D1.4.1 Plan for UK involvement in Commissioning

WP1.4 Coordination of LSST:UK Contributions to Commissioning

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1 Introduction

This deliverable comprises the document titled “LSST:UK Directable In-kind Contribution to Commissioning the Vera Rubin Observatory” created on 31/OCT/21 and presented to the Rubin System Integration Test and Commissioning (SITCom) team. The original document is available at

https://docs.google.com/document/d/1F3xMuoOruBVbZwkkxo7E0yu6RWilM07HoizV3c8Pf3w/edit?usp=sharing

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2 LSST:UK Directable In-kind Contribution to Commissioning the Vera Rubin Observatory

LSST:UK Directable In-kind Contribution to Commissioning the Vera Rubin Observatory

Dr Graham P. Smith, LSST:UK Commissioning Coordinator, gps@star.sr.bham.ac.uk
on behalf of LSST:UK and the contribution leads listed below

1. Executive Summary

This document describes the directable expertise available to Vera Rubin Observatory's (Rubin's) System Integration Test and Commissioning (SITCom) team from the LSST:UK Consortium. The expertise is summarised in the table below, and includes on-summit support for telescope and active optics commissioning (Contribution 1), and remote data analysis expertise (Contributions 2-7) that is integrated with ongoing effort within the Science Collaborations and the LSST:UK software development teams. In total, three funded staff years (SY) of in-kind effort are available, in addition to a further 2.35SY of donated effort.

Background information is provided in Section 2, the available expertise and envisaged contributions are described in Section 3, funding available to support travel and subsistence is summarised in Section 4, and equity, diversity and inclusion (EDI) is discussed in Section 5. We look forward to iterating to an agreed plan for the content and timing of our in-kind contribution with the SITCom leadership team.

Contribution title	**Contribution lead(s)** *[Asterisks indicate postdoctoral researchers]*	**"Donated" effort**		**Funded effort**	
		CY22	**CY23**	**CY22**	**CY23**
1. Active optics	Will Sutherland (QMUL) Gavin Dalton (Oxford/RALSpace)			0.2 0.0	0.2 0.5
2. Astrometric calibration	Tom Wilson* & Tim Naylor (Exeter)		0.1		0.5
3. Astrometric and photometric calibration	Nicholas Walton (Cambridge)	0.05	0.05	0.45	0.45
4. Strong lensing	Graham Smith (Birmingham)	0.05	0.1	0.2	0.5
5. Optical/near-IR data fusion	Raphael Shirley* (Southampton)	0.2	0.2		
6. Low surface brightness	Aaron Watkins* (Hertfordshire)	0.25	0.35		
7. Angular clustering	Jon Loveday (Sussex)	0.5	0.5		
Total staff-years of effort:		1.05	1.3	0.85	2.15

2. Background

LSST:UK's accepted in-kind proposal included three staff-years (3SY) of funded directable effort as UKD-UKD-13, and was based on Expressions of Interest received from the UK community in 2020. In 2021 we have received and reviewed detailed proposals from the UK community, and present them here to assist SITCom leadership in selecting their UK team members.

The available expertise comprises one on-summit contribution from Dalton and Sutherland that was explicitly discussed in the in-kind proposal. The six remote data analysis contributions emerged as concrete proposals in 2021 from the pool of EoIs in 2020, and were not individually referenced in the in-kind proposal.

The 3SY of funded effort are concentrated in Contributions 1-4, and will enable the relevant individuals to contribute through to an assumed nominal end of commissioning in late CY23. Contributions 5 and 6 offer to run their software that is already funded as UKD-UKD-5 and UKD-UKD-6 respectively on commissioning data and provide value-added feedback to the Construction Project through to the current end of their existing LSST:UK funding (March 31, 2023). Contribution 7 has requested no funding and is flexible to contribute throughout CY23.

3. Description of expertise

3.1 Active optics

Team:	Dr Will Sutherland (Faculty), Queen Mary University of London [Co-lead]. Prof. Gavin Dalton (Faculty), University of Oxford/RALSpace [Co-lead].
Relates to:	Other: Commissioning and calibration of wavefront sensor sub-system
Expertise:	Sutherland served as VISTA Project Scientist throughout the entire project (2000-2009). He led the definition of science requirements and operational concepts, and participated in conceptual and final design reviews of all subsystems. He was intimately involved in wavefront sensing throughout the project, including developing the concept for splitting high and low order wavefront sensing, providing the concept for twin low-order wavefront sensors, detailed design of WFS hardware, and developing algorithms for extracting wavefront data from defocused stars. He co-led VISTA on-sky commissioning, including 150 nights at the summit of Cerro Paranal. Dalton has broad experience of commissioning complex wide-field instrumentation on 4m and 8m class telescopes, including design and commissioning of the VISTA IR camera. He collaborated with Sutherland on setting up the VISTA WFS, telescope commissioning, and using the WFS to troubleshoot errors in the telescope alignment and secondary mirror support system left as large residuals by the initial "test camera" (Dalton et al., 2010; Sutherland et al. 2015). Dalton has also worked with a former graduate student (Hanshin Lee, now lead optical designer at HET) on theoretical alignment approaches to multi-component optical systems.

Envisaged contribution:	We envisage three main contributions: (1) review of Rubin's commissioning plan for the wavefront sensor sub-system; (2) up to 8x1month shifts on summit, shared evenly between Sutherland and Dalton, during CY23 when LSSTCam will be commissioned on-sky; (3) participation in team meetings via zoom when not present on-summit. This contribution was included in the accepted LUSC in-kind proposal.
Available (**funded**) effort:	Based on Dalton and Sutherland's availability, the following funded effort is available, although there is some flexibility to shift Sutherlands effort profile entirely to CY23, if required: CY22: Sutherland (**0.2SY**) CY23: Sutherland (**0.2SY**), Dalton (**0.5SY**)
Engagement:	Sutherland is familiar with Rubin's overall design, mainly based on public documentation and SPIE papers, and has deputised as QMUL representative at several LSST:UK Board meetings. Dalton has not had opportunity to engage yet.

3.2 Astrometric calibration

Team:	Dr Tom Wilson (Postdoc), University of Exeter [Co-lead]. Prof. Tim Naylor (Faculty), University of Exeter [Co-lead].
Relates to:	• Other: Absolute astrometric calibration
Expertise:	Naylor and Wilson have expertise in calibrating the systematic uncertainties in the astrometric calibration of wide-field survey instruments (Bell et al 2012; King et al 2013; Wilson & Naylor 2017, 2018a, 2018b). They have models in place to describe the effects of unresolved contaminant objects and unknown proper motions (the latter needed for catalogues other than Gaia) on Rubin's astrometric calibration. These models are critical to robust interpretation of cross-matches between Rubin detections and external catalogues because the astrometric differences will be considerably larger than the centroiding uncertainties which come from the Rubin pipeline and the matching catalogue. Crucially, Wilson and Naylor's software will have been tested (on DP0.2) and be running on the LSST:UK DAC in time for the on-sky commissioning of LSSTCam. In addition to quantifying the accuracy and precision of the centroids of Rubin detections, Wilson and Naylor are able to search for systematic effects due to the CCDs, the individual rafts and the focal plane optics.

Envisaged contribution:	We envisage using the cross-matching software developed in UKD-UKD-9 to calibrate the systematic uncertainties in Rubin astrometry due to unresolved contaminant objects and proper motions.
Available effort:	We estimate that the following effort is required to deliver the envisaged contribution: CY23: Naylor (0.1SY), Wilson (**0.5SY**)
Engagement:	Naylor is a member of the SMWLV and TVS Science Collaborations. Both SCs supported the acceptance of the cross-match package UKD-UKD-9 as an in-kind contribution. Naylor is also former Chair of the LSST:UK Board. Wilson is collaborating with SMWLV as part of the Crowded Stellar Fields Working Group, working to understand the effects of the Rubin Science Pipelines on measured photometry and astrometry in high density fields.

3.3 Astrometric and photometric calibration

Team:	Dr Nicholas Walton (Faculty), Cambridge Astronomical Survey Unit (CASU) [Lead]. Dr Carlos Gonzalez-Fernandez (Postdoc), CASU. Dr Anais Gonneau (Postdoc), CASU. Dr Leigh Smith (Postdoc), CASU.
Relates to:	● Example 3: Absolute photometric calibration ● Example 5: Anomaly analysis of the Engineering Facility Database ● Example 6: Extended analysis to characterize system performance at the margins of operational parameter space
Expertise:	CASU can generate very precise semi-empirical SEDs for their in-house library of non-variable stars, for which they have narrow and wide slit spectra at 400<**λ**<2400nm. These SEDs can be used to calibrate the Rubin Observatory photometric system. CASU also has expertise in evaluating astrometric residuals for wide-field imagers down to mas scales as a function of position in the sky, observing conditions, etc. They routinely measure throughput variations, electronic detector health and photometric stability using in-house pipelines, and have their own bootstrapped ubercal calibration code that can be used to cross-check the photometric performance of reduced commissioning data products.
Envisaged contribution:	We envisage CASU's expertise and tools being a directable resource able to support the absolute photometric calibration of commissioning data, and to

	evaluate the astrometric and photometric performance of Rubin against operational parameters captured by the Engineering Facility Database.
Available effort:	The following effort is available as a directable resource, with flexibility to alter the effort profile to suit SITCom's needs: CY22: Walton (0.05SY), Gonzalez-Fernandez (**0.25SY**), Gonneau (**0.2SY**) CY23: Walton (0.05SY), Gonzalez-Fernandez (**0.25SY**), Smith (**0.2SY**)
Engagement:	Walton is a member of the SMWLV observing strategy task force. Gonzalez-Fernandez contributes part time to UKD-UKD-5 (LSST/near-IR data fusion).

3.4 Strong lensing

Team:	Dr Graham Smith (Faculty), University of Birmingham [Lead]. Dan Ryczanowski (Postdoc from late 2022), University of Birmingham.
Relates to:	● Example 10: Science validation and characterization of object detection, deblending, and interaction with background modeling ● Example 12: Science validation of template generation and difference imaging
Expertise:	The robustness of the deblending, template generation, and difference imaging analysis (DIA) algorithms within the Rubin Science Pipelines are critical to demonstrating the operational readiness of the as-built Rubin system, because they are critical to many science goals across multiple Science Collaborations. The strongest tests of these algorithms can be achieved in the context of preparing to discover gravitationally lensed explosive transients, because this will occur in the most complex regions of the extragalactic sky, namely strong gravitational lenses of all masses, i.e. spanning luminous red galaxies, groups and clusters of galaxies. This complexity arises from the crowding of sources, the diffuse astrophysical LSB background, and the unusual and diverse morphology of gravitational arcs, i.e. these tests cannot be achieved in randomly selected sky locations. Ryczanowski is building the watchlist of groups and clusters of galaxies that will be used for lensed transient detection by the SLSC in collaboration with the DESC-SLTT. His expertise includes analysis and validation of photometric catalogues in crowded sky regions and identifying/characterizing the robustness of deblending. He has already adapted his group/cluster finding code to run on the Rubin Science Platform and is testing its

	performance on DP0 data. Smith has two decades of expertise in analysing and interpreting imaging observations of crowded extragalactic environments, spanning strong and weak gravitational lensing, gravitationally lensed transients, galaxy evolution including brightest cluster galaxies, and the physics of galaxy groups and clusters. As part of his group's search for gravitationally lensed kilonovae, he optimized the DIA of deep observations of cluster cores, and collaborated on the recovery of mock transient point sources that were injected into these data (Smith et al. 2019).
Envisaged contribution:	We envisage a number of tests based on known strong lensing groups and clusters located in science validation survey data (whether in wide survey fields such as Stripe 82, or pointed observations such as a Hubble Frontier Fields cluster; for further details see the SLSC Commissioning Note). Specific tests that we recommend include (1) measuring the recovery rate of lensed transients by the DIA pipeline as a function of lens-centric angle based on injecting mock point sources in to known strong lensing groups and clusters in science validation survey data, (2) measuring the recovery of accurate source detection and photometry of galaxies and lensed arcs in known strong lensing groups and clusters that are located within science validation survey fields, and (3) examining the sensitivity of these tests to details of template and prototype DRP generation, including the selection of visits that are incorporated into both. Conducting these tests as an integral element of verifying operational readiness will give critical feedback to DM based on actual LSSTCam data. In essence, we envisage stress testing the Scarlet blender, template and DRP production pipelines, and the DIA pipeline, in challenging sky regions. Note that these tests will probe up to tens of arcseconds around known lenses, and thus be at considerably higher source density and more severe complexity than is possible in cluster outskirts (e.g. by DESC-CLWG) or randomly chosen lines of sight.
Available effort:	We estimate the following effort levels for the envisaged contribution described above. Ryczanowski is available from September 2022 through to the nominal end of commissioning at the end of CY23. CY22: Smith (0.1SY), Ryczanowski (**0.2SY**) CY23: Smith (0.2SY), Ryczanowski (**0.5SY**)
Engagement:	Selection of UK expertise and development of envisaged contributions has been done collaboratively across the Strong Lensing Science Collaboration (SLSC) and DESC Strong Lensing Topical Team (DESC-SLTT). Simon Birrer led the DESC-SLTT/SLSC Letter of Intent submitted recently in the US -- it concentrates on testing delivered image quality at the telescope with lensed

	quasars, as a cap-stone test of the active optics sub-system. Ryczanowski is a member of SLSC, is developing the SLSC group/cluster lens watchlist, co-wrote the SLSC Code of Conduct, and is a DP0 delegate. Smith serves as Co-chair and Commissioning Liaison for SLSC. He led the SLSC's Commissioning Note, and one of the SLSC Observing Strategy White Papers. He is the LSST:UK Commissioning Coordinator, a member of the Dark Energy and Galaxies Science Collaborations, and a DP0 delegate.

3.5 Optical/near-IR data fusion

Team:	Dr Raphael Shirley (Postdoc), University of Southampton [Lead]. Dr Manda Banerji (Faculty), University of Southampton. Prof. Richard McMahon (Faculty), University of Cambridge.
Relates to:	● Example 8: Development of image and catalog visualization tools, including capability to interactively explore and "drill-down" into the data ● Example 9: Algorithm development for the Rubin Science Pipelines ● Example 15: Developing user-oriented documentation of science pipelines, data access services, and operational procedures, including the development of tutorials through the Rubin Science Platform
Expertise:	Shirley is developing a pipeline that combines optical imaging from Rubin with VISTA near infrared imaging, and that is based on the LSST Science Pipelines (https://github.com/lsst-uk/lsst-ir-fusion). So far this pipeline has been tested on HSC public data releases, and in future will be tested and run routinely on Rubin data. The pipeline has been running regularly over the last year and producing notebooks to be run on the Rubin Science Platform. It will be straightforward and very natural to adapt Shirley's code to run on ComCam and LSSTCam commissioning data. Benefits of doing so before the Operations Readiness Review include independent checks on the performance of Rubin's exposure processing, coadding and photometry pipelines. The distinctive expertise is the combination of optical survey data with infrared photometry from an external dataset. Doing this in commissioning will identify astrometric and photometric calibration issues by verifying whether bright objects are photometrically and astrometrically consistent between the bands. Experience of combining multiple 'obs' packages concurrently with the science pipelines will be useful for making commissioning data interoperable with other pre-existing datasets. Within UKD-UKD-5 we also have experience of producing user-oriented documentation in the form of notebooks that demonstrate pipeline runs that can be run on the Rubin Science Platform.

	Banerji has over a decade's experience in planning and exploiting wide-field optical and near infrared ground-based surveys. She is PI of the VISTA Extragalactic Infrared Legacy Survey (VEILS), which overlaps several of the currently announced LSST Deep Drilling Fields. McMahon has over 25 years of experience in data management of wide field astronomical surveys primarily in the optical and near infra-red. He is also PI of the VISTA Hemisphere Survey.
Envisaged contribution:	We envisage analyzing ComCam and LSSTCam commissioning data with the optical/near-IR fusion software developed and tested in UKD-UKD-5. This will deliver independent checks of the performance of exposure processing, coadding and photometry pipelines, including the astrometric and photometric consistency across bands. Early contributions would focus on testing obs_lsst processing of individual ComCam exposures. Later tests can expand to coadding exposures, and forced photometry on LSSTCam data.
Available effort:	Shirley et al. are available to contribute through to the end of their LUSC Phase B funding (March 31, 2023), as follows: CY22: Shirley (0.1SY), Banerji (0.05SY), McMahon (0.05SY) CY23: Shirley (0.1SY), Banerji (0.05SY), McMahon (0.05SY) Note that for this team, 0.1SY in CY22 corresponds to 0.1FTE for 12 months, whilst 0.1SY in CY23 corresponds to 0.4FTE for 3 months.
Engagement:	Shirley is in regular communication with the Data Management team and following pipeline development closely; he is an active member of the Galaxies and AGN Science Collaborations, and a DP0 delegate. Banerji is co-chair of the Galaxies Science Collaboration and member of the Dark Energy and AGN Science Collaborations. McMahon is a member of the Dark Energy and AGN Science Collaborations, and an elected member of the LSST:UK Executive Group since 2015.

3.6 Low surface brightness

Team:	Dr Aaron Watkins (Postdoc), University of Hertfordshire [Lead]. Prof. Chris Collins (Emeritus faculty), Liverpool John Moores University. Prof. Sugata Kaviraj (Faculty), University of Hertfordshire.
Relates to:	● Example 9: Algorithm development and testing for the Rubin Science Pipelines ● Example 10: Science validation and characterization of object detection, deblending, and interaction with background modeling

Expertise:	Watkins has extensive experience of LSB-optimized data reduction, having conducted deep imaging of nearby galaxies with the Burrell-Schmidt Telescope at Kitt Peak National Observatory, in broad- and narrow-band filters (Watkins et al. 2014, 2015, 2016, 2017, and 2018). He continues to work in this field, developing an LSB-optimized data reduction pipeline for narrow-band imaging from the New Technology Telescope (NTT) at La Silla Observatory, Chile, and the Nordic Optical Telescope on La Palma, on which a preliminary version of the proposed sky-subtraction algorithm was first tested and validated. Collins is recognised as an expert in brightest cluster galaxies and the diffuse intracluster light within which they and other cluster galaxies are embedded. Kaviraj has expertise in theoretical LSB studies using high-resolution cosmological simulations, and observational LSB studies including Stripe 82 and the HSC-SSP.
Envisaged contribution:	We envisage running the low surface brightness (LSB) optimized sky-subtraction algorithm that is being developed under UKD-UKD-5 in collaboration with the Data Management (DM) team on LSSTCam commissioning data in advance of ORR. The primary goal of the algorithm is to mitigate loss of astrophysical LSB flux in future data release products (DRPs), by increasing the accuracy of the full-focal-plane night-sky models. Running the algorithm on commissioning data will improve night-sky removal, and thus help to isolate large-scale asymmetric scattered light artifacts such as ghosts, glints, reflections, and flares. In turn, this will help in the modeling and removal of such artifacts. This analysis during commissioning should also improve multiple facets of the Rubin Science Pipeline upon which accurate source detection and photometry relies, e.g. in crowded fields and fields heavily contaminated with Galactic cirrus.
Available effort:	Watkins et al. are available to contribute through to the end of their LUSC Phase B funding (March 31, 2023), as follows: CY22: Watkins (0.1SY), Collins (0.05SY), Kaviraj (0.1SY) CY23: Watkins (0.2SY), Collins (0.05SY), Kaviraj (0.1SY) Note that for this team, 0.1SY in CY22 corresponds to 0.1FTE for 12 months, whilst 0.1SY in CY23 corresponds to 0.4FTE for 3 months.
Engagement:	Watkins is leading the development of an alternative sky subtraction algorithm for the Rubin Science Pipeline, in collaboration with DM and building on tests of Rubin “default” algorithm that were based on model galaxy injections in Subaru Hyper Suprime-Cam data. He is co-Chair of the LSB Working Group in the Galaxies Science Collaboration. Collins is a member of the Galaxies Science Collaboration. Kaviraj is co-Chair of the Galaxies Science Collaboration.

3.7 Angular clustering

Team:	Dr Jon Loveday (Faculty) [Lead], Todd Cook (PhD student), and Postdoc, University of Sussex
Relates to:	● Other: Additional scientific validation and characterization studies that will improve understanding of the as-built system
Expertise:	The angular correlation function of galaxies is a well-established baseline commissioning test of wide-field survey instruments. In brief, the observed scaling of the angular two-point correlation function with limiting apparent magnitude is compared with a model for the real-space correlation function and galaxy selection function. Loveday has 30 years experience of angular clustering analysis including as a test of wide field survey instruments, dating back to early work on the APM survey (Maddox et al. 1990).
Envisaged contribution:	The greater depth of Rubin data compared with previous surveys imposes a challenge on using the angular clustering of galaxies as a commissioning test. This is because realistic models for the evolution of the real space clustering of galaxies and the galaxy luminosity function are required. Loveday's group is developing the required models using HyperSuprimeCAM data, and envisage applying them to photometric catalogues based on LSSTCam commissioning data. This test can identify fundamental issues including non-random contributions to catalogue incompleteness, impurity e.g. poor star-galaxy separation, systematic biases in photometry e.g. gradients in photometric calibration across the detector. This is a powerful pre-ORR test of the entire system from detectors through to catalogue data.
Available effort:	Loveday's group offers to donate 1SY of effort as outlined below. Funding has been requested from STFC for the Postdoc, independently from LUSC. In any event, Loveday is on sabbatical in 2022/23, thus affording flexibility in how the 1SY of effort is distributed across team members. CY22: Loveday (0.1SY), Cook (0.2SY), Postdoc (0.2SY) CY23: Loveday (0.1SY), Cook (0.2SY), Postdoc (0.2SY)
Engagement:	Loveday is a member of the Dark Energy and Galaxies Science Collaborations, and a member of the LSST:UK Board.

4. Travel and subsistence funding

We have £27k of STFC funding in place at the University of Birmingham to support travel and subsistence for UK commissioning team members. This is part of our Phase B funding from STFC that runs to March 31, 2023. It will be straightforward to secure a 6-month no-cost extension for this funding, if required. We look forward to discussing with SITCom leadership how these funds can be deployed to support the commissioning effort.

5. Equity, diversity and inclusion

The LSST:UK Consortium is committed to equity, diversity and inclusion (EDI), and continually striving to improve in this area. Our Consortium Board adopted an Equality and Diversity statement at the inception of the Consortium in 2016, quickly followed by our Code of Conduct in 2017. All members of LSST:UK are required to agree to and abide by this code as a condition of membership, just as they are required to agree to and abide by the codes of conduct of the LSST Science Collaborations that they join. Indeed, several of our commissioning team have been active in creating the codes of conduct of Science Collaborations.

The diversity of our team broadly reflects the level of diversity across the Consortium as a whole. Specifically, in addition to gender diversity, our team includes colleagues from ethnic minorities, from the LGBTQ+ community, and colleagues with hidden disabilities. Also, three of our seven contributions are led or co-led by a Postdoctoral researcher. If any new hires arise from this commissioning activity, the adverts will be checked for inclusive language, the selection process will incorporate EDI best practices, and we will require colleagues involved in selection to have completed training in how to minimize the impact of unconscious bias.

Whilst our team reflects the current level of diversity in the Consortium, we aspire for the Consortium to be more diverse than it is. For example, as the start of survey operations approaches, the Consortium is actively engaged with the topic of how to provide appropriate training to early career members, and the wider community who might be encouraged to join. Ideas include applying for funding that would enable us to offer training to advanced undergraduate students from minority backgrounds.

The Consortium is also considering moving to a model of individual, rather than institutional, membership, once our data rights agreement has been signed. One attraction of a shift to individual membership is that it would offer opportunities to prioritise EDI when defining the new model, and to be more explicit and direct about promoting diversity in our membership than is possible currently via the institutional model.