric mode), 1 arcmin x 40 arcsec (polarimetric mode)*

On the one hand, a triple-etalon telecentric design is proposed [Horizontal FPI mount]. On the other hand, a collimated, tandem design for the wavelength range between 850 and 1100 nm is also included [Vertical FPI mount].

CM (classic mount) and TM (telecentric mount) are not equivalent, also for ideal interferometers, and a choice between them should be done on the basis of the scientific requirements. This choice, however, is complicated by the different effects on both mounts due to the cavity defects and by the impossibility of knowing in advance their size and distribution. So, the general conclusion is that a decision will be made once the interferometers have been manufactured and their cavity errors fully quantified.
The EST CDSR explored the two possible configurations for an FPI based NBI, classical mount or telecentric mount, leaving the final decision to a later phase of the project, when the technological issue of the cavity errors on a large diameter etalon would have been better addressed. This point has to be taken into consideration in the following deliverables of this subWP.

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The Science Requirements Document for EST and the implications for the NBIs

The EST SRD has been recently updated (May 30, 2019). This document is the baseline for defining the capabilities of the EST focal plane instruments and in particular the the future Technical Requirements Document (TRD).
In this document we report the discussion on the NBIs coming from the EST SRD, commenting on the derived scientific requirements. We also analyse, from the point of view of the NBIs, the Observing Programs proposed in the SRD.

SRD introduction: scope and science requirements for the focal plane instruments

The EST Science Advisory Group (SAG) has been constituted by EAST and the Board of the PRE-EST EU project in November 2017 and has been charged with the task of providing with a final statement on the science requirements for EST. Based on the conceptual design, the SRD update takes into account recent technical and scientific developments, to ensure that EST provides significant advancement beyond the current state-of-the-art.

The SRD develops the top-level science objectives of EST into individual science cases. Identifying critical science requirements is one of its main goals. ***Those requirements will define the capabilities of EST and the post-focus instrument suite. The technical requirements for the final design of EST will be derived from the SRD.***

The science cases presented in Part II (Sects. 1 to 8) are not intended to cover all the science questions to be addressed with EST, but rather to provide a precise overview of the capabilities that will make of EST a competitive state-of-the-art telescope to push the boundaries of our knowledge over the next few decades. The science cases contain detailed observing programmes specifying the type of observations needed to solve specific science problems. An effort is being made to define the parameters of the required observations as accurately as possible, taking into account, both, present capabilities and technological developments expected in the near future. The tables of the observing programmes corresponding to the science cases are compiled in Sect. 10. ***The EST science cases represent challenging observations that put strong constraints on the telescope and its instrument suite****. Ultimately, they will be translated into Technical Requirement Document (TRD) leading to the final EST design to be implemented during the construction phase.*

EST SRD science cases

We briefly report here the Science Goals presented in the EST SRD. They are organized in science cases and possible Observing Programs (OPs) are proposed to address the science cases in the SRD.

Some of the instrument's characteristics are initially assumed in the SRD to plan the 94 observing programs described later on in the document, from which scientific requirements for the focal plane instruments are derived:

1. *BBI: Broad Band Imagers, which take images with exposure times smaller than 1 ms.*
2. ***NBI: Narrow-Band Imagers, which scan a spectral range in wavelength. We assume that there will be three NBIs for three different wavelength regimes: blue visible, red visible, IR. For cost reasons, we assume a FOV of about 40 arcsec in diameter or 30 arcsec square side length.***
3. *SP: classical long-slit spectrograph, which scans the solar image. Slit length of 60 arcsec is assumed. Since IFUs are superior to SPs as image reconstruction techniques can be applied to their spectral images, only one SP from blue visible to IR is assumed.*

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4. *IFU: Integral Field Units, which record spectrum and image simultaneously for a relatively small FOV of about 10 arcsec. We assume that IFUs are available for the spectral range from 392 nm to 1600 nm. At this point of development, it is unknown whether micro-lense systems (which are restricted to short wavelength ranges) or reflective image slicers (which can cover large wavelength regimes) are to be preferred.*

All instruments, except for BBIs, are assumed to be operated in polarimetric mode, unless stated otherwise.

In the following table we summarise the science cases from the point of view of requested NBI performances.
The last two columns refer to the request to observe with different kind of instruments simultaneously: NBIs and IFUs or NBIs and BBIs respectively. This underline the synergies of the NBIs with the other focal plane instruments. SP are not requested in combination with NBIs since IFUs have similar spectral properties while providing imaging capabilities that are more easily combined with NBIs observations.

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	Science goal (SG)	science cases (SCs)	observing programs (OPs)	OPs requiring NBIs	NBI+ IFU	NBI+ BBI
1	Structure and evolution of magnetic flux	8	12	6	2	6
2	Wave coupling throughout solar atmosphere	4	18	14	13	8
3	Chromospheric dynamics, magnetism, and heating	9	18	6	0	0
4	Large scale magnetic structures: sunspots, prominences and filaments	12	13	9	9	8
5	Coronal Science	6	4	2	2	2
6	Solar Flares and Eruptive Events	10	13	6	1	5
7	Coupling in partially ionized solar plasma	5	9	0	0	0
8	Scattering physics and Hanle-Zeeman diagnostics	3	7	1	0	0
total		57	94	44	27	29
				47%**	61%*	66%*

**respect to total OPs; *respect to total NBI-OPs

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Observations usually requires to observe spectral range that include the following lines:

Line	wavelength (nm)	Instrument
Ca II K	393,4	NB1
Ca II H	396,8	NB1
Mg I 517.3	517,3	NB2
Fe I 520.5	520,5	NB2
Fe I 525.02	525,02	NB2
Fe I 557.6	557,6	NB2
Na I D2	589	NB2
Na I D1	589,6	NB2
Fe I 617.3	617,3	NB2
Fe I 630.2	630,2	NB3
H-alpha	656,3	NB3
Fe I 709.0	709	NB3
Ca II 854	854,2	NB3
Si I 1082	1082,7	NIR NB1
He I 1083	1083	NIR NB1
Fe I 1565	1565	NIR NB2

We matched each line with the corresponding NBI in the following tables.

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OPs present requirements specifications for the instrument and goal specifications. In the following two tables we provide a summary of the OPs requesting NBIs in different modes. The table includes the number of OPs requesting NBIs for each SG (NBI-OPs). FOV column report how many OPs request a FOV ≤ 40 arcsec, which is the baseline FOV indicated in the SRD. Cadence column report how many OPs request a cadence ≥ 30 s. SNR column report how many OPs request a SNR ≤ 1000. Diff. limited column report if the OPs request spatial resolution at diffraction limit for the observations. No polarimetry column report how many OPs request spectral observations without polarimetric measurements.

Requirements table

SG	NBI-OPs	NB1	NB2	NB3	NIR NB1	NIR NB2	FOV	Cadence	SNR	Diff. limited	No pol
1	6	0	5	4	4	3	5	4	4	4	0
2	14	6	6	11	9	1	14	7	10	14	5
3	6	5	1	6	5	0	6	1	6	5	1
4	9	1	0	6	9	3	6	6	8	8	0
5	2	1	0	2	2	0	2	0	1	2	0
6	6	1	4	5	6	2	4	0	6	4	1
7	0	0	0	0	0	0	0	0	0	0	0
8	1	1	0	0	0	0	1	0	0	0	0
tot.	44	15	16	34	35	9	38	18	35	37	7
		34%	36%	77%	80%	20%	86%	41%	80%	84%	16%

Line observations seems to prefer NB3 and NIR NB1 instruments. While 40 arcsec FOV seems to be adequate for most of the OPs (86%), 30 s cadence is sufficient in just 41% of the OPs. On this point we underline that some OPs are considering as "cadence" just the product of the exposure time by the number of spectral points requested. A more suitable definition of the cadence should also consider the spectral point time settling and time lapse due to pre-filter change. Since some OPs require a 1s cadence,

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this has to be evaluated and considered in the framework of instrument control optimization. On the other hand, some OPs (16%) do not require diffraction limited observations, while requesting higher SNR. Pixel binning or change in the plate scale on the scientific camera should be considered for these OPs.

Goal table

SG	NBI-OPs	NB1	NB2	NB3	NIR NB1	NIR NB2	FOV	Cadence	SNR	Diff. limited	No pol
1	6	2	5	6	4	4	0	3	4	4	0
2	14	6	6	11	9	1	7	5	9	14	5
3	6	5	1	6	6	0	6	1	6	5	1
4	9	1	0	6	9	3	3	4	3	9	0
5	2	1	0	2	2	0	2	0	1	2	0
6	6	2	5	5	6	2	0	0	6	4	1
7	0	0	0	0	0	0	0	0	0	0	0
8	1	1	0	0	0	0	1	0	0	0	0
tot.	44	18	17	36	36	10	19	13	29	38	7
		41%	39%	82%	82%	23%	43%	30%	66%	86%	16%

In the more demanding goal requirements, some additional wavelengths are considered in some OPs. Cadence becomes even more demanding. At the same time, a FOV of 40 arcsec is sufficient in just 43% of the OPs, which suggest to take into consideration either to study a dedicated optical relay system to change FOV or a dedicated NBI for large FOV. In this case, it must be considered that the MCAO corrected FOV is 60 arcesec while the available FOV after spatial filtering at F1 is 120 arcsec. Some of the largest FOV (e.g., 120 arcsecs) requested are more compliant with the AFDT of EST.

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Furthermore, we briefly report for each Scientific Goal the requests on the NBIs, underlining possible issues:

	Science goal (SG)	OPs requests for NBIs
1	Structure and evolution of magnetic flux	Large FOV in some OPs; others requires high SNR (could be solved with binning)
2	Wave coupling throughout solar atmosphere	Very high cadence at diff. limit in some OPs; Combined observation of spectroscopic mode for NBIs and polarimetric for IFUs at same wavelength
3	Chromospheric dynamics, magnetism, and heating	No synergies with other instruments, all available light goes to the NBIs
4	Large scale magnetic structures: sunspots, prominences and filaments	All OPs require simultaneous observations with BBIs and IFUs
5	Coronal Science	Very high cadence, simultaneous observations with other instruments
6	Solar Flares and Eruptive Events	Very high cadence and large FOV; spectral range exceeding usual prefilters
7	Coupling in partially ionized solar plasma	No Ops requires NBIs, IFUs are preferred
8	Scattering physics and Hanle-Zeeman diagnostics	No Ops requires NBIs except one, SPs are preferred

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EST focal plane instruments

In the EST conceptual design from 2011, the post-focus instrument suite consists of

- ***5 narrow-band imagers (NBIs) with wavelength ranges (WR) in nm between 390 – 500 (WR1), 500 – 620 (WR2), 620 – 860(WR3), 800 – 1100 (WR4), 1500 – 1800 (WR5).***
- *4 spectrographs (SPs) with ranges between 390 – 560, 560 – 1100, 700 – 1600, 1000 – 2300. These SPs were thought to be configured as long-slit spectrographs, as multi-slit multi-wavelength SPs with an integral field unit (IFU), or as double-pass imaging spectrographs (TUNIS or MSDP type of instruments).*
- *3 Broad Band Imagers, two with 380 – 500, and one with 600 - 900. They are associated to the NBIs of the corresponding wavelength.*

The light distribution system foresees exchangeable dichroic and partial beam splitters. This allows either simultaneous observations with all instruments by sharing light of a specific wavelength or observations where a subset of instruments is fed with all light of a specific wavelength.

Design developments 2011 – 2019

Since the preliminary design phase, some 10 years ago, significant developments on post-focus instrumentation have happened. In recent years, prototypes of Integral-Field-Units (IFUs) with solar spectro-polarimetric measurements have successfully been developed and tested. [...]
*With such IFUs, the 2D spatial information and the spectral dimension is recorded simultaneously, while traditional spectrographs and narrow band imagers either have long slits that scan the solar surface or **take very narrow-band images that sequentially scan through wavelength**.*

*This has fundamental consequences for those IFU systems that record coherent 2D images. **Post-factum image restoration techniques can then be applied to the IFU data**.*

Post-factum image restoration techniques can be also applied to 2D images from FPI based NBI. This important resource must be taken into consideration in the instrument pipeline.

*Hereby, highest, diffraction-limited, spatial resolution can be achieved with **full spectral integrity**.*

Spatially scanned maps with such long-slit spectrographs ask for a non-rotating solar image, since image rotation squeezes and stretches the solar scene. With IFUs, the requirement of de-rotating the solar image is less stringent, since the larger fields-of-view are build up by mosaics. And since each tile of the mosaic has short exposure times, the image rotation is negligible, also for image restoration techniques.

These considerations also apply to the NBI, but for the cadence related problems. Each spectral point of the observation typically has an exposure time < 1 s which allows for post-factum derotation. Long duration spectral scans may introduce issues at the edge of the FOV due to the rotation.

Photon flux

***Compromises need to be done between spatial resolution, spectral resolution, and SNR**. This is based on two fundamental properties:*

1. ***The number of photons collected by pixels that sample the diffraction limit of a given aperture is independent of the aperture**. I.e. the advantage of a **larger aperture** can either be used to **increase the spatial resolution or to increase the number of photons (SNR)**.*
2. ***The solar scene evolves with time**. This severely **limits the exposure times** that are needed to freeze a snapshot of the solar evolution.*

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Solar evolution limits also cadence time associated to line sampling.

Hence, the top-level goal for the final design of the telescope is two-folded:

1. *EST should be capable to reach the **highest possible image quality and spatial resolution**, i.e. diffraction limit. With the **option to sacrifice spatial resolution in favour of collecting more photons**.*
2. ***The final design must be optimised for the highest possible photon flux, with the premises of securing polarimetric accuracy and sensitivity.***

Optical design of the NBIs must be optimized for the highest possible throughput. Binning or scale plate interchangeable optics must be considered to obtain higher SNR if needed.

Field-of-view (FoV)

EST is designed to study the small-scale structure of the solar atmosphere. The science cases presented in the SRD request to resolve sub-structures from some 0.2 arcsec down to the diffraction limit (0.026 arcsec at 500 nm with a 4 m aperture).

While scientists desire to have the FoV as large as possible, the reasons for limitations are manifold:

1. *The **size of optical surfaces** in the telescope light beam increases with increasing FoV, leading to a **substantial increase of costs**. This cost increase is particularly high for NBIs. Large FoVs at highest spatial resolution are expensive.*
2. *The performance of the MCAO system degrades with increasing the wavefront-corrected FoV. The expectation is that **MCAO will correct a FoV of less than 60 arcsec in diameter**.*

***The FoVs of IFUs is expected to be limited to some 10 by 10 arcsec^2. These IFUs will be complemented by Narrow Band Imagers (NBIs)**. For the science cases in the SRD, **a FoV of some 40 by 40 arcsec^2 is sufficiently large**. The science cases require simultaneous observation in three or more different wavelength regions. I.e., **rather than requesting a larger FoV, the science cases require a multitude of NBIs and IFUs that operate in different wavelengths simultaneously**. If compromises need to be done, priority will be given to simultaneous multi-wavelength observation over larger FOVs.*

If individual FoVs do not need to be larger than 40 by 40 arcsec^2, one could, in principle, relax the original requirement for the telescope FoV of 120 by 120 arcsec^2. Such large FoVs are traditionally required for context imaging. Instead of designing EST with such a large FOV, one could consider an auxiliary telescope with a FOV of 400 arcsec in diameter that delivers images, Doppler maps, and magnetograms with a spatial resolution of 0.5 arcsec or better, i.e. it should be equipped with an adaptive optics system. This could be a high-res mode of the auxiliary full-disk telescope (AFDT) that is foreseen in the preliminary EST design, or a second auxiliary telescope.
The AFDT foreseen in the CDSR is equipped with one H-alpha channel, one Ca II K channel and a broad band channel. To obtain dopplergrams and magnetograms a NBI channel with large FOV and polarimetric capabilities must be considered, either based on FPIs or other filtergrams types.

Pointing requirements

*Absolute positioning is needed for simultaneous observations with other telescopes. Taking into account that the FoVs of IFUs is expected to be smaller than 10 by 10 arcsec^2, an absolute pointing on the solar disk should be in the order of **1 arcsec** to guarantee the needed overlap with observations from other telescopes.*

***Mosaic with NBIs:** For obtaining a large FoV mosaic with the NBIs, the **tiling should be done by re-pointing the telescope**. For this, the relative pointing is requested to have an **accuracy of 1 arcsec.** The*

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re-pointing of the telescope including a closed-loop in the adaptive optics system at the new position should be performed as fast as possible. A time lapse of ***2 seconds or less would allow for valuable time cadence of larger FOVs.***

Wavelength range

The telescope should cover the ***spectral range from Ca II K 393.4 to Fe I 1564.8 nm****.* ***The choice of coatings should favour the transmission in the longer wavelengths up to 1083 nm****. The longer wavelength regime is considered to be more important to measure the magnetic coupling in the chromosphere.*

Image rotation

While the removal of the (rotating) transfer optics is of great advantage in terms of photon flux and image quality, it ***reintroduces image rotation****. There are three options how to deal with this:* ***(1) a rotating Coudé room, (2) a separate image de-rotator, or (3) accept image rotation.*** *A rotating Coudé room is the straigh-forward solution, but costly and may reduce the space for the instrument platform. Introducing a separate polarimetrically compensated image de-rotator with 4 additional mirrors appears to be a bad solution with respect to optical quality and photon flux.* ***As mentioned above with instrumentation based on IFUs and NBIs, the problems of image rotation are much less severe and would be acceptable.*** *Image rotation would not be acceptable for long-slit spectrographs. They would need to be equipped with an internal image de-rotator.*

Instrumentation and light distribution

The main science driver for EST consists in understanding the magnetic coupling of the solar atmosphere. This is reflected in many of the science cases described in the SRD. In the corresponding observing programmes, measurements probing many different layers of the solar atmosphere are required to be taken co-temporally and co-spatially in many different wavelengths, as e.g., ***Ca II K 393.4 nm, MgI 517.3 nm, Fe I 525.0 nm, Fe I 557.6 nm, He I 587.6 nm, Fe I 617.3 nm, Fe I 709.0 nm, H 656.3 nm, Ca II 854.2 nm, Si I 1082.8 nm, He I 1083.0 nm, Fe I 1564.8 nm, etc****. For the observing programmes in Part II, typically three or more of these lines are required to probe the photosphere and chromosphere.*

Here again, time and photons are limited, such that ***it is desirable that multiple instruments operate at different wavelengths simultaneously. Ideally, each instrument would receive all available photons of a specific wavelength.***

Efficient NBIs have low spectral resolution (between 30 000 and 100 000), meaning that science cases which request high spectral resolution (around 200 000) need to be served with IFUs or long-slit spectrographs.

It must be considered that the NBIs requirements defined in the EST CDSR set the spectral resolution of the NBIs at 150 000, thus opening the use of NBIs in some of the IFUs proposed OPs. IFUs remains of primary importance providing complementary information respect to NBIs e. g. in OPs requesting extended spectral range with multiple lines to be observed, or in OPs requesting high spectral purity or simultaneous spectral and 2D spatial information in small FOV. NBIs on the other hand offer more flexibility in the selection of the spectral region of interest containing the required spectral lines.

The post-focus instrumentation and light distribution concept of the preliminary design from 2011 is powerful and sophisticated. With this concept, simultaneous observation as desired in the previous paragraph are *possible. Yet, the old concept foresees to share light between SPs and NBIs. And IFUs are foreseen to replace classical long-slit spectrographs.*

*As a consequence of the lesson learned during more recent developments, **one should also consider to replace some of the NBIs by IFUs, or have both types of instrument for some wavelength ranges,** depending on whether **large FOV or short time cadence and high spectral resolution is needed** for the science case. Different types of instruments for the same wavelength may be necessary to achieve the goals of different science cases, but **simultaneous observation at a specific wavelength with different types of instruments, i.e. sharing the light at a specific wavelength, is not needed.***

Regarding light distribution this decision will provide higher number of photons in band to the NBIs. On the other hand the synergies with other instruments must be carefully considered. A paradigm shift from line-based OPs to wavelength bands related to focal plane light distribution must be considered.

In this respect, the consensus of the present EST Science Advisory Group differs from the Preliminary Design Study: the light distribution should be such that each instrument receives all photons of a particular wavelength.** Many of the top-level science goals need high SNRs to observe features that have short evolution time scales. Hence, **the exposure time and the observing cadence must be short**. **Although IFUs have smaller FOVs than NBIs, they have higher spectral resolution and potentially can complete one measurement in a shorter time span.

Since photon flux and solar evolution time speed are critical, measurements should in general be done simultaneously rather than sequentially in 5 or more spectral lines. I.e., EST should be equipped with a multitude of exchangeable NBIs and IFUs. [TBC in the SRD]

However, in this document, we do not yet recommend how many NBIs and IFUs should observe at which wavelengths. Such a concept yet needs to be developed, and depends on the outcome of ongoing design studies of IFUs. [TBC in the SRD]

Requirements for instrumentation and light distribution

Many of the top-level science cases request to observe in many different layers of the solar atmosphere simultaneously. Up to three photospheric lines together with up to three chromospheric lines are requested. The selected lines for the Zeeman and Doppler diagnostics are one of the following: Ca II K 393.4 nm, MgI 517.3 nm, Fe I 525.0 nm, Fe I 543.5 nm, FeI 557.6 nm, He I 587.6 nm, Fe I 617.3 nm, Fe I 709.0 nm, H 656.3 nm, Ca II 854.2 nm, Si I 1082.8 nm, He I 1083.0 nm, Fe I 1564.8 nm. For the diagnostics using scattering polarization the following lines are proposed: Ca II H , Ca II K , Ca I 422.7 nm, Ti I 453.0 nm, Sr I 460.7 nm, C2 molecular line at 514.0 nm, Na I D1 and D2 589 nm, Ca II 854.2 nm.
*Simultaneous observation in 6 different spectral lines are requested by the high-impact science cases. Some of those require larger FOVs, others require spectral integrity and smaller time cadences. I.e., **6 NBIs exchangeable with 6 IFUs for 6 different simultaneous wavelength regimes would suffice to serve science requirements.***
*The **spatial resolution of NBIs** and IFUs in some cases should be **close to the diffraction limit**. However, many science cases ask for **high SNR** that will require to increase the collection area, i.e. **reduce the spatial resolution**. This could be achieved by a **variable image scale or by binning of the recorded pixels.***

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Specifications from the SRD

Telescope specifications

We include here some of the telescope specifications derived from the EST SRD. These specifications are summarized in subsequent table.

Telescope specifications

1. *FOV:*
   (a) Telescope FoV (Field stop in F1): Diameter of 85 arcsec corresponding to square of 60 by 60 arcsec^2.
   (b) Seeing-corrected FoV: 40 by 40 arcsec^2.
   (c) For context information larger FOVs are essential. This requires an auxiliary telescope at the EST site that delivers images, Doppler maps and Magnetograms for a FOV of at least 300 arcsec in diameter with a spatial resolution of 0.5 arcsec being equipped with an adaptive optics system.
2. *Pointing:*
   (a) Pointing accuracy on solar disk: 1 arcsec.
   (b) Relative pointing accuracy for individual tiles of mosaic with NBIs: 0.5 arcsec
   (c) Telescope repointing time for tiles in NBI mosaic: 2 sec
   (d) Relative pointing accuracy for individual tiles of mosaic with IFUs (small FoVs): 0.1 arcsec
   (e) Repointing time for tiles in IFU mosaic: 1 sec
3. ***Optical quality: Optimised for high photon flux and best optical quality**, i.e. optimised for a minimum amount of optical surfaces.*
   (a) Diffraction-limited image quality
   (b) Quantify effective PSF, Strehl
4. *Secondary Mirror:*
   (a) Design with Deformable Secondary Mirror (DSM) is to be preferred if technically feasible.
   *(b) I**n case of design with DSM: Image rotation is acceptable for NBIs and IFUs.** Long-slit spectrographs need **internal image de-rotator**. Rotating Coudé platform to be preferred if it allows for sufficient space for instruments.*
5. *Polarimetric accuracy of $5 \cdot 10^{-5}$ and sensitivity of $3 \cdot 10^{-5}$*
6. *Wavelength coverage: 390 nm - 1600 nm*
7. *Pointing off the solar disk: < 100 arcsec*

EST telescope specification	details
Diameter	4 m
Configuration	On-axis gregorian telescope
Wavelength range	390 nm - 1600 nm
FOV	120 x 120 arcsec^2
Polarimetry	sensitivity of $3 \cdot 10^{-5}$
Spatial resolution	up to 30 km on the solar surface, with MCAO at diffraction limit

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NBIs specifications

We summarize in this section the scientific requirements and the technical issues coming from the analysis of the EST SRD that must be discussed in the design of the NBIs for EST.

- Review the instrument spectral resolution, previously set to 150 000 in the EST CDSR.
- Classic mount vs telecentric mount.
- Number of NBIs and light distribution in 5 different bands.
- FOV of 60 arcsec in diameter, 40x40 $arcsec^2$.
- Synergies with other instruments (others NBIs, IFUs, BBIs and SPs) and light distribution system philosophy (no light sharing at the same wavelength).
- NBIs cadence capabilities in connection with instrument control and FPIs positioning. Technical time lags to be added to exposure times in single spectral point observations.
- Diffraction limited observations vs high SNR observations. This issue requires the analysis of binning and/or variable image scale optics solutions.
- Post-factum image restoration techniques to enhance spatial resolution in connection with NBIs pipeline.
- After transfer optics modification with the possible implementation of adaptive M2 and derotator removal, EST will have more photon flux (7 mirrors removed). At the same time image rotation has to be addressed in a different way. Three possible solutions are envisioned: i) rotating Coudè room; ii) New de-rotator, either global or at instrument level; iii) Image rotation on scientific camera corrected with post-factum techniques. Solutions ii) and iii) require additional studies for the NBIs technical implementation.
- Mosaic capabilities must be explored in terms of cadence, electronic control, and instrument pipeline. (large FOV with diffraction limited observations OPs).
- Highest possible transparency in the required bands for the different NBIs must be considered, in particular in the required lines wavelength ranges (minimum amount of optical surfaces). Telescope and transfer optics coatings should favour the transmission in longer wavelengths.
- Photon counts program should be further implemented to compare photon flux and SNR for NBIs, IFUs and SPs in various observing conditions, in particular to compare the different instrument capabilities in terms of high cadence observations.

In the following table we report the baseline for the scientific requirements for the NBIs. The requirements here reported are not in the final version; they combine the requirements defined in the EST SRD and the NBIs details described in the EST CDSR and are reported here as one of the steps in the scientific and technical requirements loop in support of the instrument design process.

NBIs Scientific Requirements	Details
Wavelength range	390 nm - 1800 nm
Number of NBIs	≤ 6
Spectral resolution	> 150 000
FOV	40 x 40 $arcsec^2$, 60 arcsec in diameter
Spatial resolution	diffraction limited
Transparency	> 30%

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References

EST CDSR	European Solar Telescope: Conceptual Design Study Report", RPT-EST-0001 Issue:2.A
EST SRD	Science Requirement Document (SRD) for EST (30 May 2019 version) by the EST Science Advisory Group under the H2020 PRE-EST project

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