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Revision	**Name**	**Comments**
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1.1	Iain Steele	Updates 20th Oct 2021
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2.0	Iain Steele	Release version
2.1	Iain Steele	Updated following PDR (13th Dec 2021)
2.2	Iain Steele	Minor updates to reflect project changes in last few years (22nd April 2025)

List of Abbreviations

IAC	Instituto de Astrofísica de Canarias
LJMU	Liverpool John Moores University
UoO	University of Oviedo
NRT	New Robotic Telescope
CMT	Carlsberg Meridian Telescope (Automatic Transit Circle)
ORM	Observatorio del Roque de Los Muchachos
LT	Liverpool Telescope
A&G	Acquistion and Guidance
CCI	International Scientific Committee
TSO	The Schools Observatory
PETeR	The Educational Project with Robotic Telescopes
STEM	Science, Technology, Engineering and Mathematics
GRB	Gamma Ray Burst
GW	Gravitational Wave

Contents

1 Introduction

1.1 System Overview

The general concept of operations for NRT is an extension of the successful model that has been in operation at the current 2.0m Liverpool robotic telescope (LT) on La Palma since 2004.

NRT will be a ~4m telescope with an Altitude-Azimuth design and Cassegrain optical layout giving an final focal ratio between f/7.5 and f12. This configuration leads to a reasonably compact design with a reasonable primary – secondary mirror separation that could fit within a commercial enclosure. The primary mirror will be segmented, with 18 segments. The segments will be used in a co-aligned manner but not phased. The wavelength range of the telescope will be 0.33 – 2µm. Axis slew speeds and accelerations will be such that a target on any location on the sky can be acquired in under 30 seconds.

The telescope will be unstaffed and operate robotically at the Observatorio del Roque de Los Muchachos, La Palma. It will use a fully opening clamshell enclosure to ensure all sky access down to a 20 degree altitude at all times.

A science operations centre will be based at the Astrophysics Research Institute in Liverpool, UK to provide user support and data archiving and distribution as well as coordinating operations and maintenance activities.

The science objectives of the telescope are based around rapid follow-up of targets of opportunity. Robotic telescopes are powerful tools for time-domain science. The main targets will include optical transients from new synoptic surveys such as ZTF, LSST (Rubin Observatory), the counterparts of gravitational wave sources discovered by the LIGO-Virgo Consortium, and gamma-ray bursts and other high-energy transients reported by new space missions such as SVOM and the Einstein Probe, and ground-based observatories such as CTA. Follow-up of transiting exoplanets is a core component of the science case of the current Liverpool Telescope, and we anticipate this will continue to be part of our programme.

To meet the science goals of the telescope a suite of instrumentation will be developed, all of which will be simultaneously mounted on the Cassegrain station. Our first light instrumentation will comprise a new low resolution optical spectrograph and a new fast-imaging optical camera. First light polarimetric and IR imaging capability will be provided by transfer of Liverpool Telescope instruments to NRT.

NRT will be delivered by a consortium of partners. Current partners are LJMU, IAC and the University of Oviedo.

1.2 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:

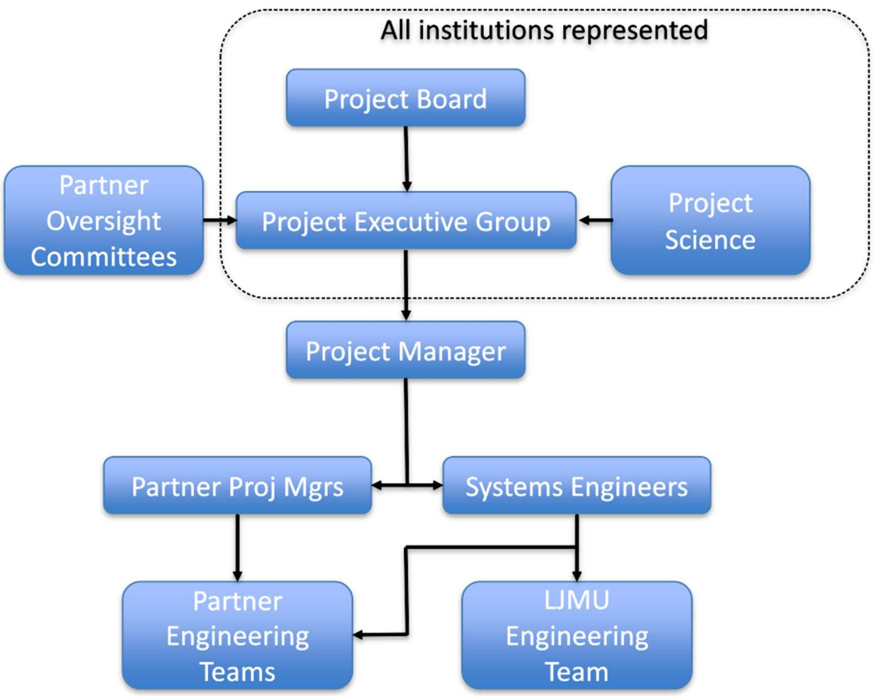
- The Science Case Document (NRT-LJMU-SCI-RS-1) provides a summary description of the scientific questions the telescope science team have identified in time domain astrophysics that the telescope aims to address.
- The Operations Concept Document (NRT-LJM-ENG-RS-2) expresses the stakeholders’ intentions 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.

1.3 NRT Stakeholders

1.3.1 Governing Body

NRT Project Board



A project board has been established. Membership of the Project Board is balanced across the funding representatives of the consortium participants and currently comprises senior representatives of LJMU, IAC and Oviedo. New project partners will be similarly entitled to representation on the Project Board. The board meets every 6 months and is charged with the following tasks:

- Supporting the development of a Consortium Agreement for the design phase, and approving any subsequent changes to the Agreement;
- Overseeing progress of the initial design phase of the NRT project against the programme plan, schedule and agreed milestones;
- Confirming priorities, resolving issues and providing advice as requested and required by the Project Executive Group;
- Approving major changes to specification, cost, schedule and science scope in the project;
- Acting as an interface to the ORM and advising the ORM and CCI on the NRT as part of wider strategic discussions concerning the ORM; and

- Advising the Project Executive Group on financial planning and funding matters, as required.

NRT Project Executive Group

The project executive group meets every 2 weeks. It consists of the overall project PI and local PIs from each institute, the Project Scientist, the Project Manager from each institute and the Systems Engineer from each institute. This group has the following tasks:

- To make day to day decisions regarding project execution and coordinate the activity of the different partners;
- To ensure delivery of the project in a cost-effective and timely manner;
- To provide checks and balances for the science, engineering and budget decisions made during the project;
- To develop plans such that the project has a positive lasting scientific, societal and industrial impact.

1.3.2 Education and Outreach Users

Robotic telescopes are powerful tools for societal and educational impact as all interactions with the telescope, from scheduling observations to obtaining data, are done remotely. This enables the same access to the telescope for educational and public users across the world as is enjoyed by the professional astronomical community.

The main vehicles for the societal impact of the NRT will be The Schools' Observatory (TSO) and the Proyecto Educativo con Telescopios Robóticos (PETeR). The TSO website currently receives 1.5 million visits per year, and to date there have been over 200,000 requests for Liverpool Telescope data from more than 3,500 schools. PETeR is an inquiry-based online laboratory that offers schools the possibility to carry out astronomical observations and research projects using professional robotic telescopes. It is open to the participation of the entire Spanish educational community from primary to secondary schools and vocational training. It is also open to schools from other countries through collaboration on specific projects with national schools. It currently has approximately 370 educational users, reaching about 12,000 students per year.

The NRT will significantly enhance the activities of TSO and PETeR. The new telescope will mean that much more observing time can be released on the existing LT for educational activity, and this will be coupled with the NRT time which will be used by the most motivated students, leading ambitious projects contributing to the scientific research programme of the telescope. There will also be the opportunity to engage with the public and schools during the development of the telescope reaching students in other STEM areas such as engineering and computer science. The latter is of particular interest since 'big data' and 'AI' challenges are key aspects of NRT. Such challenges are also well matched to 'crowdsourced' solutions and a citizen science programme would be a natural way to take these aspects outside of the classroom.

1.3.3 Scientific User Community

The user community will comprise astronomers from the partner institutes and in some cases wider national communities depending on local funding agreements. The current participation of STFC and IAC guarantees access to the whole UK and Spanish astronomical communities. Based on the current LT user base (564 unique-named PI and CoIs in the past 3 years), we anticipate a demand of over 1000 users for NRT over the first 3 years of full operations.

As well as traditional PI-led allocation, we propose to operate a public spectroscopic transient classification survey. This will classify ~10,000 objects per year and represents an increase of a factor of 5 over the current combined worldwide effort of all observatories (2,000/year).

1.3.4 Science Working Groups

Time domain science, by definition, is a rapidly evolving field, and a core goal of the NRT project is to maintain and increase the scientific flexibility, which is a feature of the LT. This drives the design requirements, for example a range of instrumentation will need to be simultaneously mounted at the Cassegrain focus. An example of the LT's flexibility is GRB science. The science case for the LT was written in the pre-Swift era, and so rapid response to GRB afterglows was not considered. However, it quickly became clear that this was an area well suited to exploitation by a robotic telescope, and our first rapid polarimeter, Ringo, was a simple instrument aimed at a particular, high-impact science goal, driven by user demands. In order to maintain the same level of strong communication between science users and observatory management, we will establish science working groups who act as liaisons for their science communities.

The NRT project has consulted with the time domain community throughout the design process and will continue to conduct a thorough consultation with future NRT users during the build and operational phases to ensure that the instrumentation can meet developing science requirements. The telescope design process consults the science requirements, and these are only edited or updated with approval from the NRT science team. Once the telescope design is finalised, any changes to science requirements can only be absorbed by the instrumentation plan (i.e. the overall telescope design will not change once the final design is approved).

The NRT science team have previously been advised by science-specific working groups along with a general overview science group in Spain. We have recruited existing LT and future NRT users to six core working groups:

- Supernovae
- Gamma Ray Bursts
- Tidal Disruption Events and AGN
- Stellar astrophysics
- Exoplanets and Solar System Bodies
- Multi-messenger counterparts

In addition, a general overview science group was been established in Spain under the leadership of the IAC to consult more widely with the Spanish Community. We will carry out bi-annual interactions with these groups, along with bespoke sessions for particular science areas where necessary. The groups have already discussed new areas of interest, feedback on topics such as instrument development, and are updated on details of the technical status of the observatory.

1.3.5 Observatory Staff

As a robotic facility, there shall be no science observatory staff on site except when the telescope or instruments are being commissioned. There shall be engineering staff on-site for a specified number of days per week, but this is unlikely to be every weekday and will be daytime only. Time on-site for maintenance purposes shall be reduced where possible.

1.3.6 User Roles

The NRT will support a range of users interacting both remotely and on-site. It is intended to be completely unstaffed during normal observing. This allows users to remotely observe and carry out research including those topics listed in the science case.

The various user groups are shown below with their expected access requirements which will be used to define data flow and observatory operation modes.

User Type	Description	Access Requirements
NSO Observer/Peter Programme	A pupil at a school who is signed up to either programme	• Simplified observation entry • Simplified data reduction tools
Observer	Remote observer who has been allocated telescope time by a Time Allocation Committee	• Observation entry • Access to raw and reduced Data • Support with observations
Science Support Staff	Remote support staff, who are responsible for general operations of the telescope and management of observations	• Observation database management • Telescope and weather state • Telescope operational metrics • Observer support system
Commissioning Staff	Staff, remote or on-site, who are installing and commissioning new instruments or systems.	• Manual observing access • Manual control of systems
Engineering Staff	Staff, remote or on-site, who are responsible for maintenance and repair of telescope systems.	• Manual control of systems

1.4 Future of the Liverpool Telescope and Joint NRT/LT operations

An options review was performed to study the relative costs and scientific productivity of maintaining or decommissioning the current LT once NRT was built. This review estimated that maintaining LT alongside NRT would increase the publication output of the NRT by ~50% (based on opportunities for dual facility observations) and that there were no particular cost savings associated with decommissioning LT. This is due to the high cost of removal from site that would be required under the CCI agreement and the fact that having two facilities doesn't mean there are double the costs as the team have ability to cost-share operations and maintenance staff between the two facilities. We therefore aim to maintain a simplified operation of the LT, with a single instrument, imaging facility to operate alongside NRT, supporting 4m NRT spectroscopy with complementary 2m imaging. Post NRT commissioning we plan to investigate extending the NRT scheduling model to LT so that the two facilities could operate as a "transient factory" with automated load-balancing or joint scheduling between the two telescopes.

1.5 Operations Funding

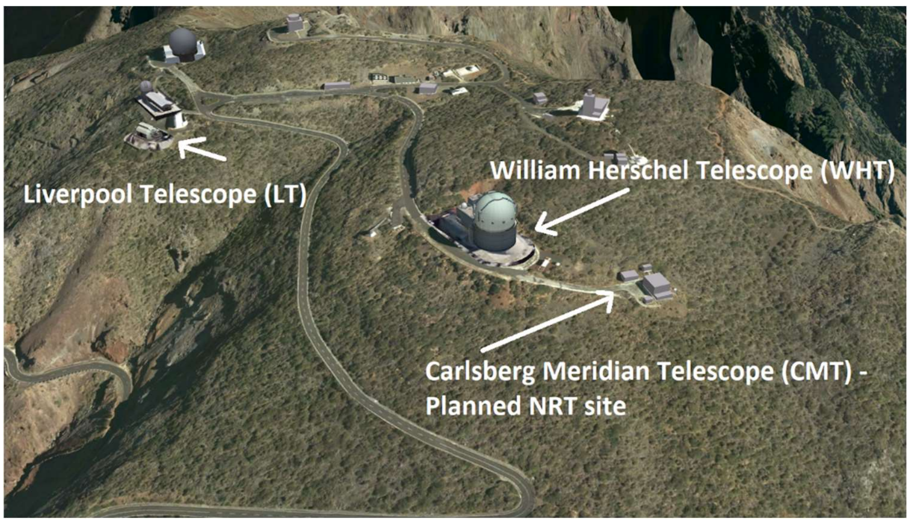
Operating costs will be assumed by the current and future partners of the NRT consortium; they may seek external contributions, for example, from research councils or individual or external consortium science teams. A contractual agreement will be signed specifying the details and the relative contribution(s) of each partner. This may be different to their level of contribution to the construction costs.

2 Facilities

2.1.1 NRT Site Facilities

The New Robotic Telescope will be constructed at the Carlsberg Meridian Telescope (CMT) site on the 'Observatorio del Roque de Los Muchachos' (ORM) in La Palma (Canary Islands, Spain). This site provides a good climate, enabling a high percentage of superb quality astronomical observing throughout the year. A site of this quality allows for obtaining the maximum return of science potential from this telescope.

The CMT site's nearest neighbour is the William Herschel Telescope (WHT) operated by ING. The CMT site is positioned to the Southwest of the WHT at a distance of approximately 75m. ORM also hosts the current 2m Liverpool Telescope at a distance of ~550m from the CMT.



There are plans in place to build the European Solar Telescope (EST) at ORM. The EST structure will be approximately 44 metres in height, and approval has been granted for the facility to be located at the site of the existing Dutch Optical Telescope (DOT). This is approximately 80 metres from the CMT site and will impact the NRT field of view to the east, southeast up to 28-30 degrees (with possible additional disruption due to seeing effects around the structure). The NRT science case is not severely impacted by this as it is still at relatively high air mass and obstructs just 0.07-0.08% of the NRT visible sky (which covers >20 degrees above the horizon).

Existing facilities at the CMT site include a double garage and mains electrical and computer networks.

The site offers excellent partner/host organizations in addition to the existing LJMU infrastructure provided by the existing Liverpool Telescope.

Use of the CMT site was approved by the CCI; the committee overseeing observatory developments at ORM, at their meeting on 14th October 2021.

2.1.2 Off-Site Facilities on the ORM

Off-site office facilities are available at sea level on La Palma (CALP). Use of this facility is not anticipated during the operations phase but may be beneficial during the construction for administrative activities.

2.1.3 LJMU Facilities

The Astrophysics Research Institute (ARI) at LJMU performs teaching and research in observational and theoretical astrophysics. The Technology Group within ARI provides the scientific, operations and maintenance team for the current Liverpool Telescope and carries out instrument development work for LT and other telescopes. Facilities available include an uncertified ISO Class 5 clean-room, a dark-room equipped with a telescope beam simulating optics, a server room and a small electronics and instrument assembly workshop.

2.1.4 IAC Facilities

Instituto de Astrofísica de Canarias (IAC) is a Spanish research centre that manages the Canary Islands' Observatories, and carries out astrophysics research and technological development projects.

The centre has a significant engineering team and technical staff, and facilities that enable the IAC to undertake forefront technological projects. The capabilities are focused on the fields of optical manufacturing, optomechanical design and integration, cryogenics and vacuum, precision mechanics, digital electronics, detector characterization, and development of software and control systems.

2.1.5 University of Oviedo Facilities

University of Oviedo hosts the Institute of Space Sciences and Technologies of Asturias (ICTEA). This is a multidisciplinary research institute at Universidad de Oviedo in the fields of Astronomy, Geology, Mathematics and Medicine. ICTEA is located at School of Mining, Energy and Materials Engineering of Oviedo. The centre has more than 25 teaching and research laboratories.

2.1.6 Site Environmental Conditions

Site Characteristics (Median values, unless stated)	ORM (Spain)
Altitude of site (m)	2325
Fraction of yearly Photometric usable time (%)	72
Seeing at 60m above ground (arcseconds)	0.7
Precipitation water vapour (% time $<$ 2mm)	$\geq$20
Mean nighttime temperature (°C)	7.6
Extinction (Vmag/airmass)	0.137

2.1.7 Operating Conditions

From reference document: NRT-LJM-ENG-TN-4

NRT Enclosure Operational Environmental Conditions	Value
Temperature range	-10^{o}C <= temp <= 30^{o}C
Humidity	0-90%
Pressure	500-1013mbar
Wind speed	The maximum sustained wind speed is 30km/hr with gusts up to 80km/hr

2.1.8 Environmental Monitoring

During safe operating conditions, environment monitoring will be used to facilitate the scheduling and efficient execution of observations that are approximately matched to environmental conditions. This is particularly crucial for an autonomous, robotic telescope. Environmental monitoring will be provided to enable real-time response to observing conditions. Monitoring will include, for example, measurements of temperature, pressure, humidity, precipitable water vapor, particulate count, atmospheric turbulence, and seeing. Scheduling and data simulation tools will be used to facilitate planning based on those measurements. In addition, tools and services will be used to forecast environmental conditions and further facilitate planning. Records will be kept of all environmental conditions measured to facilitate planning and analysis of the operations.

2.1.9 Seismic Requirements

The NRT will be designed and constructed anticipating seismic activity at the site. To meet the projects expectations regarding the operability and lifetime of the Observatory, the NRT will be able to withstand earthquakes that have a 50% or greater likelihood of yearly occurrence without impacting standard maintenance or servicing schedules. The NRT will also be designed and constructed to survive an earthquake that has more than a 10% likelihood of occurring within 50 years, such that it can be returned to full operation with spares and materials on-site. Allowable time and cost to repair associated with these events will be determined by the Project based on risk and cost assessment.

3 Scientific Performance

3.1 Image Quality

The objective spatial resolution requirements that enable the most demanding observations anticipated with NRT are discussed in detail in the Science Cases Analysis Document (Phase A – Science Case). The resulting requirements are summarized in the master requirements workbook. In addition to those requirements, the global efficiency and effectiveness of the Observatory will be impacted by the median image quality of the NRT, because the sensitivity of the NRT will be limited by image quality during background-limited observations; the required exposure times required to achieve a given signal to noise are inversely proportional to image quality. The expectations of our partnership for scientific productivity are therefore impacted by median image quality as much as by the best image quality. To guarantee the efficiency of the Observatory, the Observatory should not significantly degrade the atmospheric seeing by <0.2 arcseconds at 80% EE. Specifically, the following image quality performance will be delivered in median environmental conditions (e.g. temperature, temperature gradient, atmospheric pressure, and wind).

The NRT will be a seeing limited telescope. The telescope optics, drives, enclosure and structure should degrade the natural site seeing by less than the requirement across the full operating wavelength range. The engineering considerations that will share the budget are anticipated to be:

- Optical manufacturing quality;
- Structural alignment and support of optical elements, including the procedures for measuring, adjustment and maintenance of the mirror segments (active optics) and the secondary mirror via a hexapod;
- Induced turbulence from the structure and enclosure known as ‘Dome seeing’;
- Tracking performance of the telescope with autoguider.

3.2 Throughput Maintenance

NRT will maintain optical throughput at better than 85% of the theoretical maximum at all times. We will achieve this through a process of periodic re-aluminization of primary mirror segments at an average rate of one per month. This should be achievable by a team of no more than 2 on-site staff and not result in telescope downtime. This implies that one spare mirror of each of the three mirror shapes will be needed.

In order to allow this procedure to be carried out safely, and at any time of year, mirror removal and fitting should be possible with the enclosure closed.

3.3 Observing Efficiency

A wide range of functional performance factors will also have significant impact on the efficiency of the Observatory in executing observations. In general the NRT will be designed to facilitate on-sky, observing efficiency, subject to limitations imposed by safety and maintenance requirements, and the Observatory will monitor performance, end-to-end, to facilitate continuous improvement in performance (See Section 8).

3.4 Pointing, Offsets, Focus and Tracking

The telescope hardware and software systems will be designed such that it can point to any location above its observing horizon with sufficient pointing accuracy that a target could be acquired blind onto a small (e.g. 10x10 arcsec) IFU spectrograph. The time from start of slewing to start of science exposures will be <30 seconds in all cases.

Small (< a few arcmin) and quick (< a few seconds) offsets to the telescope pointing (e.g. to adjust the position of a target in the focal plane onto a spectrograph slit or to “nod” to blank area of sky) will be enabled using the hexapod system that will support the secondary mirror. The hexapod will also adjust the telescope focus to compensate for temperature and pointing dependant effects and to correct differences in focal plane position between instruments.

A common autoguider for all instruments will be provided, that will support both sidereal and non-sidereal tracking. It will be fixed in the telescope focal plane and have sufficient field of view to always acquire a guide star at all sky positions and without the use of a guide star catalogue.

It is anticipated that science observations will begin without the autoguider locked, with locking taking place during the early part of science data taking. Given this it should be possible to lock and unlock the autoguider without disrupting telescope tracking. The control of autoguider focus will be separate from that of the telescope to allow guiding while the main science instrument is defocussed (e.g. when observing a bright target).

4 Instrumentation

4.1 Facility Instruments

Based on an analysis of the science case we have developed a baseline, two-generation instrumentation plan for the telescope. To ensure the project retains its existing and grows its potential user-base we will continually engage with the time domain community through science working groups and via the project team's own research. Feedback from this and from a formal user-group will shape both the Generation 1 and 2 plans.

Generation 1 aims to provide a basic set of low-cost, simple, high-throughput instruments that enable many of the key science cases to be delivered from soon after first light. It is based around the development of two new instruments (NR-SPRAT and NR-IMAGER) as well as the transfer of two existing instruments from LT to NRT (NR-MOPTOP and NR-RAPTOR). A summary of the properties of the first light instruments is shown below.

INSTRUMENT	**Wavelength**	**Field Of View**	**Notes**	**Science Cases**
NR-SPRAT	3750 - 7500 Å	Long slit	Spectrograph R~350	Type Ia SNe, Type II SNe, unknown transients (e.g. AT2018cow), strongly lensed SNe, GW counterparts, TDEs, exoplanets, solar system bodies
NR-IMAGER	3500 - 10000 Å	7.5 x 7.5 arcmin	*ugriz* filter set	Superluminous SNe, strongly lensed SNe, exoplanet transits
NR-MOPTOP	4000 - 8000 Å	5 x 5 arcmin	Polarimeter BVRI filter set	GRBs, blazars, unknown transients, CTA follow-up, GW counterparts
NR-RAPTOR	1.6 - 1.8 μm	3.2 x 2.6 arcmin	H band filter	Type Ia SNe, GW counterparts, faint red transients, dust forming novae

Generation 2 aims to supplement and in some cases replace the first light instrumentation suite over the first 5 years of telescope operations to provide full imaging and low and medium resolution spectroscopic capability over the optical and near-IR wavelength ranges. As described above, this plan is provisional and will be shaped further by the science working groups over the next few years as well as user feedback once NRT becomes operational. Concepts at this stage include:

- A new polarimeter to replace MOPTOP to provide full simultaneous colour capabilities with fast readout such that the instrument would provide linear and circular polarimetric capabilities at millisecond cadence.
- A new Image Slicer IFU spectrograph will complement NR-SPRAT by extending the low-resolution wavelength range into the near-IR.
- A SoXS-like instrument. As the rapid blind pointing capability for spectral classification would be covered by NR-SPRAT and the Image Slicer instruments, a cross-dispersed long-slit instrument is proposed for the follow-up science spectrograph where rapid acquisition becomes less important. This long-slit spectrograph is proposed to have a spectral resolution R~3500-5500 over a wavelength range of 0.36-1.83μm captured in a single shot.
- A wide field imaging camera (possibly 15x15 or 30x30 arcmin)
- A simultaneous 4 or 5 band fast imaging camera.

4.2 Visitor Instruments

We aim to support long-term (>6 months) visitor instruments that meet the operational requirements for robotic operation.

5 Science Operations

5.1 Time Allocation

The majority of LT time is allocated via biannual calls for proposals to three committees representing the UK, Liverpool JMU and Spanish user communities. While this generally works well it has some flaws: the nature of target-of-opportunity science means individual targets cannot be easily assigned to specific users, leading to some duplication of observations for high profile targets. For NRT, on which we anticipate early-time transient classification to be a major activity, there is also the worry that a particular science PI might 'waste' a large fraction of their individual time allocation following up transients which after identification turn out not to match their particular science case but may well be of use to a different PI. There is clear value to both PIs in coordination, as well as rapid propagation of results to the time domain community. Cenko+ (2020) makes the recommendation: 'ToO policies are constructed to encourage groups to pool resources, work together (where sensible), and maximize the science possible from any given dataset'.

The final time allocation model will be a matter for discussion by the telescope stakeholders. However, the NRT project will advocate a hybrid model in which the available telescope time is split between a traditional PI-led committee-allocated model, and Key Science Programme(s) to be undertaken as a joint venture between all the partners:

- PI-led programmes: PI-led programmes will be allocated by a peer review committee. Such committees may be shared between partners or individual to them at their discretion. Time will be allocated on a particular telescope (in the case of possible future joint operations of the LT and NRT) based on a science case. No allocation will be made to a specific instrument on that telescope to allow flexibility of approach, and NRT staff will not check that targets observed are

compliant with the original science case for the proposal to remove “human-timescale" delays from the observing process.
- Key Science Programmes: All partners will be given the option to join one or more Key Science Programmes that will be operated on the telescope by the NRT project. The first example of this is the proposed ‘SPEC’ programme. This is anticipated to consist largely of spectroscopic, transient response observations. The purpose of SPEC is to respond to the challenges of time domain science in the upcoming era. The coming decade will see an unprecedented rate of transient triggers; a huge increase in the number of possible targets which will interest different scientific communities. Targets will be prioritised by transient brokers based on limited information. An open and collaborative approach to the follow-up strategy will maximise efficiency, widen the user base and enable equal access to the classification spectra. Data obtained via this programme will be made available to all partners in the NRT project. The relative financial and in-kind contributions of partners will be recognised by allocating pro rata representation on the collaborative science team which will plan and schedule the SPEC programme. The science working groups would report to this team in order to optimise the target selection strategy.

Our current proposal to the project board is that ~40% of the total telescope time is devoted to the SPEC programme, with the remaining time allocated via time allocation committee(s). This will permit classification of 10,000 targets per year brighter than r=20.5. This represents a factor of 5 increase over the number of spectral classifications (2012) delivered worldwide in 2019 (Kulkarni, S, 2020 arxiv.org/2004.03511) by the combined resources of the entire astronomical community. All partners will have full access to all of this SPEC time, as well as a pro rata share of the remaining time based on the contribution to capital and operation costs.

To illustrate how this would work for a particular science user, they might be an active participant in the collaborative SPEC programme, but also have applied for an individual and proprietary allocation in the relevant TAG time. Following discovery of a particularly interesting target via SPEC, they might trigger their own time in order to intensely monitor its spectral and photometric evolution. Or they might use their allocation to pursue one of the other science cases, such as the long-term monitoring of a blazar or the study of exoplanet transits.

5.1.1 Director’s Discretionary Time

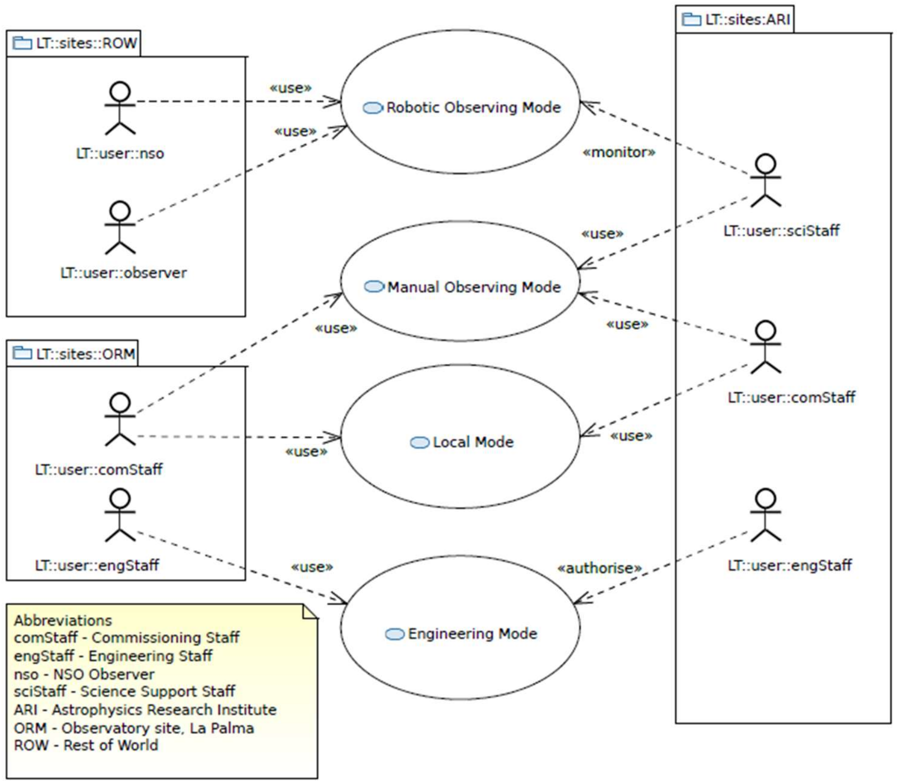
A small fraction (1-2%) of director’s discretionary time (DDT) may be implemented to allow exploration of high risk, high reward scientific and technical questions.

5.1.2 Outreach and Education Time

A fraction (to be agreed by the NRT Board) of NRT time will be made available for advanced outreach projects that cannot be executed with an expanded outreach programme on the Liverpool Telescope.

5.2 Operating Modes

The operating modes of the observatory are drawn from the science requirements and the user groups’ access requirements. The graphical representation of these modes and user interactions is shown in diagram below.



These modes shall use multiple levels of interlocks to restrict system access to users with the necessary knowledge and skills to operate the facility systems in a safe manner but allow access or control to meet the individual user requirements above.

5.2.1 Robotic Observer Mode

Robotic observing mode will form the key operating mode of the telescope for carrying out observations based on inputs from NSO Observers and Observer user groups. In this mode, all telescope and instrument systems are directly controlled only by the Robotic Control System according to observation specifications requirements provided by users. There is no direct interactive control of individual telescope mechanisms. All other user groups will be able to monitor the telescope while in this mode.

Robotic mode by default is performing pre-requested observations, making real time scheduling decisions based on observing conditions. An override mode and API will be implemented to allow the telescope to be overridden for Target of Opportunity (ToO) alerts, such as those from Gamma-ray Burst (GRB) events and expected Gravitational Wave events.

Key features of robotic operation include:

- Time is allocated by a semesterly process in units of hours rather than nights, allowing the full range of time domain topics to be pursued, including those that might only need a small allocation (such as a very rare transient subclass) or small amounts of time spread widely over long-time baselines.

- Additional telescope time is offered via a same-day-decision 'Reactive' mode, for unforeseen targets-of-opportunity.
- A 'Phase II' system for entering observing groups is an online application available on any modern operating system from anywhere in the world.
- Software APIs for entering observing groups which enables follow-up to be scripted (e.g., for automated follow-up of targets found with other robotic facilities).
- An automated scheduler that chooses what to observe based on science priority, sky conditions, target altitude etc., and reacts in real time to changing conditions or the addition of new observing groups to the queue.
- Override modes (abort current observation) are available for targets which require the fastest response, such as GRB afterglows or microlensing events.
- Data products that are fully reduced (including, e.g. wavelength and flux calibration for spectra) and are available within a few minutes of observation.
- All data to be available via a science archive with a modest (1 year) proprietary period.
- Daily calibrations (flats, photometric and spectrophotometric standards) are taken by default and outside of individual time allocations for all users to share.
- Users do not lose any of their allocated time due to bad weather.
- Time is paid back for observations compromised by technical faults.
- If a particular instrument is unavailable, observations using other instruments can be executed instead.

5.2.2 Human Observer Mode

Manual observing (either remotely or on site) is defined as the use of the telescope by a trained observer who will control the operation of the telescope and instrumentation directly. This mode of operation will only be used by trained staff of the collaboration (i.e. no visitor mode will be provided) and only for commissioning and testing activities. User interfaces that are controllable either local to the telescope or remotely will be provided to enable this. This should be in the form of two interfaces, a Telescope Control System (TCS) to acquire and track targets, and an Instrument Control System (ICS) to setup instrument options and take science data. During instrument commissioning or specific testing, it should be possible to drive the telescope both locally and remotely without the robotic control active. Specific controls will need to be in place to prevent injury or damage to equipment. For example, staff on site can prevent the telescope from accepting any remotely issued commands.

5.2.3 Local Mode

Under local mode the telescope systems and instruments shall prevent all remote and/or robotic movement. This mode allows the telescope and systems to be powered, whilst engineers have access to the enclosure. All systems on the telescope (axes, mechanisms, instruments) will be able to be controlled from within the dome only, via an industrial control pendant or direct PLC control. Movement of the telescope or mechanisms will require the holding of a dead man's switch and emergency stops will be positioned within reach of the movement control.

5.2.4 Engineering Mode

In Engineering Mode, the telescope is fully operational and full access is permitted. This is an unusual circumstance, requiring specific conditions to be met for engineering mode to be granted. A procedure will be documented, including at minimum a permit to work system, hardware interlocks and "no lone working" permitted.

5.3 Typical Sequence of Night-time Activities

In this section we outline the typical sequence of night-time activities in routine robotic operations. This is not a complete definition of the sequences and their implementation (which will be defined by "use case" analysis), but serves to give a general picture of night operations based on the successful model used at LT.

5.3.1 Start of Operations

- Power up all systems.
- Home all mechanisms (e.g. telescope axes, linear stages etc.)
- Assuming weather is within observing limits, open enclosure
- Open mirror cover (if included)
- Set default focus of secondary mirror based on current telescope tube temperature and enable automated tracking of telescope focus with temperature and altitude changes.

5.3.2 Evening Twilight

- Automatic twilight flatfield acquisition using blank areas of sky and with the telescope either not tracking or with positional offsets between each exposure. The selection of instruments and configurations on any particular night will be determined automatically by considering factors such as the relative age of existing calibration files.
- Depending on the repeatability of the axis encoder system, it may be necessary to use an autoguider or science camera as part of an axis "Zeroset" procedure by pointing at a small sample of objects to adjust the axis home positions.
- Check Telescope Focus on a bright star, adjust if necessary.
- Check Mirror alignment using Wave Front Sensor on a bright star, adjust if out of tolerance.

5.3.3 Night-Time Operations Loop

- DO
  - Select next Observing Group from a database based on conditions, science priorities and current telescope configuration and pointing. Note new observations can be added to the database by users/software at any time during the night.
  - Slew and Configure telescope and instrument
  - Start Exposing on science instrument
  - Start Autoguider if required (longer exposures)
  - Pipeline data to update conditions (seeing, photometricity)
- UNTIL WEATHER BAD:
  - Close Mirror Cover
  - Close Enclosure
  - Park Telescope
  - Wait until weather GOOD then start new Observing Group
- OR UNTIL OVERRIDE:
  - Abandon current exposure
  - Start new Observing Group specified in the override
- OR UNTIL MORNING TWILIGHT

5.3.4 Morning Twilight

- Execute Twilight Flat Fields (as per evening twilight).
- Close Mirror Cover
- Close Enclosure
- Park Telescope
- Power Off

5.4 User Support

A documentation suite shall be available to scientists for the use of all instruments and operating modes of the telescope. In addition, documentation will be provided to allow third parties to develop and deploy instruments to the telescope with appropriate support from the NRT team. A Science Operations & Data Centre will provide daytime user support based on an email or helpdesk based system.

5.5 Commissioning and Early Science Operations

Our timescales are guided by the delivery of the 6x inner ring of M1 mirror segments as these are required for achieving engineering first light. Commissioning will be started without the full set of 18 mirrors and some early science operations will form part of the later commissioning activities. There is an expectation that a full set of mirrors will be available by the time the project enters full science operations which are expected to commence 2 years after the start of commissioning.

6 Data Management

6.1.1 Science Data Contents and Formats

All science data obtained at the NRT using any instrument will be stored. The archive will be developed and maintained by NRT Staff and will include all data taken as part of any scheduled observing programs and calibration data taken to support instruments in use at the Observatory. In addition to the science data itself, the archive will include “metadata” relevant to the science data with the goal of maximizing the future utility of the archive for a range of purposes. The metadata may include such information regarding the observing target, exposure details, enclosure configuration, telescope configuration, instrument configuration, environmental conditions, astronomical conditions (e.g. moon coordinates), and proposal information. Science data will be archived in both raw and reduced formats.

All scientific data produced by NRT will be archived and distributed using the FITS format, taking advantage of the World Coordinate System standards. Interoperability with Virtual Observatory standards will be implemented.

6.1.2 Data Processing Tools

Data produced by NRT will be capable of being processed and analysed using standard astronomical software tools such as IRAF and the AstroPy toolkit.

6.1.3 Data Reduction and Calibration Pipelines

Data reduction and calibration pipelines will be delivered with all instruments. To facilitate rapid data reduction and publication of scientific results, the data pipelines provided by all instrument teams will be made available via the archive. These tools will be used by the Observatory staff to process data before distribution to users.

To facilitate the community development of data tools, the data pipelines will be provided "open source" to investigators and the Observatory will provide strategies to facilitate the exchange of updated data processing tools. The archive will also include quicklook tools to allow the data to be re-processed rapidly.

6.1.4 Data Archiving

NRT will maintain a data archive for the life of the facility. The essential functions of the data archive are:

- to capture and curate raw data to assure that it is not lost,
- to associate that data with appropriate metadata and data reduction tools, and
- to support multiple scientific uses of any data.

The goal of the archive is to increase the scientific productivity of the NRT by facilitating the efficient distribution and reduction of data for scientific analysis and publication. In addition to archiving scientific data and metadata, the archive will store the data reduction tools provided by the instrument teams so that they can be used and improved by the community.

The archive interface will support access, queries, and quicklook tools that facilitate the use of the archive for purposes including the execution of the originally proposed observing program, future scientific programs, assessment of Observatory operations, and engineering diagnostics.

In addition to the primary archive, a "local" archive will be provided at the NRT site to ensure data security for a period of at least one month without requiring a network connection to either the sea-level facility or to the site of the primary data archive. The Archive will be designed, developed, and supported during operations to meet the specifications given in this document and subject to the judgement of the NRT to balance cost and performance.

6.1.5 Engineering Data

NRT will collect and archive selected engineering data from the telescope, instruments and systems that may be useful to assess the status of hardware, diagnose failures, refine observing processes, or assess operations. These will be accessed through an engineering data management system that will be developed during the Construction phase. To the extent practical, engineering data will be archived for the life of the observatory.

6.1.6 Data Access

Data access policies and procedures will be designed to be in compliance with the General Data Protection Regulations (GRPR).

Data will be made available to Investigators at the NRT site through local hardware and to remote investigators at any location at which remote operations are supported. NRT will provide access to raw data and "quick-look" products via the data archive to any approved investigators within 5 minutes from any location in standard operation. For data taken in all standard observing modes with on-telescope instruments, NRT will provide access to final processed data products appropriate for scientific analysis within 24 hours of observations [project goal: 1 hour]. NRT will provide the support necessary to assure the quality of these data products. To maximize the scientific productivity of the NRT, the NRT project also endorses a policy of open data access that would include the Contributors and potentially the broader community after the proprietary period has passed (if applicable). The data access policy is subject to approval by the NRT Board.

7 Observatory Technical Operations

7.1 Lifetime

The lifetime of the observatory shall be at least 25 years.

7.2 Enclosure

The telescope will be housed in an enclosure to protect it from the environment when conditions are outside of operational limits, during the daytime or when engineering and maintenance activities are taking place. The enclosure should be able to open and close with the telescope in any position and should not introduce any delays in the time to acquire a target. For this reason, a fully opening enclosure as successfully used at Liverpool Telescope is anticipated.

7.3 Nighttime Operation

Weather and maintenance permitting the observatory shall perform science operations from dusk to dawn, 365 days of the year. No daytime science operations with the enclosure open will be permitted.

7.4 Engineering Time

Engineering time is considered to be any daylight hours or during weather when it is not possible for science observations. Engineering time shall consider safety aspects when lone working is prohibited by on-site processes and procedures. Some fraction of daytime engineering time may be required for the collection of science calibration data which may require the telescope to be powered up and/or the enclosure to be in relative darkness.

7.5 Down Time

The operational downtime per calendar year shall be less than 3% of the available observing time. All components shall be rated for use at the site altitude (2325m).

7.6 Maintenance Time

Daylight hours will be reserved for maintenance in order to reduce the amount of operational downtime experienced by the science users of the telescope.

7.7 Commissioning Time

Telescope and commissioning time shall follow the construction phase and the handover of the project from the Engineering team to the Science team. The commissioning phase shall take at least 24 months.

This will be led by the NRT science team and follow the commissioning plan created by the Project Scientist.

7.8 Instrument Requirements

Instruments shall be designed for long lifetimes (~10 years) with a high-degree of up-time and low on-site maintenance needs as required for a robotic telescope facility. They shall use commercial off the shelf components wherever possible and avoid the need for regular consumables (e.g. liquid Nitrogen). In order to support automated calibration and data reduction they should minimize the number of different operating modes and configurations they implement. All instruments will be required to have full software (as well as opto-mechanical) compatibility with the NRT software systems to allow robotic operation.

7.9 Instrument Stations

All instrumentation shall be housed at the Cassegrain interface. There shall be 6x side-port instruments and 1x straight through instrument. At each port as well as an opto-mechanical interface, remotely controllable mains and low voltage electrical supplies, a pneumatic supply and a computer network interface will be provided.

7.10 Instrument Calibration

Where possible, instruments should auto calibrate at the beginning of the evening. If this is not possible, they must be calibrated when installed on the telescope and their calibration data stored so that it does not become corrupted.

7.11 Safety

Safe systems of work and risk assessments will be developed for all routine and one-off operations and maintenance procedures. Lone working will be not appropriate under many scenarios.

7.12 Handling Equipment

All items of equipment (instrumentation, A&G box, mirror segments etc.) over 20kg in weight should be supplied with handling equipment such that they may be safely removed and fitted from the telescope and transported by a maximum of 2 people.

7.13 Configuration Management

A unified configuration management system will be implemented that allow change tracking and roll-back as well as deployment of new versions of software systems without the need to reimplement configuration changes.

7.14 Fault Recovery

As a robotic facility a simple, robust and reliable system of automatically recovering from system faults will be implemented. This must have as its key priority the safety of personnel and equipment, followed by the ability to restore the system to a known and well-defined state such that data may be obtained with confidence. A hierarchy of fault levels will be established to help define the appropriate responses. In the event of unrecoverable faults, the system should place itself in a safe state (e.g. enclosure closed, powered off) wherever possible.

8 Performance Assessment & Improvement

NRT is committed to meeting the scientific goals of the project through a process of continuous improvement that incorporates feedback from the project board, scientists, and staff. The User Working Group minutes provides a detailed discussion of the performance criteria that are of interest to the scientific stakeholders, including potential metrics by which those criteria could be monitored. The NRT's operations planning, evaluation, and continuous improvement strategies will incorporate these and other criteria for assessing the scientific and technical performance of the NRT, following the specifications below.

8.1.1 Assessment of Technical Performance

The NRT will develop a strategy for consistent monitoring and tracking of Observatory performance to support maintenance, troubleshooting, and performance improvement. Tools and strategies will be developed to enable the status of all critical subsystems to be monitored from a single control "station" (physical or electronic) to facilitate the prompt identification of long-term performance problems that may impact night-time operations.

8.1.2 Daytime Operations

The NRT Project will develop processes for assessing the health of the Observatory and all subsystems, including facility instrument, during routine daytime operations. These will incorporate the operational strategies and recommendations of the subsystem development teams as well as feedback from Project Science Staff during commissioning.
Metrics will be developed to monitor the efficiency and effectiveness of daytime operations. These will include:

- Maintenance efficiency – time spent engaged in reactive engineering efforts (in response to failures or errors) as opposed to time spent proactively improving performance or developing new capabilities.
- Telescope and instrument release times – the time of day at which telescope, and instruments are made available each day for scientific operations.
- Time spent on instrument calibration during daytime versus night-time operations – the effective use of daytime for preparation of the instruments.

8.1.3 Night-time Operations

The efficiency and effectiveness of night-time operations contributes directly to the scientific impact of the Observatory. Statistics related to all functional and scientific performance requirements for the

Observatory are of interest. A subset of metrics that will be developed to monitor the efficiency and effectiveness of night-time operations include the following:

- Efficiency of night-time initialization procedures for all subsystems.
- Instrument switching times.
- Instrument configuration accuracy, efficiency, and completeness.
- All steps associated with target acquisition, including dome slewing, telescope slewing, and establishment of guiding and image quality.
- Calibration overheads.
- Total open-shutter time on the scientific targets.

8.1.4 Data Quality Metrics

The NRT will monitor all characteristics for which science requirements have been defined. Those that can be measured using "quick-look" data tools will be monitored as part of night-time operations. The most important of these are throughput and image quality. Throughput of the instruments and telescope will be monitored separately to support maintenance of each. Image quality characteristics that will be monitored during observations will include, for instance, encircled energy, Strehl ratio, and PSF characteristics (stability, uniformity, etc.) at the focal plane of the telescope and instruments.

NRT Staff will include personnel that are responsible for identifying performance trends (via use of AI etc). Additional metrics will be developed utilizing processed data products that can be used to monitor the performance of instruments (e.g. fibre throughput or instrument flexure) and support their maintenance.

8.1.5 Widening access

We aim to ensure that the NRT project is a welcoming, fair and equal place for all of our staff and users. As part of the project documentation, we will develop a partner code of conduct which will be signed and adhered to by all parties and users of the telescope. The NRT team values diverse collaborations and knows how crucial it is to have a variety of people contributing to such an innovative project. We also acknowledge the problems with diversity in astronomy and engineering and are actively working to improve representation by attending diversity workshops, analysing interview techniques, changing practices and targeting engagement and outreach activities to a wide variety of audiences.

From the onset we will ensure that telescope allocation committees are diverse, trained and are beneficial to all involved with family-friendly scheduling and remote participation options. Where appropriate we will encourage early career researchers (including PhD students) to participate in learning and development opportunities and ensure that bias-training is an essential part of contributing to any assessment (be it interviews or telescope proposal reviews). We will provide proposal mentoring opportunities which allow inexperienced applicants to submit their proposals early for mentoring by experienced users, giving them feedback and allowing them to rework their proposal before the official submission deadline.

We will work to ensure that technical members of staff are recognised in a variety of ways and not just assessed by publications and have a defined career and promotion path within their respective institutions. We will encourage the inclusion of technical staff on scientific papers that have benefitted from their work. In addition, they will be supported to pursue core personal development and professional qualifications beyond those of direct project need.

8.1.6 Scientific Productivity Dashboard

The fundamental product of the Observatory is data. Scientific publications that result from those data can only be produced by scientists, and that rate of those publications will be influenced by the policies adopted by each Contributor to encourage rapid publication. In addition, the scientific metrics that are of most interest to each Contributor will vary. With those caveats, the scientific productivity is of unanimous interest to the NRT and its project board, and the NRT will monitor a wide range of metrics with the goal of developing strategies that will increase that impact. We will aim to develop a dashboard to track and present this data in an automated fashion, Metrics will include:

- The number and impact publications, potentially with adjustments for long-term science programs.
- The number and value of external grants attached to NRT science programs.
- The number of PhD theses based “significantly” on NRT data.
- The number of undergraduates at NRT institutions involved in NRT science programs.
- The number of Contributor institutions collaborating per proposal.
- The number of non-Contributor institutions collaborating per proposal.

NRT may choose to invest in higher risk scientific programs that have lower impact on short timescales. Such proposals could be explicitly identified, and time allocation committees may choose to allocate some fraction of observing time to programs which have high scientific merit regardless of their estimated risk of success, be it scientifically, technically, or operationally.

8.1.7 Assessment of Contributor Satisfaction

Feedback will be collected regarding all Observatory services in support of scientific stakeholders, including the application process, the scheduling process (sometimes called “phase II”), execution of observations, data quality, data completeness, the data archive, and data reduction. This information will also be incorporated into the Dashboard tool.

NRT will develop “user groups" out of the science working groups to provide users with a channel for communicating with the NRT Staff and Board.

8.1.8 Assessment of Public Relations

It is in the best interests of the NRT and the partner institutions to develop and maintain visibility within the public and the scientific community. This effort should be assessed by professional development and outreach staff, and may include the following metrics to be incorporated into the dashboard:

- The number of Press Releases issued per month that refer to NRT.
- The number of K-12 students, undergraduates, and graduate students participating in NRT-related outreach and/or education programs in all of the partner countries.
- Other activities to be determined.

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