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Revision History		
Revision	**Name**	**Comments**
1.0	I. Steele	Initial Version
1.2	I. Steele	Version for internal review
2.0	I. Steele	Released Version
3.0	I. Steele / H. Jermak	Updates to sciReq:instruments:no, sciReq:massspace and updates to sciReq:polclen as per NRT_CR9.
4.0	É. Harvey	Added new spectrograph throughput requirement – sciReq:specthru as per NRT_CR10.
5.0	H. Jermak	Update to science requirements following descope discussion

List of Abbreviations

SC	Science Case
SR	Science Requirement(s)
CR	Change Request
PSF	Point Spread Function
IFU	Integral Field Unit
NRT	New Robotic Telescope
LT	Liverpool Telescope
WHT	William Herschel Telescope
TCS	Telescope Control System

Contents

1 Reference Documents

RD	Title	Code
RD01	NRT Science Case	NRT-LJM-SCI-RS-1
RD02	NRT Phase A Review	NRT-LJM-MNG-RP-3

2 Document Overview

This document is one of the top-level "Foundation Documents" that define the New Robotic Telescope project. The scope of each document is as follows:

- The Science Case Document (NRT-LJMU-SCI-RS-1) provides a summary description of the scientific questions the telescope science team have identified in time domain astrophysics that the telescope aims to address.
- The Operations Concept Document (NRT-LJM-ENG-RS-2) expresses the stakeholders' intentions for the telescope. It provides a high-level summary of the project organization, site constraints and scientific and technical operational plans.
- The Science Requirements Document (NRT-LJM-SCI-RS-2) provides a set of high-level science requirements of the telescope and observatory that are informed by the Science Case and the Operations Concept.
- The System Level Requirements Document (NRT-LJM-ENG-RS-3) contains top level engineering requirements for the telescope and observatory necessary to deliver the Science Requirements and Operations Concept.

3 Introduction

The NRT Science requirements (SR) are derived from the summary science case (SC) documented in NRT-LJM-SCI-RS-1. The science case and these derived requirements were reviewed in the Phase A Design study and are presented here for information.

It should be noted that additional opportunities will arise over the lifetime of this telescope due to the discovery of new classes of astronomical object, through the construction of new discovery and feeder facilities, and through advances in detector technology. An obvious historic example is the case of Gamma-ray bursts. This has been one of the most scientifically productive areas of astronomy for the Liverpool Telescope but was unforeseen when the science case was written. When developing the science requirements, it is important therefore that the telescope has the flexibility to address future challenges.

Some of these requirements derive from the intention to maximally exploit the advantages offered by the robotic nature of the telescope. In most cases a minimum (base) and target requirement is presented. For each requirement we provide a description of the requirement, the science drivers that impact the requirement, and a justification for the base and target figures.

4 Science Requirements (SR)

4.1 Collecting Area – SciReq:aperture

Alias	SciReq:aperture	
Description	Primary Mirror collecting area	
Base Requirement	8 metres^2 (Effective area)	
Target Requirement	11 metres ^{2} (Effective area)	
Date	**Author**	**Change Description (CR ref)**
25/04/2025	HEJ	Changed base requirement from 4π metres^2 to 8 metres ^{2} and target requirement from none to 11 metres ^{2}. This accounts for the ~4 metre class diameter requirement (and segment shape) and also allows for a potential descope *if significantly cost reducing*.

Description
The collecting area of the telescope is defined as the area of the primary mirror. It is presented as effective area to account for segment shape and maintain the 4 metre class designation. This value takes into account any central aperture or the secondary mirror obscuration. The base requirement of 8 metres ^{2} is equivalent to ~2.8xLT's collecting area and the target requirement of 11 metres ^{2} is equivalent to ~3.6xLT's collecting area (accounting for edges).

Science Drivers
All science cases can benefit from a greater collecting area which provides higher signal-to-noise values and increased efficiency through reduced exposure times. For many time domain science cases, such as gamma-ray bursts, exoplanet transits, and gravitational wave counterpart follow-up, the larger aperture enables better temporal sampling of rapidly evolving events.

Justification
The project is to build a 4m class telescope; approximately two times as large in diameter as the 2m Liverpool Telescope, with about four times the collecting area. The 4m class definition is large enough to meet the scientific goals and is covered by both the base and target requirements. Figure 1 of the Science Case (RD01) demonstrates the significant improvement in sensitivity that results from an increase from 2- to 4-m aperture, especially for spectroscopy. Moving from (for example) 4-m to 6-m, does not result in as significant gains in sensitivity. A 4-m baseline specification therefore represents a “sweet spot” in aperture. While a target requirement could have been expressed as to have as large a collecting area as possible, this would have significant cost, slew speed and mass implications throughout the project. We simply note therefore that this parameter should be maximised when there is an opportunity in the design process to do so at no cost.

4.2 Wavelength Range – SciReq:wavelength

Alias	SciReq:wavelength
Description	Wavelength Range
Base Requirement	0.35-> 2.0um at all focal stations
Target Requirement	0.30-> 2.4um at 2 or more focal stations

Date	**Author**	**Change Description (CR ref)**

Description
The optical design of the telescope will allow instruments to make use of the wavelength range defined in the requirements. The Point Spread Function (PSF) of sources across the field will meet image quality requirements at these wavelengths. Thermal emissivity of the telescope structure at longer wavelengths is discussed separately in SciReq:emissivity.

Science Drivers
The science cases will be informed by observations from the near-ultraviolet to the near-infrared, although the visible (BVRI) range is more important than the extremes. Shorter wavelength observations are particularly important for sources such as novae, kilonovae, blazars and comets. Longer wavelengths provide scope to pursue more highly redshifted extragalactic transients such as supernovae and GRB afterglows.

Justification
As a minimum the telescope should be designed for observations from the B-band to H-band, which is a common range for ground based optical telescopes. The target is to cover a useful scientific range from U-band to K-band, stretching the flexibility of the telescope to accommodate instruments optimised for these wavelengths.

4.3 Field of View Diameter - SciReq:fov

Alias	SciReq:fov
Description	Field of View Diameter
Base Requirement	10 arcmin diameter
Target Requirement	14 arcmin diameter

Date	**Author**	**Change Description (CR ref)**
25/4/2025	HEJ	Changed base requirement to 10 arcmin and target to 14 arcmin; removing wide field (~30 arcmin) capability due to descope discussions. Removed discussion about corrected or uncorrected FoV as it is not relevant for this requirement.

Description
The field of view is the diameter of the circular area on the focal plane for which there is less than 10% vignetting and the diffraction limited PSF specifications are maintained.

Science Drivers
The science case for the telescope is built around single object follow-up, and so there is no requirement for a very large field of view. Nonetheless for imaging there are science cases where a larger field of view is required. One example is the follow-up of poorly localised transients, specifically for GRB follow-up. The Burst Alert Telescope (BAT) on SWIFT has a 2σ error circle of 3 arcmin (90% confidence),

however the successor SVOM observatory is expected to have 10 arcmin error circle (https://tinyurl.com/4et3je6x). These inform the base requirement. Another example is exoplanet studies which make use of high precision, short exposure imaging. Here the target is commonly very bright, and a wider field of view allows for a greater number of brighter comparison stars in the field for photometric calibration.

A large field of view also benefits spectroscopic observations. If the field is too small then acquisition onto a long slit is complicated by the lack of stars with which to determine the world coordinate system for an acquisition image. Some long-slit spectroscopy science programmes (for example exoplanet transit spectroscopy) require a slit long enough to cover both the target and a bright comparison star.

Justification
For accurate photometry using comparison field stars for calibration, the 14 arcminute field at worst case (pointing at Galactic pole) should have on average 1 star of V=12 and 20 stars with V=16. The target requirement will provide scope for future larger field instruments (which will fill the resource gap left by the introduction of the WEAVE instrument to the WHT).

4.4 Sky Access - SciReq:skyaccess

Alias	SciReq:skyaccess	
Description	Sky Access	
Base Requirement	Full sky down to 20deg above horizon, <2deg Zenith blind spot	
Target Requirement	Full sky down to horizon <1deg zenith blind spot	
Date	**Author**	**Change Description (CR ref)**

Description
Sky access is defined here as the ability of the telescope to point to and track the whole sky between the limits given in the requirements. There should be no additional obscuration from the telescope enclosure or NRT buildings.

Science Drivers
For time-critical, target-of-opportunity science it is often necessary to observe a target as soon as it is visible, with airmass a secondary consideration. Increased sky access also provides a greater overlap with the footprints of Southern surveys such as LSST, and all-sky gravitational wave or space-based detectors. With increased sky access, monitoring programmes can run for longer, and individual, continuous observations (such as an exoplanet transits) can last longer.

Justification
Astronomical observations are typically made above 30° elevation, equating to an airmass of <2. A 20° elevation limit will allow observations up to an airmass of 3. A limit lower than 20° would be beneficial for the occasional observation, but the impact of very high airmasses means it is unlikely to be used routinely. Note also that the topology of the mountain and other structures will not allow full horizon access across the entire azimuth range, even if this is within the capability of the telescope and enclosure.

4.5 Blind Pointing Accuracy - SciReq:pointingblind

Alias	SciReq:pointingblind	
Description	Blind Pointing Accuracy	
Base Requirement	5 arcsec RMS at all focal stations	
Target Requirement	3 arcsec RMS at all focal stations	
Date	**Author**	**Change Description (CR ref)**

Description
The blind pointing accuracy is the difference between actual and requested tracking position after a slew command between any two pointings. The error budget is expected to be shared between:
• Axis control accuracy
• Astrometric calculation accuracy
• Pointing model accuracy
• Non-repeatability of any mechanical deformation uncorrected by pointing model.

Science Drivers
For high-speed, spectroscopic follow-up of localised transient sources (GW counterparts, GRB afterglows, supernovae), the blind pointing accuracy is important so that targets can be acquired directly onto small field instruments, such as Integral Field Unit (IFU) Spectrographs, without the requirement of acquisition imaging using a wider field imager. During monitoring programmes, a repeatable field position for the science and calibration sources is also beneficial.

Justification
The base requirement is informed by improving on current LT pointing accuracy which is better than 10 arcsec RMS. The target requirement allows for direct acquisition on future instrumentation with small fields of view. For example, an image slicing IFU spectrograph being designed for the telescope is expected to have a field of ~ 5 × 8 arcsec in size.

4.6 Offset Pointing Precision - SciReq:pointingfield

Alias	SciReq:pointingfield	
Description	Offset Pointing Precision	
Base Requirement	0.3 arcseconds RMS	
Target Requirement	0.1 arcseconds RMS	
Date	**Author**	**Change Description (CR ref)**

Description
The offset pointing precision is the difference between actual and requested offset whilst tracking a single field. These values should be valid for offsets up to 10 arcmin.

Science Drivers
All science cases benefit from high offset pointing precision. The NRT's science case necessitates many spectroscopic observations where the precise position of the source with respect to the slit is imperative, particularly with time-critical observations.

Justification
For the NRT science cases, the spectrograph slit width will generally be similar to the FWHM seeing, allowing maximal resolution whilst not compromising throughput. The requirements are chosen with this in mind. The telescope should be capable of 0.3 arcsec RMS accuracy in offsets up to 10 arcmin with a target of 0.1 arcsec RMS. For efficiency these offsets should be quick to execute. The provision of a hexapod tip-tilt mechanism for the secondary mirror should afford this opportunity.

4.7 Image Quality - SciReq:iq

Alias	SciReq:iq	
Description	Image Quality	
Base Requirement	< 0.3 arcsec deterioration at 80% EE	
Target Requirement	< 0.2 arcsec deterioration at 80% EE	
Date	**Author**	**Change Description (CR ref)**
25/4/2025	HEJ	For descoping reasons the base requirement has been reduced to <0.3 arcsec and target to <0.2 arcsec.

Description
The NRT will be a natural seeing-limited telescope. The telescope optics, drives, enclosure and structure should not degrade the natural site seeing by more than the requirement across the full operating wavelength range. This requirement shall apply for 99% of cases across the full field of view. The engineering considerations that will share the budget are anticipated to be:

• Optical manufacturing quality
• Structural alignment and support of optical elements
• Induced turbulence from the structure and enclosure known as ‘Dome seeing’
• Tracking performance of the telescope with autoguider

Science Drivers
All science cases will benefit from improved image quality. Better signal-to-noise improves the scientific quality of data and allows for greater operational efficiency.

Justification
The telescope should be seeing limited. The median 80% EE seeing value in La Palma is between 1.25 arcsec and 1.50 arcsec across the optical wavelength range. Our aim is that the degradation is approximately ~15-25% of this value.

4.8 Focal Plane Geometry - SciReq:fpg

Alias	SciReq:fpg	
Description	Focal Plane Geometry	
Base Requirement	between f/5 and f/12	
Target Requirement	n/a	
Date	**Author**	**Change Description (CR ref)**
25/4/2025	HEJ	**Base requirement changed to between f/5 and f/12 following descoping discussion although we anticipate this will not be required**

Description
The focal plane geometry is affected primarily by the focal ratio. This will impact the specifications of instrument field lenses, instrument pixel size for well-sampled PSFs and the field curvature on larger field instruments.

Science Drivers
The NRT will be a flexible telescope for emerging science cases in the field of transient astronomy. A major success of the LT group has been to rapidly produce small, innovative instruments for specific science projects (i.e. the RINGO series of polarimeters for GRB afterglow studies). The final focal ratio of the telescope should be slow enough to accommodate simple instrumentation without the need for re-imaging optics capable of handling a fast input beam. This will also apply to the uncorrected pixel scale, to allow adequately sampled PSFs with common detector pixel sizes. By providing a similar field curvature as the LT, instruments can easily be moved from one telescope to the other.

Justification

The telescope focal length should be between 20-m (corresponding to ~f/5) and 50-m (~f/12), yielding a plate scale of between 102 and 244 microns per arcsec. This will ensure that that the best seeing PSFs (0.5 arcsec FWHM) are not undersampled with detector pixels 35 microns in size. This is much larger than current CCD and CMOS technology, however it is anticipated that future detectors (e.g. MKIDS) may have larger pixels, especially in their early incarnations.

The focal ratio should be faster than f/12 to ensure the telescope plate scale does not become unfeasibly large and therefore require extreme image demagnification in the reimaging optics to achieve reasonable image sampling.

4.9 Polarisation Cleanliness - SciReq:polclen

Alias	SciReq:polclen	
Description	Polarisation Cleanliness	
Base Requirement	<%5 induced with <0.5% RMS stability at one instrument port	
Target Requirement	<%1 induced with <0.1% RMS stability at one instrument port	
Date	**Author**	**Change Description (CR ref)**
17/12/2021	IAS	Minor update to description to add all timescales (NRT_CR9)

Description
Polarisation cleanliness is a measure of the induced linear polarisation by the telescope optics, including the tertiary (science fold) mirror. The value should be met across the full operational wavelength range and over all timescales with appropriate calibration observations. The values of induced linear polarisation and variability can be modelled in any optical design, taking account of deformation and non-alignments of the mirrors. However, in operation the value will be affected by the aluminisation process, coatings and the stability by the cleanliness of the optical surfaces over time.

Science Drivers
Polarimetry is a core component of the LT instrumental suite and similarly, polarimetric capabilities are required on the NRT to address a variety of different science cases. Synchrotron emission processes in GRBs and blazars imprint a polarisation signature at optical wavelengths which can serve as a probe of magnetic field structures within the jets. Sensitive polarimetric measurements are an important tool to study poorly understood time-domain phenomena such as Tabby's Star, along with other potentially dusty environments.

Justification
Polarimetric operations on the LT show that instrumental polarisation of up to 5% is inevitable when a 45-degree tertiary mirror is used; this is necessary with the current LT instrumental configuration and will be considered in the NRT instrumentation configuration. The target requirement given here could only be met if the polarimeter was mounted on a straight-through Cassegrain port. Stability of the induced polarisation is important in detecting significant polarisation changes in sources, which are often noise limited.

4.10 Emissivity - SciReq:emissivity

Alias	SciReq:emissivity	
Description	Emissivity	
Base Requirement	Minimisation of near infrared background is a design consideration	
Target Requirement	Aspects of the telescope will be designed to minimise NIR background while not compromising optical performance.	
Date	**Author**	**Change Description (CR ref)**

Description
For near-infrared observations in the J and H bands, the emissivity of the primary and secondary mirror aluminium coating is to be ~0.03. This means they will emit ~3% of the radiation that a perfect black body would at the given mirror temperature and that they will absorb the same proportion of flux. This background is unavoidable using aluminised mirrors. However, radiation from the thermal blackbody

signature from the telescope structure such as the secondary mirror vanes, baffles, segmented mirror structures, and other mechanisms in the optical path, will further contribute to the background in these bands.

Science Drivers

The ability to observe at longer wavelengths enables the pursuit of targets at higher redshifts, as well as intrinsically red objects. To maximise signal-to-noise at these wavelengths the thermal emission of the telescope should be minimised where possible through design of the structure and/or baffling.

Justification

There are scientific arguments to optimise the design of the telescope for both visible and infrared observations. The visible (BVRI) range is the scientific priority for the telescope, and performance at these wavelengths must not be compromised. However, a telescope optimised for visible observations (through secondary mirror size and baffle design) can still provide adequate performance in the infrared. The requirement here is that appropriate design decisions are made to ensure infrared performance is not unnecessarily compromised.

4.11 Non-Sidereal Tracking - SciReq:nonsidereal

Alias	SciReq:nonsidereal	
Description	Non-Sidereal Tracking	
Base Requirement	Non-sidereal tracking will be available	
Target Requirement	Non-sidereal tracking will be available with autoguiding to track a target to better than 0.2 arcsec over one hour moving at up to 15 arcsec/sec	
Date	**Author**	**Change Description (CR ref)**

Description

Non-sidereal tracking is the ability to track a vector on the sky for sources which do not have fixed position within a field during the time frame of an exposure. These objects include Solar System bodies such as asteroids or comets, and satellites. Mechanically, non-sidereal tracking will change the zenith blind spot size, and in this mode the zenith blind spot requirements do not need to be met.

Science Drivers

The ability to track non-sidereally is a requirement for Solar System science. NEOs (Near Earth Objects) can have high non-sidereal rates of ~ 10 arcsec/sec.

Justification

Non-sidereal tracking is a required, but not commonly used, feature. Here we place no constraints beyond baseline availability on the open loop (non-guided) accuracy of tracking. Our target is to develop an autoguiding system with dynamic source selection, which will enable use while tracking non-sidereally. The figure of 15 arcsec/sec is to enable tracking of geostationary satellites, but will be fast enough for the vast majority of NEOs.

4.12 Time to Target - SciReq:slewtime

Alias	SciReq:slewtime	
Description	Time to Target	
Base Requirement	<45-60s (95th percentile)	
Target Requirement	<30s (95th percentile)	
Date	**Author**	**Change Description (CR ref)**
		Target requirement changed to 30 seconds, base 45-60 seconds, although with the stipulation that this should only be adopted if there is a *significant* reduction to cost.

Description
Time to target is specified as the time taken from the issuing of the TCS command to the time of starting an exposure. This includes the telescope blind pointing time, mirror settling time, and any necessary mechanical movement of the enclosure. This time does not include any additional acquisition overhead (such as offsets to place a star on a spectrograph slit) or the time required to lock the autoguider although these also should be minimized (e.g. though the use of a tip-tilt secondary mirror to allow rapid offsetting). We specify this number as a 95th percentile, i.e. it is allowable for up to 5% of times to target to be outside the requirement.

Science Drivers
Time to target is a core scientific requirement of the NRT. Rapid follow-up of transient events will be a unique feature of the NRT, expanding on the successes of the LT in probing early time jet physics of GRBs, which require observations in the first minutes of an event trigger. The NRT will be a unique instrument for transients, able to observe the parameter space within the first minute of target identification.

Justification
Slew speeds of 10°/s are now possible with large telescopes. A maximum slew of 180° (disregarding cable unwraps) on azimuth will take around 20s of acceleration, movement and deceleration to complete. Structure settling times for similar telescopes are on the order of 2-5 seconds on top of this.

4.13 Instrument Change Time - SciReq:instrumentchange

Alias	SciReq:instrumentchange	
Description	Instrument Change Time	
Base Requirement	<10s (95th percentile)	
Target Requirement	<5s (95th percentile)	
Date	**Author**	**Change Description (CR ref)**

Description
The instrument change time is the time it takes to switch the light path from one instrument port to another port at a given focal station (Cassegrain or potential future Nasmyth). We specify this number as a 95th percentile, i.e. it is allowable for up to 5% of times to be outside the requirement. This time will need to be met by the following processes occurring in parallel:

• Retraction, deployment and/or rotation of a science fold mirror in an A&G box mounted at Cassegrain or Nasmyth focus.
• Z-axis movement of M2 to provide correct focus for the instrument selected.

Science Drivers
The instrument change time should be minimised so that it does not become the limiting factor in transient follow-up, especially in the case of short slews. Once a target is acquired, observation sequences involving multiple instruments will be more time efficient and allow higher sampling frequencies of observations.

Justification
Instrument change times should be invisible in the normal schedule operation of the telescope, not adding any extra time to operations as it will occur in parallel with other limiting operations. A 10s change time will enable this and is an achievable target given current actuator technologies.

4.14 Number of Instruments - SciReq:instruments:no

Alias	SciReq:instruments:no	
Description	Number of Instruments	
Base Requirement	7 instruments simultaneously mounted at focal station instrument ports (including up to 2 non-science instruments such as WFS)	
Target Requirement	No target requirement	
Date	**Author**	**Change Description (CR ref)**
15/12/2021	DC	Added clarification to base requirement and justification text update - NRT_CR9

Description
This figure is the number of instruments that can be simultaneously mounted and selected for observation within the time overhead defined in SciReq:instrumentchange. This number informs the payload of the telescope, the focal stations used, and the supply of necessary power, data and pneumatics.

Science Drivers
For long term monitoring and transient response science cases the telescope requires multiple instruments to be permanently mounted; the autonomous and robotic nature of the telescopes means that there will not be technical staff available to change instrumentation manually. The current LT instrument suite and the diversity of the NRT science case gives an indication of the range of capabilities which are required by the community.

Justification
The minimum requirement is 5 instrument ports available for an optical imager, NIR imager, polarimeter, spectrograph and fast readout imager. To allow a wider range and greater availability for visitor and prototype instruments, 7 ports is the base requirement. This could be achieved for example with an hexagonal A&G unit in a Cassegrain only configuration with 6 side ports and one straight through port.

4.15 Compatibility with LT - SciReq:ltcompatibility

Alias	SciReq:ltcompatibility	
Description	Compatibility with LT	
Base Requirement	No base requirement (if cost reduction is significant)	
Target Requirement	The NRT will fully support all instruments which are currently in use on the LT.	
Date	**Author**	**Change Description (CR ref)**
25/4/2025	HEJ	Removal of base requirement if cost reduction is significant

Description
The compatibility of instruments between the LT and NRT will depend on the mounting. The backfocal distance of the NRT (distance between mounting face and focal point) should be longer than on the LT, to allow instruments to be mounted with the addition of a spacer or adapter. Ideally the optical design will provide the same focal plane geometry as the LT, allowing movement of instruments with minimal change in field size and pixel scale.

Science Drivers
The ability to move instruments between the LT and NRT increases the flexibility of the combined observatory to react to changes in demand for specific observations. Compatible mounting and the same focal plane geometry means that some new instrumentation could be tested or commissioned on the LT before being transferred to the NRT.

Justification
As a minimum the possibility should exist for instruments developed initially for the LT to be mounted and used on the NRT, perhaps with small modifications to the field optics. The ideal situation is to have the same focal plane geometry as LT allowing full compatibility, however it is understood that this requirement may not be met due to other technical and cost constraints.

4.16 First Light Instruments - SciReq:firstlight

Alias	SciReq:firstlight	
Description	First Light Instruments	
Base Requirement	Visible imager, spectrograph, high speed imager	
Target Requirement	Visible imager, spectrograph, high speed imager, imaging polarimeter, infrared imager	
Date	**Author**	**Change Description (CR ref)**

Description
The ideal situation is for a new specific instrument suite to be available for NRT first light, however, there is mitigation to reuse the LT imaging and polarimetry instrumentation. At first light the following instruments baseline functionality is required. It may be that a single instrument can deliver more than one function.

- A visible wavelength imager which has a field of view of >5 arcmin with standard filter wheel set.

- A single object spectrograph with low dispersion across the visible wavelength range.
- A high-speed imager capable of exposures of 10-100ms, single or multi-band in the visible.

As a target we also aim to provide

- An imaging polarimeter, single or multi-band, in the visible range.
- A near infrared imaging camera

Science Drivers
The first light instruments are required to provide the greatest flexibility (i.e. not too specific) whilst also being suitable for the primary science drivers of the telescope. The instruments listed above will support the early rapid follow-up observations in imaging and spectroscopy of new transient sources from surveys. The high-speed imager will be an important calibration tool during commissioning.

Justification
The first light instruments are chosen for verification of the telescope's performance and to enable the widest possible scientific observations to be undertaken, with minimal outlay, during the first semesters of operation. If SciReq:compatibility is met then there is the possibility to use existing LT instruments for early operations.

4.17 Instrument Size and Mass - SciReq:massspace

Alias	SciReq:massspace	
Description	Instrument Size and Mass	
Base Requirement	Side port instruments of 0.72x0.72x0.9m with a mass up to 120kg Straight through port instrument of 1.4x1.4x1.0m with a mass up to 120kg Total focal station instrument mass shall not exceed 560kg. This includes non-science instruments mounted at instrument ports.	
Target Requirement	Side port instruments of 0.72x0.72x1.5m with a mass up to 120kg Straight through port instrument of 1.4x1.4x1.8m with a mass up to 120kg Total focal station instrument mass shall not exceed 560kg. This includes non-science instruments mounted at instrument ports.	
Date	**Author**	**Change Description (CR ref)**
15/12/2021	DC	Updates and clarification of dimensions and mass requirements NRT_CR9
25/4/2025	HEJ	Reduced side port instrument length limit from 1.5m to 0.9m and straight through port instrument length from 1.8m to 1.0m as per descope discussions and moved original base requirement to target requirement.

Description
The size and mass of instruments is to be considered in the mass budgets and mechanical designs of the telescope. The telescope will need to meet all slew speed and image quality requirements (SciReq:slewtime, SciReq:iq) with this payload of instruments for the numbers of instruments specified in SciReq:instruments:no.

Science Drivers
Sizes and masses are specific to the instrument type and design but must include all instrument components. Cryostats and cooling systems for large field instruments can be large and heavy. Spectrograph light paths can often be on the order of a metre or more, and it is common for spectrographs to have 2 arms, requiring two light paths and two cryostats.

Justification
The base requirement here is loose. It is not expected that each instrument port will enable or be limited to the base requirement. However, a design assumption should be that every instrument port can be simultaneously occupied by an instrument of the mass and size specified in the base requirement. The target requirement is a firm upper limit for one instrument and should be met with all the other ports simultaneously populated with instruments which meet the base requirement.

4.18 Visitor Instruments - SciReq:visitor

Alias	SciReq:visitor	
Description	Visitor Instruments	
Base Requirement	Visitor instruments will be permitted on the telescope	
Target Requirement	One port will be permanently available for visitor instruments	
Date	**Author**	**Change Description (CR ref)**

Description
Visitor instruments are instruments that are designed and constructed by a third party. They may not have been specifically designed for the NRT and do not form a part of the core instrumentation suite but may be hosted by the telescope for a period, usually with a specific scientific goal in mind.

Science Drivers
There are multiple science cases that could be explored with the NRT using visitor instrumentation, particularly as budgetary and time constraints may not allow as broad an instrumentation suite as desired by users. For this reason, it is scientifically important to allow for visitor instrumentation at the NRT. This is not something that has ever been introduced at the LT, as instrumentation is typically developed with users for their science cases, but will be a capability for the NRT.

Justification
The NRT robotic observation model is incompatible with the classical model of visitor instrumentation, where several nights are exclusively booked on a facility for on-site user mode usage of the instrument. However, there is an obvious science benefit to providing access to novel instrumentation from other groups. Longer-term (at least a full semester) visitor instrumentation will therefore be welcomed, providing they can be integrated into the robotic scheduler and control system. Visitor instruments would need to be available to other science users while mounted. It is highly unlikely that service (non-robotic) observation modes would be offered with visitor instruments.

The target is that a focal station will be left permanently available for visitor instrumentation, but this will depend on the total number of available focal stations (SciReq:instruments:no).

4.19 Tracking Accuracy - SciReq:tracking

Alias	SciReq:tracking	
Description	Tracking Accuracy	
Base Requirement	0.2 arcsec RMS	
Target Requirement	0.1 arcsec RMS	
Date	**Author**	**Change Description (CR ref)**

Description
The tracking accuracy is defined as the root mean squared value of offsets from the requested tracking position, over a specified time period. Tracking accuracy must be met for 3 minutes open loop and for 1 hour closed loop (with the autoguider). NOTE: The assigned values are preliminary estimates in line with achievable values from other 4m class facilities. This requirement affects SciReq:iq and will need to be modified once a budget breakdown is made between optical quality, structural deformations, instrumental requirements, which feed into the image quality requirement.

Science Drivers
All science cases benefit from accurate tracking to avoid degraded image quality caused by tracking errors. It is particularly important for those time-critical observations that cannot be repeated.

Justification
The figures presented here are preliminary values. A full breakdown of contributors to the optical image quality will be performed within budgets applied to these elements.

4.20 Autoguider Accuracy - SciReq:guided

Alias	SciReq:guided	
Description	Autoguider Accuracy	
Base Requirement	<0.1 arcsec RMS	
Target Requirement	<0.05 arcsecond RMS	
Date	**Author**	**Change Description (CR ref)**

Description
This requirement is an extension of SciReq:tracking to emphasise the importance of the autoguider system to deliver high image quality in long exposures.

Science Drivers
Autoguider-induced tracking errors can affect high-precision photometry where the aim is to keep the science target on the same pixel throughout a long (often several hours) sequence of exposures.

Autoguider induced tracking errors can also affect the point spread function of single long exposures, giving non-symmetrical PSFs that can affect count extraction from sources and image subtraction techniques for transient detection and host galaxy removal.

Justification
The baseline requirement would result in a PSF asymmetry of <20% of the FWHM in the best site seeing (0.5 arcsec GWHM). The target requirement improves this to <10%. The requirements are similar to

those achieved on other 4-m class telescopes and should therefore be technically feasible within the error budget. Contributions to the error budget for this quantity will include centroid accuracy, differential atmospheric refraction between the science and autoguider targets, and any flexure between the science instrument and autoguider focal planes.

4.21 Optical Throughput - SciReq:throughput

Alias	SciReq:throughput	
Description	Optical Throughput	
Base Requirement	> 70% throughput at straight through port. >60% throughput at side port.	
Target Requirement	>75% throughput at straight through port, >65% throughput at side port.	
Date	**Author**	**Change Description (CR ref)**
4 Jan 2022	EJH	Introduced with change request NRT_CR10
8 May 2025	IAS	Updated to make telescope rather than spectrograph throughput.

Description
This requirement describes the throughput needed for rapid classification of transients.

Science Drivers
Rapid spectroscopic classification of transients is a main science driver for the NRT.

Justification

An average reflectivity target of 85% per mirror surface is presumed achievable. This yields 0.85*0.85 = 72% at a straight through and 0.85*0.85*0.85 = 62% at the side port.

Spectroscopic classification is anticipated to comprise >40% of annual observations, which is equivalent to 800 hours per year. For 10,000 targets this gives 4.8 minutes per target, and allowing for overheads this gives 4 minutes spectroscopy exposure time per target. A signal to noise ratio of 10 is required for reliable classification. For a resolving power of 250, with an air-cooled DU 420A- BEX2-DDd, at -80 degrees C, sky magnitude of 22, atmospheric transmission of 80%, telescope throughput of 75%, spectrograph throughput of 35%, in 0.7" seeing for a 4 minute exposure gives an SNR of 10. For the same conditions a spectrograph throughput of 55% gives an SNR of 15.

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