NOT Technical Report

Technical status and upgrade plan

Revision 1.0

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	NOT Technical Report *Technical status and upgrade plan*	Rev. 1.0 May 22, 2026

Approvers List

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Revision History

Rev.	Date	Change Description	Pages Affected
1.0	Apr 21, 2026	Initial release	All

1 Preface

The aim of this document is to list and summarize the current technical status of the NOT, apart from its computer systems, and list future maintenance and development projects to inspire further discussion on their more detailed execution and provide rationale for seeking funding for further developing the telescope infrastructure. The projects are divided into sub-categories *1.)* necessary maintenance, *2.)* recommended maintenance, and *3.)* performance upgrades. It is highly recommend to seek funding and personnel to carry out all necessary and recommended maintenance to guarantee unhindered operation long into the future. The list of potential projects is not exhaustive.

Contents

1.1 Reference documents

Ref.	Date	Author	Title
RD1	2023	Viuho	NOT Alignment Report - Re-aluminization 2023
RD2	1983	Korhonen	Interferometric method for optical testing and wavefront error sensing[1]
RD3	1992	Korhonen et al.	Hartmann interferometric testing of large mirrors[2]
RD4	2000	Erm & Gutierrez	Integration and tuning of the VLT Drive Systems[3]
RD5	1995	Klougart	BroCam: a versatile PC-based CCD camera system[4]
RD6	1994	Kozlowski et al.	2.5-um PACE-I HgCdTe 1024x1024 for infrared astronomy[5]
RD7	2012	Storz et al.	Standard modes of MPIA's current H2/H2RG-readout systems[6]
RD8	1991	Roddier et al.	A Simple Low-Order Adaptive Optics System for Near-Infrared Applications[7]
RD9	1995	Andersen et al.	The High Resolution Adaptive Camera for the NOT
RD10	2024	Viuho & Cox	Rotator Power Amplifier Refurbishment
RD11	1989	Nielsen	Cassegrain adaptor for the Nordic 2.5-m telescope – Functions and how to use them
RD12	2024	Jamieson	A review of deep learning methods for digitisation of complex documents and engineering diagrams[8]
RD13	2017	Tiffenberg et al.	Single-Electron and Single-Photon Sensitivity with a Silicon Skipper CCD[9]
RD14	2021	Chierchie et al.	Smart Readout of Nondestructive Image Sensors with Single Photon-Electron Sensitivity[10]
RD15	2023	Holland	Fully depleted charge-coupled device design and technology development[11]

RD16	2019	Ramirez-Laboreo et al.	Fully depleted charge-coupled device design and technology development[12]
RD17	2024	Lee et al.	First laboratory and on-sky results of an adaptive secondary mirror with TNO-style actuators on the NASA Infrared Telescope Facility[13]
RD18	2023	Jovanovic et al.	2023 Astrophotonics Roadmap[14]
RD19	2012	Djupvik et al.	User Requirements for the new Controller and Data Acquisition System for NOTCam

1.2 Abbreviations and acronyms

AC	Alternating Current
ALFOSC	Alhambra Faint Object Spectrograph and Camera
AO	Adaptive Optics
CCC	Closed-Cycle Cryocooler
CCD	Charge-Coupled Device
CPU	Central Processing Unit
DC	Direct Current
ELT	Extremely Large Telescope
EPROM	Erasable Programmable Read-Only Memory
ESO	European Southern Observatory
FIES	FIber-fed Echelle Spectrograph
FTE	Full-Time Equivalent
LIDAR	LIght Detection And Ranging (sensor)
LSST	Legacy Survey of Space and Time
NBI	Niels Bohr Institute
NIR	Near InfraRed (0.7 – 1.1 μm)

NOT	Nordic Optical Telescope
NTE	NOT Transient Explorer
OCR	Optical Character Recognition
ORM	Observatorio Roque de los Muchachos
OS	Operating System
PA	Power Amplifier
PIC	Photonic Integrated Circuit
PID	Proportional-Integral-Derivative
PLC	Programmable Logic Controller
PSU	Power Supply Unit
RC	Ritchey-Chrétien (telescope design)
RRM	Rapid Response Mode
SBC	Single Board Computer
SWIR	Short-Wave InfraRed (1.1 – 2.5 μm)
TCS	Telescope Control System
ThAr	Thorium-Argon
TMS	Thermal Monitoring System
TNO	Netherlands Organisation for Applied Scientific Research
ToO	Target-of-Opportunity
UV	UltraViolet (0.3 – 0.4 μm)
VIS	VISual (0.4 – 0.7 μm)
VLT	Very Large Telescope
VME	Versa Module Eurocard
WFS	Wave-Front Sensor
WG	Working Group
WP	Work Package

2 Introduction

Despite its mature age, the NOT remains as a highly productive facility and a workhorse for the Nordic astronomy. The NOT is globally one of the leading facilities in the transient follow-up due to its unique flexible scheduling and Target-of-Opportunity and Rapid Response Mode (RRM) observing modes. NOT offers an excellent optical performance (**RD1**) and is very highly reliable (in 2025 0.2% of observable time was lost due to hardware related technical down time, Sec. 3.2). Combined with the one of the best site characteristics at the Observatorio Roque de los Muchachos (ORM), and practically no pointing limits (altitude range 6.5 – 89° available apart from South where the peak of Roque is visible at ∼10°), the NOT is an ultimate transient follow-up facility. Recently, the telescope's unique characteristics have been bolstered by the introduction of the Rapid Response Mode allowing the even earlier detection of transient phenomena. The RRM can be used with the existing instrument suite, although it has been developed with the forthcoming NOT Transient Explorer (NTE) -instrument in mind.

This document is divided into sections covering the status (Sec. 3), suggested changes to current operations (Sec. 4), suggested technical technical maintenance and development, further divided into three sub-categories *1.)* necessary maintenance (Sec. 5), *2.)* recommended maintenance (Sec. 6), and *3.)* performance upgrades (Sec. 7). The category 1 in (Sec. 5) includes items that are required to be addressed to guarantee telescope operation for the until and beyond the coming decade without considerable increase in technical downtime. While not necessarily highlighted in this document, the prioritized upgrades also open up further development pathways for additional performance improvements (f.e. faster non-sidereal tracking and increased autonomy). It would be highly advisable to seek funding and labor for the projects listed in the necessary and highly recommended sections. Practical limitations and more detailed requirements for the projects should be further discussed with the NOT staff.

This document mostly focuses on the telescope and other fixed infrastructure at the ORM site and an important technical change is mostly ignored, namely, the arrival of NTE. NTE is expected to be delivered with all necessary equipment, relevant spares, and documentation, leaving the majority of observatory integration work to commissioning, calibration, and computing system integration tasks which are not covered by this document. Nevertheless, there are few technical hardware related items that are important for the telescope and potentially affect the technical operations after the NTE acceptance (Sec. 7.1 and 7.9). It should be noted that delivery of NTE will solve some of the issues with the aging BIAS and CCD3 systems (Sec. 6.1 and 7.14).

3 Technical status

3.1 Instrumentation

NOT's current instrument setup consists of, ALFOSC[1] (VIS imager and low-res spectrograph), FIES[2] (VIS high-res spectrograph), NOTCam[3] (SWIR imager and low-res spectrograph), and STANCAM[4] (VIS imager). Additionally, visitor mode instruments DIPOL[5] (imaging polarimeter), SOFIN[6] (high-res spectro-polarimeter), and FASTCAM (lucky and speckle imager) are used relatively often.

Approximate time allocation for the instruments at the telescope is 75% ALFOSC, 20% FIES and 5% NOTCAM. FIES and STANCAM are always available while ALFOSC and NOTCAM are mounted on the Cassegrain focus one at a time. The visitor instruments DIPOL, SOFIN and FASTCAM replace ALFOSC or NOTCAM on the Cassegrain as requested and allocated time for. STANCAM and the FIES fiber feeds are mounted on the instrument adapter which itself is never removed from the telescope. The forthcoming NOT Transient Explorer (NTE)[7] instrument will offer simultaneous VIS – SWIR imaging and medium-resolution spectroscopic capabilities, conceptually, merging the functionality of ALFOSC and NOTCAM into a single instrument available on the Cassegrain for the majority of time. After NTE has been commissioned, ALFOSC and NOTCAM are expected to be decommissioned, while operation of FIES and STANCAM continues similar as today. Only functionality that NTE does not offer compared to ALFOSC and NOTCam is imaging polarimetry. Imaging polarimetry as a capacity should not be lost and ways to maintain the capacity after NTE delivery should be investigated (see Sec. 7.5).

[1] `https://www.not.iac.es/instruments/alfosc/`
[2] `https://www.not.iac.es/instruments/fies/`
[3] `https://www.not.iac.es/instruments/notcam/`
[4] `https://www.not.iac.es/instruments/stancam/`
[5] `https://www.not.iac.es/instruments/dipol-uf/`
[6] `https://www.not.iac.es/instruments/sofin/`
[7] `https://www.not.iac.es/instruments/nte/`

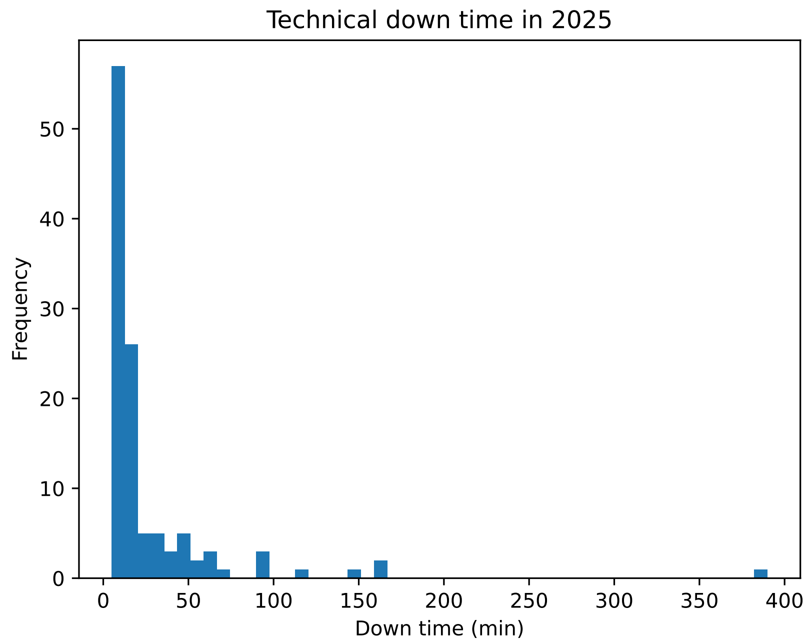

Figure 1: Histogram of the technical downtime duration in 2025.

3.2 Technical downtime

Operating philosophy of the NOT has been focused on the long-term operation since the inauguration of the telescope. This is reflected in a large and broad selection of spare components which have been purchased together with each of the operational sub-systems. Stocking a large quantity of spare components is a core reason behind the extremely low technical downtime of the NOT: in case of a component failure a replacement component is readily available at the site and can be installed in a matter of minutes or hours. It should be noted that even in 2026 it is challenging to deliver spare components to La Palma, and delays due to customs handling can be expected. Another core reason for the low technical downtime is that the telescope and its constituent sub-systems are extremely well understood, and both the staff and students are well trained to recover the telescope from the typical fail scenarios. The recurring fail scenarios are well documented and recovery is typically possible in <10 min. This manifests the importance of documentation and training for highly efficient operation.

A technical down time histogram for 2025 is presented in the Fig. 1. Total of 130 h was lost in the 12 month period, counting 1.4 % of the total observable time. 6 h out of the 130 h was due to external power cuts. Telescope or instrumentation related hardware faults caused a total of 9.5 h, or 0.2 % of time lost. The faults included a TCS power supply slowly dying of old age causing a series of TCS hard crashes, TCS soft crashes related to changes in the network configuration, damaged staircase light sensor, and a failing rain sensor reporting false rain. The remaining 115 h consist of a mix of recurring known issues, software related error, and user errors. The recurring technical issues were typically solved by the staff and students in less than 10 min.

3.3 Spare status

General spare status is still good, however, recently several non-replenish-able spare components have been used leaving their respective sub-systems without necessary spare components. Many of the operationally critical systems at the NOT originate from the late 1980's when the telescope was raised, and it is not possible to purchase swap-in replacements any longer. In this situation, purchasing a new functionally comparable product will either prompt a re-refurbishment of the entire telescope control system (not feasible as a maintenance operation), or designing an I/O interface between old and new hardware. Developing an I/O compatible spare systems is time consuming, and the process may include reverse-engineering of existing non-documented system. In the cases where non-replenish-able spares have run out, such development projects have been started, and are currently at various development stages. Extended pre-installation testing is required to ensure safe deployment the new replacement systems. Listing of spare component status by sub-system can be requested from the author.

4 Suggested changes to the technical operations

4.1 Staffing

With Peter Brandt, Graham Cox and Ingvar Svärdh leaving the NOT over the past years, the on-site technical operations team has reached its all time lowest staffing consisting of only 1.5 FTEs in 2025. The situation has improved for the 2026 by increasing to total of 2.5 FTE. Simultaneously, the over-the-seas support at the partnering universities has diminished.

Current technical operations team covering electronic, mechanical, cryogenic, hydraulic, optical and pneumatic engineering disciplines consist of three individuals, Carlos Perez, Joonas Viuho and Christian Moreno. Carlos Perez mainly organizes the day-to-day operation of the telescope, f.e. including LN2 supply, planning maintenance of the telescope and building infrastructure, hydraulic systems, all analog control logic, and AC electric installations. Responsibilities of Joonas Viuho include all optics, all digital- and micro-electronics, detector systems, including all their associated non-user level software components, and overall instrument performance. Tasks on cryo-vacuum systems are shared between Carlos Perez and Joonas Viuho. Christian Moreno is moving from the computing department, taking part in the daily operations on the course of 2026 extending his knowledge about the NOT. Part of the Christian Moreno's responsibilities will still remain with the computer and network infrastructure, and there is a steep learning curve to assume responsibilities on the telescope hardware.

With 35 yr in operation, the amount of technical service tasks can not be expected to be reduce; merely they can be expected to increase as the systems age. Currently, non-critical system have been left without maintenance and some of them, such as the temperature monitoring system (TMS) have already partially failed. While for example TMS may seem like a non-important part of the telescope daily operation, its functioning is critical for f.e. the telescope automatic temperature focus correction, and automated warnings f.e. about electronics room over heating.

While the current staffing allows the operation of the telescope as it is, only a limited amount of new development is possible. The planned and expected larger maintenance operations will take a long time to execute with potential additional backlog accumulated on the way. Action should be still taken to seek for an additional experienced on-site technician/engineer with a broad background and skills in analog and digital electronics, electronic design, as well as, microprocessor level programming. The telescope operates on historical system and in order to be able to migrate from the current system to (more) modern hardware, the potential candidate should have understanding of both legacy and current systems.

4.2 Digital documentation

Currently, technical documentation is only available physically at the site in a paper format. Having documentation in a more shareable format is critical to facilitate future collaborations with the host and partner institutes to update the aging systems. The first efforts on this front have been already made by digitizing the telescope technical drawings printed on the A4 or A3 sized sheets. A Subversion (SVN) version controlled repository has been set up, and it currently hosts a tree structure covering the telescope and its current instrumentation. In addition to the telescope drawings, the available materials include majority of the original CAD design data of the instruments designed by Niels Bohr Institute, and part of their electronic designs.

Further, the scanned or photographed copies should be vectorized to allow conversion to file formats understandable by a 3D CAD software. Scanning and OCR'ing old user guides, technical datasheet and similar allow these materials to be become computer searchable greatly easing access to needed information. However, the entire process is time consuming and ungrateful.

All future development projects should deliver a full copy of all of their technical documentation including, optical, mechanical and electronics design files before allowed to be used for routine operation. If the documentation is not delivered, the systems should be considered as 'visitor instruments' only which the NOT does not offer technical support for.

4.3 Establishing framework for technical collaboration

Astrophysics as a field is very technology driven. Access to the latest technology and the ability to deploy them, have enable new experiments to be planned which have lead to confirmations of existing theories and completely new discoveries. This is as true today as it has been in the times of Tycho Brahe or Galileo Galilei. Electronic imaging and digital data processing has driven the astrophysics as a field forward during the 20$^{\mathrm{th}}$ and 21$^{\mathrm{st}}$ centuries, and the relevant technologies today include f.e. quantum optic photonic devices.

A clear framework should be established for future technical collaboration to introduce new advanced bleeding edge technologies to the astronomical mainstream. NOT's flexible operating model, high level of modularity, and relative easy of access to the on-sky observing time make the telescope a valuable partner in technology demonstration programs with the final aim of adoption at the larger facilities. From the side of the NOT three things are required: *1.)* clearer communication on availability of such programs, *2.)* details on how observing time and technical assistance at the telescope is paid and allocated for, and *3.)* clearer technical documentation on how to interface with the telescope. All of these are relatively easily achievable goals.

4.4 Work package division and working groups

There has been discussion of structuring telescope tasks into work packages. This effort should be re-visited to allow clear organization of future documentation and to clarify the nominal responsible contact points for projects. Additionally, working groups on imaging, polarimetry, high and low-res spectroscopy should be re-introduced to keep in touch with the user base and follow their needs. The working groups have existed historically in the early years of the telescope but disappeared sometime between 2000 – 2010. The working groups could be aligned with the existing working groups related to f.e. ESO activities at the hosting universities or countries.

Suggestion for potential organization (*incomplete*).

- 1 Scientific organization
  - 1 WG – VIS imaging
  - 2 WG – VIS low-res spectroscopy
  - 3 WG – VIS hi-res spectroscopy
  - 4 WG – VIS polarimetry
  - 5 WG – NIR imaging
  - 6 WG – NIR low-res spectroscopy
- 2 Operations
  - 1 Schedules
  - 2 Maintenance
- 3 Telescope
  - 1 Telescope
  - 2 Adapter
  - 3 Rotator
- 4 Instrumentation
  - 1 ALFOSC
  - 2 FIES
  - 3 NOTCAM
  - 4 STANCAM
  - 5 NTE
  - 6 Visitor
- 5 Computing infra-structure
  - 1 Data
  - 2 Documentation
  - 3 Control
  - 4 User experience
  - 5 Web

5 Maintenance – necessary

Non-routine service items will be listed in this section. Rationale for the different items ranges from operational safety to guaranteeing extended period of operation. Several of the items are costly and require funding outside of the operations budget. The telescope is operated on a large amount of legacy hardware which replacement with limited man power and financial resources takes a long time. The items in this section are listed in an approximate order of priority. The listed work effort and the cost are approximate and not based on actual quotes. The order of magnitude in the cost and effort can be expected to be reasonable. The gut estimated costs are fixed to 2025 and inflation corrections should be applied if the projects will be pursued in the future. The given deadlines are estimates when the given project should be accomplished to guarantee continuous uninterrupted operation given the number of spare components and their expected remaining life time.

5.1 TCS CPU and OS upgrade

Depends:	–
Priority:	*Critical*
Complexity:	*Very high*
Hardware cost:	*< 15 kEUR*
Effort:	*1 - 2 FTE*
Deadline:	*< 5 yr*
Status:	*In progress*

Firstly, it should be noted that the telescope standard maintenance and several of the potential upgrade projects depend on the replacing the TCS CPU and operating system (OS) to a more developer friendly platform. At the same time it should be very much appreciated that the current TCS works extremely reliably, its source code is practically fully debugged, and it is not an easy task to deliver a system with the same level of quality.

The spare status of the different electronic sub-system of the TCS is still reasonably good. The system is guaranteed to be maintainable for a number of years with the existing spare stock. Replacing the TCS CPU requires extensive planning and testing to ensure a smooth transition without affecting the normal telescope operation. This type of transition has been achieved before by the original system developer Ingvar Svärdh, but with a smaller generational leap in the CPU and the operating system architecture, and more available technical support staff at the telescope. Also, the earlier and current systems have utilized the same communcation interface, VMEbus, which has become deprecated since. VMEbus migration is further covered in the Sec. 5.2.

Currently, the TCS runs on a Motorola 68k -series CPU which communicates with the rest of the control electronics over a VMEbus. The TCS runs on a real-time operating system called OS-9. OS-9 is closed source, it is not supported by its original developer, and does have limited documentation available. It has several of its own quirks and is fundamentally different from Linux making any new software development under OS-9 a challenge. OS-9 is significantly more primitive than modern Linux kernel based operating systems. The new CPU should implement the ARMv8 -instruction set to guarantee extended future lifetime (similar to processors in Raspberry Pi boards and large amount of industrial controllers). The operating system should be Debian flavored Linux to align it with the rest of the NOT computer systems. The TCS CPU modernizatin is the single most important technical upgrade at the NOT since several other TCS related hardware changes depend on the possibility to modify TCS source code in a safe manner.

The first step in the TCS CPU upgrade and OS transition process is to compile the original TCS C-source code for a Linux kernel. This is a step already achieved by Sergio Armas and Ingvar Svärdh. A Single-Board Computer (SBC) has been purchased and setup to run the TCS code. The SBC with a modern ARM CPU has been able to run the TCS software correctly without any I/O devices connected in a simulation mode. In order to communicate with the rest of the control system, the SBC needs to be able to read and write on the VMEbus. This is a stage which is still yet to be demonstrated. Sergio Armas and Joonas Viuho have been able to write to the bus, but correct read-write communication has not been established yet.

5.2 TCS – I/O from VME to Ethernet/EtherCAT

Depends:	*TCS CPU and OS upgrade*
Priority:	*Critical*
Complexity:	*Very high*
Hardware cost:	*200 - 300 kEUR*
Effort:	*3 - 4 FTE*
Deadline:	*< 7 yr*
Status:	*Not started*

After the TCS CPU has been replaced and the operating system has been upgraded to a modern Linux, a larger amount of network I/O will be available. As a consequence, the TCS I/O can moved from the VMEBus to standard Ethernet/EtherCAT network interface. Both Ethernet/EtherCAT based solution can be implement on standard network equipment that the NOT staff is already familiar with. Running VMEbus and EtherCAT in parallel allows migration of one control sub-system at a time from VMEbus to EtherCAT, eventually leading to retirement of the VMEbus. Retiring the VMEbus will also lead to retiring the entire strapfields (*loads of wiring*) connecting the main TCS rack, *'condor nest'*, and the *'eagle nest'* at the observing floor, greatly simplifying the control system. Finally, the TCS will operate in their own private network. By the end of this project, a large majority of the telescope control electronics will be replaced, making the project expensive. Possibly, Mercator and the ING telescopes can offer inspiration on their component selection since they have gone through similar transition lately. Accomplishing the project would allow easier future maintenance of the telescope control system by removing the dependency on the legacy system, and allow replenishing the spare stock.

5.3 Auto-guider camera replacement

Depends:	*TCS CPU and OS upgrade*
Priority:	*Critical*
Complexity:	*Medium/High*
Hardware cost:	*∼10 kEUR*
Effort:	*1 FTE*
Deadline:	*< 5 yr*
Status:	*Not started*

The current auto-guider camera is an old CCTV intensified CCD (ICCD), analog TV setup, and a VME frame-grabber card. The ICCD streams video directly to the left hand side TV in the control room. A frame-grabber reads the image data for TCS which processes its and draws it back with the added guide-boxes on the right-hand side TV. The video output from the camera is analog TV signal and is transmitted via coax-cable to the control room. While a spare frame-grabber and spare camera exist, the system is old and complicated to service, and the spare ICCD has worse noise performance than the operational one. Servicing the system relies on availability of legacy hardware and understanding legacy protocols. As such the system is not attractive to maintain and deserves a replacement as soon as possible.

Two obstacles prevent immediate replacement of the auto-guider system: *1.)* The ICCD is in the direct telescope focus, *2.)* alteration of the TCS source code is required. The first problem is optical: the ICCD has >20 μm pixels to match the telescope plate scale, and such large pixels have not been available on commercial detectors for a long time. Currently, the typical pixel size for a similar camera is 3-6 μm. Adapting such a camera requires optical design and installation of a focal reducing fore-optics for the auto-guider camera. The second point relates mostly to risk since any new development under OS-9 which is haphazard.

Depending on the exact way of implementation and available funding, the auto-guider replacement can be divided into several phases. Implementation of a focal reducer to match a modern chip pixel scale can be separated from the rest of the project. Performance can be demonstrated in the telescope Cassegrain focus as a visitor instrument on a technical night. Ideally the TCS CPU and OS have been replacement before the replacement of the auto-guider.

5.4 STANCAM replacement

Depends:	–
Priority:	*High*
Complexity:	*Low (Medium with focal reducer)*
Hardware cost:	*~60 kEUR (+ 10 kEUR focal reducer)*
Effort:	*0.2 FTE* (+ 0.2 FTE focal reducer)
Deadline:	*< 3 yr*
Status:	*Started, report written on replacement candidates in 2022*

STANCAM is an always available standby CCD camera mounted on a folded Cassegrain focus. Its operation is critical for FIES target acquisition and fiber guiding. Additionally, STANCAM is used for VIS photometry by ToO and monitoring programs when ALFOSC is not available at the telescope (i.e. NOTCAM or visitor instrument mounted). STANCAM uses a BIAS (**RD5**) detector control system which as a system should be urgently retired. Very limited spares and no technical experience exists for servicing the BIAS system. By modern standards the 1k $\times$ 1k Tektronix TK1024A -CCD has a low QE, and for guiding purposes very slow readout (full frame without binning takes 43 s readout). Apart from the large pixel size finding a replacement is not difficult. STANCAM has 24 $\mu\mathrm{m}$ to match the telescope plate scale, a pixel size that is no longer available in modern detectors. The new STANCAM could be combined with a focal reducer to convert the telescope plate scale to match the smaller pixels of modern detectors (~10-15 $\mu\mathrm{m}$ typical for scientific grade detectors). A focal reducer would make it easier to provide the current $3'\times3'$ field-of-view of STANCAM easier and also more cost effective (smaller area detector).

The upgrade can be divided into two phases, the first involving direct replacement of the detector, and the second adding the focal reducer. With direct swap-in replacement with a typical currently available scientific CCD, the STANCAM on-sky area would reduce to $1.2'\times1.2'$ until the focal reducer is introduced. NOT's capabilities could be easily extended by always available fast photometry, speckle imaging, and enhanced U band imaging if STANCAM is replaced with an up-to-date camera offering >100 fps readout speeds. Alternatively, instead of using a filter exchanger and single detector, a multi-color dichroic based instrument could be envisaged to be placed at the STANCAM position.

5.5 PLC replacement – Upper and lower hatch + STANCAM filter exchanger

Depends:	–
Priority:	*Critical*
Complexity:	*Medium*
Hardware cost:	*∼6 kEUR*
Effort:	*0.3 FTE*
Deadline:	*< 3 yr*
Status:	*Not started*

The dome hatches and STANCAM filter exchanger are operated by Festo FBC-101-B -PLCs. While extremely reliable and robust, the PLCs are several decades old. Their functioning being critical for the telescope operations, their urgent replacement should be considered. The PLCs require an occasional intervention using a Windows 98 based laptop running a DOS emulator. Currently a single spare FBC-101C exists. The PLCs could be replaced with more recent similar devices allowing the old laptop and the associated programming equipment to be retired, replenishing the spare stock, and ensuring safe and reliable operation long into the future.

5.6 Refurbish / replace operation critical part of the TMS

Depends:	–
Priority:	*High*
Complexity:	*Medium*
Hardware cost:	*< 2 kEUR*
Effort:	*0.2 FTE*
Deadline:	*Immediately*
Status:	*Not started*

Temperature Monitoring System (TMS) is used for monitoring temperature at telescope building. The temperature values recorded by the TMS are stored in a database. The data is used for example monitoring the detector temperature, and it provides operationally critical temperatures (f.e. electronics room temperature, NOTCam compressor cooling water temperature) which are also used feeding NOT's alert system. Additionally, the TMS data is used for telescope automatic focus correction. A significant fraction of the TMS system has failed (see Sec.7.8), and only acquiring operation critical data has been maintained. The operation critical part of the TMS should be replaced even though the whole system could not be replaced (Sec. 7.8). New temperature sensors and controllers should be purchased, calibrated, and fitted on the telescope. A new database digestion interface should be developed for the new sensors.

5.7 Replace Danica TPS19sm PSUs

Depends:	–
Priority:	*Critical*
Complexity:	*Medium*
Hardware cost:	*<5 kEUR*
Effort:	*0.3 FTE*
Deadline:	*< 2 yr*
Status:	*Started – prototype developed*

TCS uses several Danica TPS19sm -type power supplies (PSU). These power supplies are not necessarily designed for their rated continuous power output, and especially in case of the rotator interlock PSU, the copper tracks on the Printed Circuit Board (PCB) burn after a certain amount of operating hours. Further, some of the key components in the PSU get damaged over time. So far, the PSUs have been repaired to keep them in operation (f.e. burnt tracks have been replaced with jump wires, damaged components replaced). Since the power supplies are critical for the telescope use, and they are not electronically very complicated, a replacement PSU should be designed with higher heat resistance and wider copper tracks. Spare repaired PSUs still exist but the stock needs replenishing soon. Instead of fixing the old damaged PSUs, 'new' PSUs should be design and built around an improved PCB design. An improved prototype has been partially made but need to be further iterated on in the course of 2026.

5.8 New weather station

Depends:	–
Priority:	*Critical*
Complexity:	*Medium*
Hardware cost:	*∼10 kEUR*
Effort:	*0.5 FTE*
Deadline:	*Immediately*
Status:	*Not started*

Weather data is critical for the TCS. TCS directly monitors the weather data and auto-closes the telescope in case it is not closed by the observer in adverse weather conditions. Additionally, TCS keeps the observer informed about the weather conditions and the telescope pointing limitations. Currently, two weather stations are used in parallel (*'old'* and *'new'* weather stations), and their data is vetted against each other. The old station from early 1990s and while it has spare boards, only a single EPROM with the microprocessor code exists. The *'old'* weather station has more reliable rain sensor than the new one which is the main reason for operating the stations in parallel. At minimum, the microprocessor board should be replaced, and a new control software developed. A spare system based on an Arduino Nano -microprocessor board has been prepared, but never installed and tested on the station. Any replaced weather station should be run in parallel with the old weather station for a duration of several months to provide a dataset that can be used for cross-calibrating the two stations.

6 Maintenance – highly recommended

Non-routine services items that may not need to be acted on immediately are listed here. While these projects of a lower priority that the items listed in the previous section, their execution should be strongly considered.

6.1 Migration away from the CCD3 system

Depends:	*NTE delivery (partially)*
Priority:	*High*
Complexity:	*Low (outsourced)*
Hardware cost:	*>120 kEUR*
Effort:	*0.5 FTE*
Deadline:	*<5 yr*
Status:	*Not started*

CCD3 -CCD controller system is developed at the Niels Bohr Institute (NBI) and it has been left without technical support since 2018 when the detector engineers supporting the system were laid off. Currently, the NOT staff is able to replace damaged parts of the CCD3 system with the existing spare components. It is not possible to replenish spare stock any longer and the life time of the CCD3 system depends on the currently available spares. Modifying the PCB designs to function with more recent Field-Programmable Gate Arrays (FPGAs) is beyond the current capabilities of the NOT staff, and in practice would prompt design of an entirely new CCD controller.

Replacement of the controllers could be tied to a detector upgrade. All detector controllers should be replaced at the same time, and the NTE detector choices should be kept in mind to avoid multiple detector systems to allow spare components to be shared between instruments. The current CCD are from 2016 and while still competitive, the detector field has moved forward. For example, notable advancements in the development of so called *'Skipper'* CCDs (f.e. **RD13, RD14**) have been made recently. While the earlier Skippers were slow to readout, their latest variation Multi-Amplifier Sensing (MAS) CCD (**RD15**) (multiple Skipper outputs in a series) offers single electron sensitivity with no penalty on dynamic range in less than 10 minutes, making the an ideal detector choice for photon starved spectroscopy.

6.2 Alt-Az drive PI board refurbish / software implementation

Depends:	*None (hardware implementation) / TCS CPU and OS upgrade (software implementation)*
Priority:	*High*
Complexity:	*High*
Hardware cost:	*<5 kEUR*
Effort:	*0.5 FTE*
Deadline:	*<7 yr*
Status:	*Started – prototype developed, pending live testing*

The telescope altitude and azimuth drives amplifiers have been upgraded some years ago, and sufficient quantity of spare amplifiers exists. However, the telescope drive frequency response is conditioned by PI boards implementing a 'Wilson' frequency response. This drive profile is probably fine tuned specifically for the telescope, and is crucial f.e. for correct tracking and slewing. The PI boards in operation are still original. NOT's now retired electronics engineer Graham Cox has designed a replacement system for the PI boards. The replacement boards have not been tested on the telescope under operating conditions. *LTspice* -software simulation results in the exact drive profile indicated by the original telescope documentation. Operational testing is critical before the replacement system can be concluded to be in a ready state. The replacement may require further PID loop optimization on the side of TCS. This may imply additional testing and analysis of telescope tracking after the PI board replacement.

6.3 Rotator drive power amplifiers refurbish

Depends:	–
Priority:	*High*
Complexity:	*Medium*
Hardware cost:	*<5 kEUR*
Effort:	*0.5 FTE*
Deadline:	*<5 yr*
Status:	*Started – replacement system in testing*

Telescope rotator is still driven with the original Inland DCM1-7014 -amplifiers, and the only existing spare was used a few years back. A new spare system has been developed around Maxon ESCON 70/10 -servo controllers which offers similar functionality as the original amplifiers. ESCON 70/10 is rated at a lower output power than the original amplifiers, but the rated 14 A output of the original amplifiers is not utilized by the TCS. The rotator has been driven by the new amplifiers in a test, but the tracking oscillated which indicated that further PID optimization is required. Further bench top optimization will be continued before the next tests on the telescope, and final integration on the amplifier rack. The project and its status is described in **RD10**.

6.4 Guide probe power amplifiers refurbish

Depends:	–
Priority:	*High*
Complexity:	*Medium*
Hardware cost:	*< 5 kEUR*
Effort:	*0.3 FTE*
Deadline:	*< 5 yr*
Status:	*Started – prototype developed, not tested*

The auto-guider probe linear stage is also driven by its original amplifiers. There are no direct replacement spares. Development of a spare system has been started by NOT's now retired electronic engineer Graham Cox. It is not totally clear if the existing schematic diagrams describe the actual amplifiers that are in operation, and their PCB design has to be cross-checked against the operational boards themselves. The amplifier boards are installed in a difficult to access location, and inspecting the boards itself is a major operation. After the layout of the boards is confirmed, the design of the replacement spare system can be continued and completed.

6.5 Telescope and adapter 3D CAD

Depends:	–
Priority:	*Medium*
Complexity:	*Low*
Hardware cost:	*∼3 kEUR*
Effort:	*0.3 FTE*
Deadline:	–
Status:	*Not started*

As a part of the general digitization effort of the telescope technical documentation, the original mechanical drawings on paper will need to be scanned. Further, the scanned drawings should be traced to vector graphic format with both the text and the dimensions recognized, to allow potential conversion to a CAD compatible file format. This could eventually lead to creation of a full 3D CAD model of the telescope, which would otherwise require too much labour. If a stage where correctly digitized drawings can be read with software such as AutoCAD is reached, it is relatively effortless to continue to 3D modeling the parts. This allows relatively easy and quick way to create a detailed 3D model of the telescope, and would be especially relevant for the instrument adapter. The availability of 3D CAD model of the adapter. Similar projects have been previously done using deep learning (**RD12**).

6.6 Dome cleaning / surface treatment

Depends:	–
Priority:	*Medium*
Complexity:	*Low*
Hardware cost:	*∼5-10 kEUR*
Effort:	*0.3 FTE*
Deadline:	–
Status:	*Not started*

The NOT dome outer shell is made of plane aluminum profile. The material choice has been due to its low weight, high reflectance, and reasonable emissivity. The aluminum surface reflects the sunlight during the day time functioning as a passive cooling system. Over the years the dome surface has stained and oxidized. The stained dome reflects less solar radiation and consequently strains the dome refrigerator especially during the summer season. The dome aluminum panels should be either re-polished and/or cleaned to save on energy cost and allow the telescope to stay closer to the projected night time temperature during the summer months. Available treatment methods should be investigated. A crane needs to be hired for the work and the labor should be outsourced. ***The dome should not be painted***.

6.7 Service building maintenance

Depends:	–
Priority:	*High*
Complexity:	*Low (outsourced)*
Hardware cost:	*∼15 kEUR*
Effort:	*0.1 FTE*
Deadline:	*$<$ 2 yr*
Status:	*Not started*

The service building needs a basic service including fixing cracks on the mortar and repainting to ensure that the building remains in good condition for the years to come.

6.8 Building rail inspection

Depends:	–
Priority:	*High*
Complexity:	*Low (outsourced)*
Hardware cost:	*∼3 kEUR*
Effort:	*0.1 FTE*
Deadline:	*< 2 yr*
Status:	*Not started*

An external party should be consulted on the wear of the building rail and the building drive wheels. Significant wear has been observed on the rail and the wheels and there are peculiarities in the wear-down. A potential reason for the peculiar non-even wear has been identified and further inspection by an expert would be of interest.

7 Maintenance/development – regained or added performance

This section includes projects that either enhance or re-establish the capacities of the telescope, but are not a requirement for the minimum level of operation. The suggested upgrades enhance the overall photon collection efficiency of the telescope and the performance of its instrument suite, which allows NOT to remain the top performer in its class and continue competing with larger telescopes in terms of scientific output.

7.1 Preparation for NTE delivery and acceptance

Depends:	*NTE delivery*
Priority:	*High*
Complexity:	*High*
Hardware cost:	*∼10 kEUR (excl. cleanroom, Sec. 7.9)*
Effort:	*1.5–2 FTE (partially outsourced, outside NOT staff expertise)*
Deadline:	*<5 yr*
Status:	*Not started*

After commissioning NTE is supposed to replaced the current NOT instruments ALFOSC and NOTCAM since it combines their functionality into a single instrument. The added functionality brings also added mass to the instrument adapter. The total mass of NTE is ∼800 kg while ALFOSC and NOTCAM weight 250 kg and 450 kg respectively. Together with the NTE lifting arm and additional ∼200 kg of counterweight required on the telescope top ring, the total load on the altitude and azimuth drives will increase approximately by 1 ton. The added mass on the top ring will cause the telescope tube trusses to sag more which in turn affects the M2 active altitude correction. The added mass on the center section will cause a slight tilt of M1. These changes will have an implication on the telescope optics, and altitude and azimuth drive servo loops. Ideally, the effect of these changes are studied before delivery of NTE. TAdded mass changes the telescope moment of intertia. Moment of intertia affects the altitude and azimuth control servo loops, and the eigenfrequency of the telescope structure. It is prudent to test the telescope behaviour with the added mass and carry out more detailed structural analysis of the telescope to understand the effect on optics, and measure the needed altitude correction with the additional counterweights. In order to do this, the NTE lifting arm needs to be delivered to the ORM. In addition to the servo loop analysis, any potential NTE cryo-cooler vibration induced image quality degradation could be studied.

7.2 Re-establish wavefront sensing capabilities

Depends:	–
Priority:	*Medium*
Complexity:	*Medium*
Hardware cost:	*–kEUR*
Effort:	*0.5 FTE*
Deadline:	–
Status:	*Not started*

If the telescope automatic focus correction is kept spot on (see Sec.5.6) the telescope image quality and sensitivity under good natural seeing conditions is limited by the M1 shape. At the moment, there is no proper way to sense the shape of the M1 during nightly operation. The hardware needed for Korhonen-Hartmann wave-front sensing (**RD2**, **RD3**) exist on the site. However, an up-to-date analysis software is lacking. Old BASIC and IDL codes exist for reference to write a modern alternative. Availability of a wave-front sensor would allow studying the M1 dynamics and identify mechanical failures of the M1 support at an earlier stage. A proper wave-front sensor is also required for assessing the potential for beam steering or Adaptive Optics (AO) at NOT. Wave-front sensor sensor system can be also used for training students in AO, which importance to astrophysics as a field will continue increase in the Extremely Large Telescope (ELT) era. AO has also applications in the industry, including open air optical telecommunication, f.e. orbital up- and down-linking, and semi-conductor manufacturing.

7.3 Tip-tilt correction (beam steering)

Depends:	*Adapter 2.0*
Priority:	*Low*
Complexity:	*High*
Hardware cost:	*50 kEUR*
Effort:	*1 - 3 FTE*
Deadline:	–
Status:	*Not started*

Most of the effects of the atmospheric turbulence can be seen in the lowest order wave-front error terms. Correcting for the tip-tilt of the incoming wave-front allows *'stabilization'* of the image: point source centroid remains at the same location (the image will still swell and change shape, effects of the higher order terms). Correcting the lowest order wave-front errors will already greatly improve the telescope image quality and sensitivity (see f.e. **RD8**). A low-order beam steering system is possible to materialize in terms of a fast tilting flat glass plate, which desired orientation is sensed with a high temporal cadence camera system. Similar system has been previously demonstrated at NOT in an instrument called HIRAC (**RD9**). HIRAC suffered from insufficient piezo actuator system damaging its control boards. Piezo technology has greatly improved since the mid-90's, and alternative viable technologies such as variable reluctance actuators (**RD16**) are available today. Depending on the available space in the adapter, tip-tilt corrector could be realized as a standalone unit to be utilized by all NOT instruments significantly enhancing the sensitivity of the instrument suite (**RD8**). Improving the encircled energy figure in a sky noise limited case practically compares to increasing the M1 size, and a reliable tip-tilt corrector unit is the most efficient means of improving the telescope overall performance. Such an upgrade would increase the spectroscopic follow up potential to fainter Legacy Survey of Space and Time (LSST) triggers than what is currently possible.

7.4 Higher order AO correction

Depends:	*Auto-guider camera replacement, Adapter 2.0*
Priority:	–
Complexity:	*Very high*
Hardware cost:	*>1.5 MEUR*
Effort:	*> 7 FTE*
Deadline:	–
Status:	*Not started*

To improve on the optical performance achievable by beam steering, a true AO system would need to be implemented. Adaptive secondary mirrors have already been introduced to mid-size telescopes with excellent results (**RD17**). An international collaboration working on adaptive secondary mirror units using TNO variable reluctance actuators exists (**RD17**), and joing it would be an attractive option for the NOT. NOT's top unit has a relatively large mass budget available for an adaptive M2. The volume and distance along the optical axis are more limited, but the top unit spider can be adjusted to allow more distance along the optical axis. Provided that a new guiding system would be able to wave-front sense, the adaptive M2 would already build on the other upgrades. Adaptive M2 offers higher order correction than the beam steering only, consequently resulting to better optical performance and sensitivity gains for all instruments (**RD8**). Adaptive M2 could be used in 'tip-tilt' mode where only the low-order errors are corrected with high frequency, while passively correcting for the M1 shape. Adaptive M2 could be also used for deforming an outgoing beam for use with orbital telecommunication (reverse AO - sense the atmospheric turbulence, deform the beam at transmit, receive a small sized optical spot on the orbit). In addition to the performance gains for 'classical' instrumentation, the higher, the higher Strehl ratios achieved by the AO allow more efficient coupling with Photonic Integrated Circuits (PICs) (**RD18**). Operating a 2.5-meter telescope at, or close to, its diffraction limit is significantly easier than a 8 – 10-meter class telescope. Adaptive M2 would make NOT an attractive test bed for future photonic instruments before introduction at larger facilities.

7.5 Common mode polarimetry unit

Depends:	*NTE delivery*
Priority:	*High*
Complexity:	*Medium*
Hardware cost:	*∼200 kEUR (NB! VIS only, extended wavelength range with added cost)*
Effort:	*1 FTE*
Deadline:	*0.5 yr before NTE delivery*
Status:	*Not started*

NTE does not offer imaging polarimetry, and folded Cassegrain focii can not be used for high-precision polarimetry. To maintain on-deman imaging polarimetry at the NOT for ToO and monitoring programs, a new polarimetry unit is needed. A common mode polarimetric unit available for the full instrument suite can be placed higher up in the telescope beam in order not to mechanically interfere with the rest of the telescope systems. The placement forces a purchase of large waveplates and retarder which are expensive. This would allow using STANCAM, ALFOSC, NOTCAM, and NTE for imaging polarimetry given that the polarizer components cover the required wavelength range. For practical reasons, the wavelength range may need to be limited to the VIS only, or multiple sets of optical components are required for the extended wavelength range. Sufficiently dimensioned components should be available for purchase in the VIS wavelength range, see f.e. VLT/FORS.

7.6 Adapter 2.0

Depends:	*TCS CPU and OS upgrade*
Priority:	*Medium*
Complexity:	*High*
Hardware cost:	*>100 kEUR*
Effort:	*3 – 4 FTE*
Deadline:	–
Status:	*Not started*

There is a general need to refurbish some of the older control electronics in the instrument adapter (Sec. 5.3, 5.4, 5.5, and 6.4). Also, the instrument adapter hosts equipment that is no longer used. Especially if new beam steering, AO or polarimetric systems are considered, it would be a suitable time to reconsider the functions and internal organization of the instrument adapter. A white paper should be written regarding the potential use cases and functions of the instrument adapter, finally leading to rebuilding or refurbishing the instrument adapter. At the moment, the adapter has very limited space for installing new hardware. Description of original adapter and its functionality is described in **RD11**. Complexity of the instrument adapter approaches that of an instrument, and the refurbish can be expected to be a major effort. TCS CPU and operating system upgrade should be completed first.

7.7 Alt-Az tachometers to encoders

Depends:	–
Priority:	*Medium*
Complexity:	*High*
Hardware cost:	*∼10 kEUR*
Effort:	*1 FTE*
Deadline:	–
Status:	*Started – prototype tested, no software integration with TCS*

When tracking (telescope moving at low speed), the tachometer output voltage is extremely low and it can be expected that the altitude and azimuth servo-loops either do not correct the tracking rates based on the tachometer feedback, or the correction is based on noise. Changing tachometers to encoders will increase the precision of the tracking rates, especially, when tracking slowly. F.e. recently, a retrograde orbit asteroid was observed and significant oscillating tracking errors were seen. This type of rare observations could be carried more effectively if the tachometers would be replaced by digital encoders. The encoder output can be used for calculating the tracking speed with significantly higher precision than what the tachometers can provide. A pilot project with partial success has been performed. A test digital encoder was installed on the telescope azimuth motor, and the telescope has successfully tracked with the encoder. However, the TCS code for encoder tracking has been only partially implemented, and no extensive testing have been carried out. It should be note that other facilities, such as the ESO VLTs use encoders (**RD4**).

7.8 Refurbish TMS system in addition to the critical components

Depends:	–
Priority:	*Medium*
Complexity:	*Medium*
Hardware cost:	*∼5 kEUR*
Effort:	*0.5 - 1 FTE*
Deadline:	–
Status:	*Not started*

Temperature Monitoring System (TMS) is used for monitoring temperature at telescope building, and its database interface is used for all temperature sensors at the site including f.e. the service and FIES buildings. Sensors in the TMS are combined with microprocessors such that the resistive temperature measurement and digitization can be done at the location of the temperature sensor. The data is transmitted digitally to a central controller unit which will further communicate it to the database. The telescope building's TMS system consist of three central units of which two have failed (TMS ranges 1xx and 3xx). While the TMS itself is not mission critical, some of the temperature readings are, since they are used for monitoring temperature of critical systems and used for automated alerts and control (i.e. electronics room temperature, telescope focus temperature). The data is useful for daily operations and long-term monitoring and should be recorded if possible and the measurements should be re-established when possible. Commercial-of-the-shelf products and systems can be used.

7.9 New cleanroom facility

Depends:	–
Priority:	*Medium*
Complexity:	*Low*
Hardware cost:	*∼20 – 30 kEUR*
Effort:	*0.1 FTE*
Deadline:	*0.5 yr before NTE*
Status:	*Not started*

The current clean room is not fit and large enough to open NTE after its delivery. The cleanroom facility should be upgrade to facilitate NTE service before NTE is delivered. The existing cleanroom room is of sufficient size for opening and servicing NOTCAM. However, the room is not exactly clean and having a downflow cabinet for detector work would be advantageous. Space for a new cleanroom installation has been envisaged from the current workshop area. The reorganization may require moving soft walls. The cleanroom could consist of two parts: a permanent smaller section with a down flow cabinet, and a larger extendable 'tent' that is large enough to host NTE together with its lifting and transport tools.

7.10 Increased FIES throughput

Depends:	–
Priority:	*High*
Complexity:	*Low*
Hardware cost:	*<1 kEUR*
Effort:	*0 FTE*
Deadline:	–
Status:	*Started*

Over the past decade, FIES efficiency has been traded for radial-velocity stability. Recently, FIES efficiency has been improved by introducing UV optimized silver coatings for its collimator and folding mirrors in 2021. An easy increase in efficiency is to introduce refractive index matching gel to all of the fiber junctions. Possible stress on the fibers hanging in the cathedral would be reduced, leading to less f-ratio degradation, and consequently less losses on the first collimator.

7.11 FIES etalon for normal operation

Depends:	–
Priority:	*Medium*
Complexity:	*High*
Hardware cost:	*< 6 kEUR low stability, or > 50 kEUR high stability*
Effort:	*0.5 – 1 FTE*
Deadline:	–
Status:	*Not started*

Future availability of the ThAr lamps is uncertain. Due to toxicity of Thorium, manufacturing of Thorium lamps has ceased in Europe, and the purchase of ThAr lamps is only available via Australian or Chinese vendors. Especially recently, there has been large variance in the lamp quality. A potential risk is that ThAr lamp supply will eventually cease or importing them will be forbidden. Introducing an etalon based wave calibration system for FIES would allow the ThAr lamps to be powered less often, thus providing longer life time for the current spare lamps stock (projected to last for two years). Cheap etalon could be sufficient for low accuracy Radial Velocity (RV) work and normal observation. Discussion have been had of acquiring a high RV stability vacuum etalons. An option seems to be available but it is associated with higher cost.

7.12 Make a Nasmyth focus available

Depends:	–
Priority:	*Low*
Complexity:	*High*
Hardware cost:	*∼15 kEUR*
Effort:	*– FTE*
Deadline:	–
Status:	*Not started*

NOT has feedthroughs through both of its altitude bearings. Currently, one of them is used for cabling, while the other is used for M1 cooling air. The M1 cooling air hose feed could be modified to allow for an optical feed to a Nasmyth station for light weight instruments. No optical or mechanical setup for the Nasmyth focus exist at the moment, but installation is technically feasible. A pickup mirror installation is needed within the M1 baffle assembly and the telescope fork will need re-balancing.

7.13 NOTCAM added capabilities

Depends:	*NTE delivery*
Priority:	*Low*
Complexity:	*Medium*
Hardware cost:	*∼10 kEUR*
Effort:	*0.3 FTE*
Deadline:	–
Status:	*Not started*

Current NOTCAM Z and Y bandpass filters perform poorly due to off-band leaks. Higher sensitivity Z and Y imaging filters could be purchased for NOTCAM to extend its usable wavelength range to bluer bandpasses. Z and Y bandpass filters are expected to be needed for NTE, and they could be procured in advance for use in NOTCam before NTE delivery and commissioning. Additionally, low resolution R∼100 prism spectroscopy mode similar to TNG/DOLORES could be introduced. It is an low cost upgrade and can be implemented with short timescale. Lower spectral resolution means less well defined fringes, a factor historically affecting popularity of NOTCAM spectroscopy, and the mode would open up new potential use cases, such as, characterization of Solar system minor bodies with broad NIR–SWIR absorption features.

7.14 NOTCAM migrate from BIAS

Depends:	*NTE delivery*
Priority:	*Low*
Complexity:	*High*
Hardware cost:	*~50 kEUR (if technically feasible)*
Effort:	*0.3 FTE*
Deadline:	–
Status:	*Not started*

If NTE is expected to arrive soon, it is hardly reasonable to upgrade NOTCAM detector system although that would provide a significant performance upgrade. Acquiring a MPIA IR detector controller (**RD07**) similar to the ones in NTE would already increase performance and remove reliance on the BIAS controller (**RD5**). NTE uses MPIA IR controller for its 2k x 2k SWIR imaging and spectroscopic detectors. If MPIA has ready/easily implementable configuration for PACE-1 Hawaii (**RD6**) arrays, this might be interesting upgrade path which could be used as NTE spares in the future. It should be noted that NOTCAM PACE-1 -array is electrically different from the later generation Hawaii arrays. If the larger 2k x 2k H2RG detectors were to be installed in the NOTCAM focal plane, only a quarter of the sensor area would be illuminated. Use of NTE controllers with NOTCAM has been suggested previously[8], and need for a controller upgrade has been argued for already a long time ago (**RD19**).

[8] https://www.not.iac.es/instruments/notcam/stc-talk-aad15.pdf

7.15 Replace staircase sensor with a LIDAR

Depends:	–
Priority:	*Low*
Complexity:	*Medium*
Hardware cost:	*5 kEUR*
Effort:	*1 FTE*
Deadline:	–
Status:	–

Currently, the building staircase collisions are prevented by a laser 'trip-wire'. This system could be upgraded with a camera and LIDAR system similar to current LIDAR modules used in new cars. In addition to the stop feature, the object in vicinity of the staircase could be programmatically recognized, solving the mystery of unexplainable building alarms! LIDARs transmit light. Depending on the amount and direction of the emitted light, considerations regarding light pollution may need to be made.

8 Conclusions

Despite of its age NOT remains a highly productive facility. The excellent optical and opto-mechanical quality, flexible scheduling, reliability, and ease of access make the telescope attractive to operate for long into the future. Its performance should be maintained and enhanced over the coming years. Maintaining the impressively low technical downtime requires investment in the telescope infrastructure. The aging systems should be modernized one by one in the order of recommended priority. Many of the upgrades depend on replacing the TCS CPU and operating system, which is the single most important technical change for the near future. Several of the potential performance upgrades and enhancements depend on general upgrades on the instrument adapter, of which modernization should be discussed with the broader community. The modernization efforts will ensure class leading performance guaranteeing highly efficient scientific output, and open up new opportunities for the telescope to remain competitive in the ELT era.

This document has provided a description of the current technical status and suggested urgent and less urgent upgrades to the telescope infrastructure. Overall, the upgrade path is complex, depends on careful planning, and requires deep understanding of the current and the future control system. To carry out the upgrades on the side of normal daily operation is a major undertaking for the telescope, and can be expected to progress slowly with the current staffing. To ensure progress at relevant time scales, the hosting institutes together with their partners should prepare to contribute to the development effort to ensure the competitiveness of the telescope.

The listing of the development projects in this document is by no means exhaustive and additional development projects and ideas exist at the time of writing. The listing has been constrained to what is considered to be achievable during the coming decade and have the highest impact on the overall scientific performance of the telesecope.

List of contents for spare component inventory is available from the author on request, as well as, suggestions, feedback, and documentation on how to pursue the suggested projects.

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