LSST:UK DAC Roadmap and Integration Plan for DEV Activities (updated)

Work Package 2.1, Deliverable D2.1.4

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1 Executive Summary

At its outset, Phase B of the LSST:UK Science Centre (LUSC) programme was intended to prepare the UK astronomical community for the start of LSST survey operations and, in particular, for its first Data Release, which was then due towards the end of Phase B. Central to that programme was the development of a UK Data Access Centre (DAC), intended to serve LSST data products to the UK community, along with analysis software and ancillary data provided by the Phase B DEV Work Packages. That DAC development plan was set out in a previous deliverable from WP2.1, namely D2.1.1 (dated May 2020).

The Phase B programme overall has been significantly affected by two factors since completion of D2.1.1: (i) the schedule of the Rubin Construction Project has been severely delayed as a result of the Covid-19 pandemic; and (ii) the adoption of the in-kind model for international participation in the LSST has changed the scope of many of the Phase B WPs, which have now become parts of the UK's in-kind contribution to Rubin operations.

The centrality of the UK DAC to the LUSC programme has not altered because of the in-kind model. However, the DAC itself has become an in-kind contribution, which will serve a fraction of the worldwide community of LSST data rights holders. Pandemic-induced delays on the delivery of DAC software by the Rubin Observatory and on the timeline for the Data Preview programme have impacted on Phase B milestones for UK DAC development, and these have been updated accordingly.

This document provides an update to the "*LSST:UK DAC Roadmap and Integration Plan for DEV Activities*" presented in D2.1.1 in the light of current Rubin and LUSC plans. By updating the DAC Roadmap it defines the capabilities of the UK DAC that should be in place at the end of Phase B (nominally 31/MAR/23) and outlines the plans for further DAC development in the early stages of Phase C, although the latter remain somewhat uncertain due to the Rubin Construction Project's recent decision not to perform on-sky observing with ComCam, which has implications for the timing and content of Data Preview 1 and, hence, for the UKDAC release schedule (see Section 3).

This document also presents an updated account of the interaction between LSST:UK and IRIS, its main infrastructure provider, which has changed significantly since the publication of D2.1.1 with the advent of the Somerville cloud system. Furthermore, it presents a revised discussion of the support provided by the DAC to the Phase B DEV WP teams, although the details of these interactions are now captured in separate DAC-DEV interface documents.

2 Introduction

In 2014 the LSST:UK Consortium defined a baseline programme for the LSST:UK Science Centre (LUSC), which would support UK involvement in the LSST. As described in the LSST:UK Long-Term Plan [3], that comprised four temporal phases and four strands of activity, of which the two principal ones were LUSC-DAC (development and operation of a UK Data Access Centre) and LUSC-DEV (software development projects in support of key UK science interests).

During LUSC Phase A (2015-2019), the DAC and DEV strands developed largely independently of each other, with the notable exception of the development of the Lasair event broker, which was undertaken by a tightly coupled team of DAC and DEV staff. The remaining work of the DAC team was primarily guided by interactions with the Rubin Data Management (DM) team, the STFC-funded IRIS[5] initiative and other data-intensive projects in the UK astronomy programme, such as Gaia, Euclid and SKA.

Those interactions aided the production of the plan for Phase B DAC development that was presented in D2.1.1. That centred on a DAC Roadmap that proceeded in four stages – from UKDAC0 in May 2020 to UKDAC3 in December 2022 – with each release including a greater selection of data (from Rubin Data Previews and Phase B DEV WPs) and featuring a fuller suite of functionality, taking the UK DAC nearer the state required at the start of survey operations.

The advent of the Covid-19 pandemic has significantly affected the implementation of that plan. The delay to the completion of Rubin Observatory construction has led Rubin commissioning to be delayed, with a resultant shift in the timeline for the Data Previews, which set the principal milestones for the release of DAC software by the Rubin Observatory and its deployment in the UK DAC. Over the same timescale, the US funding agencies have adopted the in-kind model for international contributions. As part of this, the scope of the UK DAC has increased, from serving UK astronomers alone to providing a service for a significant fraction of the international data rights community. This change has resulted in a significant fraction of the UK's data rights allocation.

2.1 High-level View of the UK Data Access Centre

These events – and the long-expected adoption of Lasair as a Community Broker – have changed the ultimate content and scale of the UK DAC, and the timeline for its development, but not the fundamentals of its design nor the principles underpinning its deployment. The high-level view of the UK DAC presented in this section differs only slightly, therefore, from that given in D2.1.1, although some features have become more definite because of progress made during the past two years.

The data to be produced by the Rubin Observatory represents a step-change in astronomy, with a volume and complexity that is not amenable to traditional workstation-based scientific analysis. Considering that, the Rubin Observatory is developing a suite of software services called the Rubin Science Platform (RSP) to provide access to, and support analysis of, LSST data release data products[1]. The RSP will run in the two Rubin-operated DACs (in the US and in Chile) and must run in any *Full* Independent Data

[1] The LSST alert stream will be handled separately, by the network of approved Community Brokers, but the Prompt Products Database that archives LSST alert information will also be accessible through the RSP at the US DAC and, possibly, others.

Access Centres (IDACs), as defined in [6]. The UK DAC will be a Full IDAC, as we plan to host all data products from each data release, so it will run the RSP.

In Figure 1, we provide a high-level overview of the expected composition of the UK DAC. To aid the plan described in this report, we highlight a partition of the components of the DAC into two parts: one with astronomer-facing elements, and one with elements to support DEV products to deliver added-value functionality and datasets (to astronomers through the UK DAC).

The astronomers' view will be based largely on software and services developed by the LSST Data Management Team (coloured in light blue):

- At the time of writing, three different user interfaces are anticipated:
  - A web-based view, called Firefly [7] [8].
  - A scripting (Jupyter Notebook) environment, called Nublado [9].
  - A programmatic API to undertake large-scale data analysis campaigns from remote, high-performance and high-throughput computing resources.
- Scientific data to be served to users is organised into three categories:
  - LSST Data Release Products, as defined in [2].
  - Third-party datasets from Ancillary Surveys, which are scientifically useful in combination with LSST data.
  - User-generated Products [2]; for example, created using DEV-developed software.
- Access to LSST Data Release Products must be restricted to Rubin data rights holders, while User-generated Products and possibly Ancillary Surveys may also have access restrictions (if they are derived from Data Release Products). Access restrictions must be enforced locally within the UK DAC, although the list of data rights holders will be provided by the Rubin Observatory.
- Lasair (coloured orange) has been selected to be an LSST Community Broker and will provide access to the Observatory's nightly alert stream. It has not yet been decided whether Lasair's user interfaces will be separate from, or integrated with, the three user interfaces (Firefly, Nublado, and API) noted above.
- Data will be ingested into the UK DAC from:
  - the Rubin Observatory[2], in the case of LSST Data Release Products and some externally generated User-generated Products.
  - Other surveys, in the case of Ancillary Surveys (coloured in dark blue).
  - Back-end DAC infrastructure in the case of UK-led User-generated Products—typically using software (algorithms and workflows) developed in DEV work packages but possibly through other Rubin International Science Collaboration roles (coloured green).

The make-up of the astronomer-facing elements is reasonably well understood and unlikely to change significantly between the time of writing and early operations. Conversely, the make-up of the DEV interface to the DAC (that is, elements coloured in green) will vary from work package to work package (and are specified in per-WP DAC-DEV interface documents): the illustration is a sample of one possible form, intended to highlight the following considerations:

- DEV algorithms and workflows that require access to large parts of an LSST Data Release and/or third-party catalogues may benefit from having access to dedicated copies of that data, in a form most amenable to ingestion into the DEV workflow

[2] Rubin Data Products will be generated across three data facilities – in USA, France, and the UK – which represent the Observatory from the perspective of DRP. Actual data may be ingested from any of the three Data Facilities, as is most convenient.

(which is not necessarily the form used to serve the data to data-rights holders). Not only might this reduce the latency in delivering the associated User-generated Products, but it will also reduce demand on user-facing services and eliminate potential contention for access.
In contrast, where there is only modest demand on input sources – both LSST Data Release Products and third-party surveys – it is reasonable to expect this demand to be served by existing user interfaces (for example, the batch processing APIs for LSST data) without the need to set up separate copies of that data.

- DEV algorithms and workflows are likely to run on UK DAC supporting services.

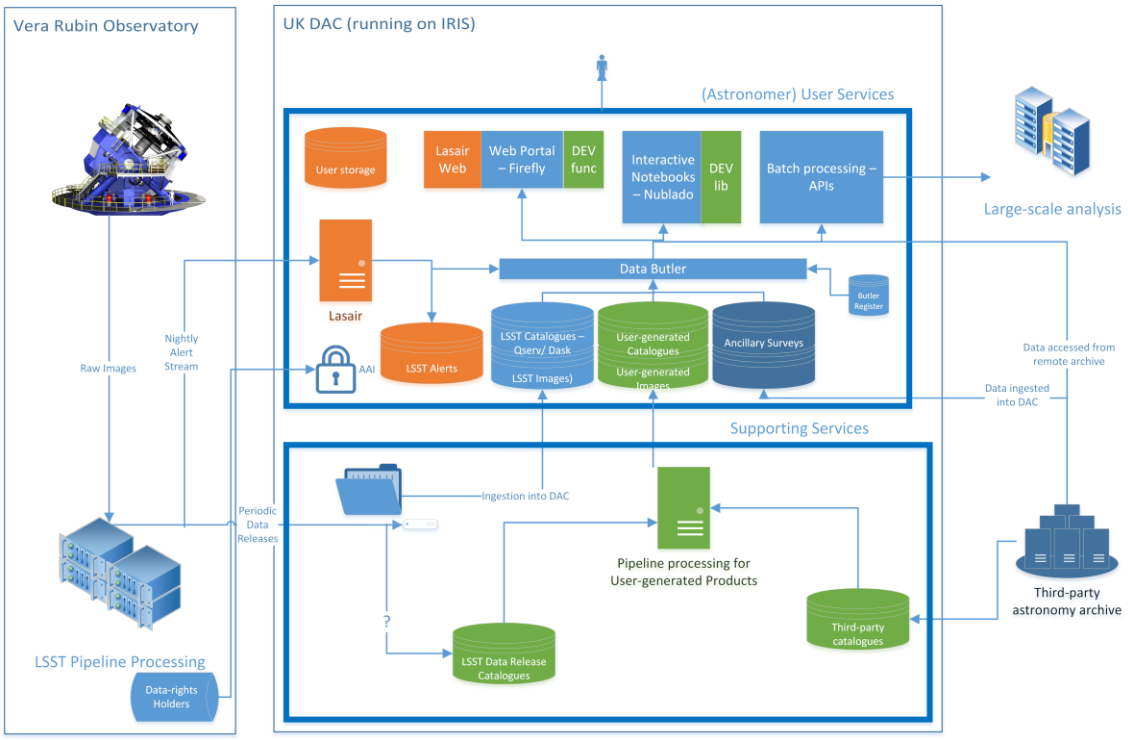

Figure 1: High-level Layout of UK Data Access Centre Service Elements.

2.2 Glossary of Acronyms

DAC	Data Access Centre (or UK Data Access Centre work packages)
DEV	Development work packages
DM	LSST Data Management Team
IDAC	Independent Data Access Centre
LSST	Legacy Survey of Space and Time
RSAP	(IRIS) Resource Scrutiny and Allocation Panel
RSP	Rubin Science Platform
SC	LSST International Science Collaboration

3 UK DAC Roadmap

A roadmap has been developed to deploy, maintain, and support a prototype UK DAC platform throughout Phase B, informed by:

- The DM team's plan for delivery of RSP services and functionalities.
- The Rubin Observatory's timeline for providing (commissioning) Data Previews.
- The LSST:UK Phase B (DAC and DEV) priorities and plans.

This will help UK-based astronomers to prepare for Rubin operations and, in the shorter term, will help with the integration of DEV products into the UK DAC. The roadmap was introduced in February 2020 and has been updated several times since, in response to changes in the Rubin schedule. The Rubin schedule is still subject to change, but those changes will now affect the Phase C version of the roadmap, so that for Phase B should now be finalised.

The roadmap is available on the LSST:UK Confluence site [4], though key points are summarised in Table 1, noting the following considerations:

- Target delivery date—the aim is to provide regular updates to the UK DAC platform, based on the forecast availability of LSST data previews and software, and aligned to the requirements of DEV activities.
- Platform—we expect the UK DAC to be hosted on infrastructure provisioned by IRIS.
- Functionality—we list the high-level service elements we expect to be available and sufficiently mature in each release.
- Data—the ancillary, user-generated, and LSST datasets that we intend to provide to aid end-user evaluation of each release.
- Access—the intended access mechanism.
- Helpdesk—the primary user-support mechanism that will be available.

One should note that the ancillary datasets listed in the roadmap are those that are proposed to be exposed to end-user astronomers, for evaluation of and familiarisation with the RSP and its capabilities: ancillary datasets that are required to support DEV activities are documented in interface requirement documents (see Section 5).

During Phase B, the DAC team has worked with DEV activities to identify and deploy LSST (or third-party) technologies and data on which each DEV activity depends, plus to identify integration points at which DEV products can be incorporated into the platform.

	UKDAC0	UKDAC1	UKDAC2	UKDAC3
Delivery Date	2020-05-01	2020-10-01	2021-12-01	2023-03-01
Platform	IRIS	IRIS	IRIS	IRIS
Functionality	• RSP components: Firefly, Nublado • Non-RSP components: none	• RSP components: Firefly, Nublado, qserv(TBC) • Non-RSP components: Lasair-ZTF (TBC), basic user storage	• RSP components: Firefly, Nublado, qserv (DP0.1), basic user storage (NFS)	• RSP components: all • Non-RSP components: Lasair notebooks, batch compute to support DEV services (TBD)
Data	UKIDSS DR11 (TBC) via existing WFAU TAP (catalogues) and SIA (images) services	UKDAC0 holdings, plus PS1 (catalogues) via DAC-hosted TAP and SIA services. Lasair-ZTF and other prioritised ancillary datasets (TBC).	UKDAC1 holdings, plus DP0.1 datasets (DESC DC2), and test DEV data from WP3.5 (VISTA and HSC) and WP3.11	UKDAC2 holdings, plus DP0.2, WP3.5 (VIDEO, VHS/VIKING), ZTF DR (TBC) and further WP3.11 data (TBD)
Access	• Authentication: EGI check-in • Accounts: admin, internal DAC test users	• Authentication: EGI check-in • Accounts: admin, invited test users from LSST:UK Consortium	• Authentication: GitHub credentials • Accounts: admin, invited users involved in DEV WPs and other activities (TBD).	• Authentication: GitHub credentials • Accounts: admin, invited users involved in DEV WPs (e.g., science teams related to WP3.5) and other activities (e.g., Lasair usage).
Documentation	Only as provided by Project	Project-provided, plus online documentation for invited test users	Project-provided, plus UK-specific online documentation	Project-provided, supplemented by UK-specific online documentation to support authorised users
Helpdesk	GitHub Issues (internal DAC only)	GitHub Issues (test users)	Community forum (for Lasair), plus GitHub issues for non-Lasair help	Community forum

Table 1: UK DAC Roadmap for Phase B.

4 Infrastructure Provision

During Phase A, it became clear that the infrastructure needed to support LSST:UK science would most likely be provided by the shared-infrastructure project IRIS [www.iris.ac.uk].

At the time of writing, IRIS offers three kinds of infrastructure:

- Large-scale high-through computing and storage on grid infrastructure managed by GridPP [www.gridpp.ac.uk].
- High-performance computing resources from DiRAC [www.dirac.ac.uk].
- Cloud computing and storage (available from several IRIS member institutions).

Time and capacity on these different infrastructures is secured through an annual (April—March) Resource Scrutiny and Allocation Panel (RSAP). The RSAP treats LSST:UK as a single user and expects the consortium to formulate a single unified request to IRIS, late in each calendar year, based on the aggregated requirements of the LSST:UK members.

For LSST:UK, the DAC team is the point of contact with the RSAP. The DAC team has engaged successfully with the RSAP since its inception in late 2018 and has, at the time of writing, secured more than 30 million core hours of computing time and 2 Petabytes of working storage.

As well as applying for infrastructure on behalf of the Consortium, the DAC team also works with IRIS to ensure that the infrastructure procured by IRIS is relevant to LSST:UK's needs. The DAC team maintains a five-year forecast of infrastructure requirements, which feeds into the IRIS Delivery Board's provisioning plans, and highlights potentially demanding LSST:UK use cases to the IRIS Technical Working Group, to ensure that LSST:UK technology needs are considered when planning and provisioning new infrastructure.

Around October of each year, the DAC team requests details, from both the DEV activities and the wider UK Consortium, of forthcoming infrastructure requirements, based on a request template provided by the RSAP. Given the potential complexity of the infrastructure available, the DAC team works with DEV teams and other Consortium activities to understand and properly size their requirements, so that a coherent and strong bid for resources can be submitted to IRIS for the December deadline. As an allocation process (rather than an award process), it is common for the RSAP to engage with the DAC team during application preparation.

Even after resources have been awarded, the DAC team continues to be a liaison between IRIS and the Consortium, monitoring and validating any deviations from the planned usage by LSST:UK, lobbying to IRIS for resolution of infrastructure issues, and securing from IRIS any top-ups or changes to the allocation that may be required.

As the project progresses, it is anticipated that the type and level of demand LSST:UK will place on IRIS will grow. The requirements that are envisaged to be the most demanding for IRIS are:

- Providing capabilities for LSST:UK to operate significantly distributed, multi-Petabyte databases.
- Providing low-latency infrastructure for consuming and processing the LSST alert stream in pseudo-real-time.
- Providing rapidly scalable cloud resources to adapt to the variable demand from users for analysis resources over the lifetime of each LSST Data Release.

The DAC team will continue to work with IRIS to satisfy these demands, along with others identified through the work of the DEV work packages.

Currently, much of the required capability is provided by the Somerville cloud service [10]. This is physically located at the University of Edinburgh's Advanced Computing Facility, at Easter Bush, outside the city of Edinburgh. It currently comprises the following resources:

- 2.6 PB HDD (Ceph-managed) [11]
- 100TB SSD (also Ceph-managed)
- 320 compute cores (16 GB/ core)
- 100 Gbps to Internet (2×100 Gbps uplink).

Somerville runs the Scientific OpenStack cloud software, which is a version of OpenStack developed by StackHPC and adopted by IRIS for its cloud infrastructure.

5 DAC-DEV Integration Planning

At the time of writing, there are nine active Phase B DEV work packages:

- WP3.2: LASAIR–the UK transient broker for LSST
- WP3.3: Spectroscopic identification of transients
- WP3.5: LSST and near infra-red data fusion
- WP3.6: Photometric redshift estimation
- WP3.7: Low-surface-brightness science using LSST
- WP3.9: LSST Point Spread Function, sensor characterisation and modelling
- WP3.10: UK Contributions to DESC Operations
- WP3.11: Cross matching and astrometry at LSST depths
- WP3.12: Support of EPO software

These work packages are developing software and data products to:

- Enhance the DAC user-facing functionality.
- Enable the creation of User-generated Products [2], to supplement the baseline LSST Data Release Products.
- Support users to incorporate ancillary datasets, alongside LSST Data Products and User-generated Products [2], into their research.

To maximise the impact of outputs from the DEV work packages, careful consideration needs to be given to how DEV outputs are integrated into the UK DAC, including:

- How DEV activities' software is integrated with software and services provided by the LSST DM team and by the UK DAC team. This is focused on the UK DAC platform though provides insight into how DEV software could be deployed on other platforms.
- How enhanced functionalities are made available to users, via the UK DAC.
- How User-generated Products and ancillary surveys are made available in the UK DAC.
- How the UK DAC infrastructure and services are configured to maximise the impact of products from the DEV work packages.

This consideration is best addressed by the DAC team and each DEV activity, in collaboration.

5.1 Project Support for DAC-DEV Coordination

As part of the setup of Phase B, an enhanced project-support mechanism was devised, building on experience from Phase A and recognising the need for the outputs of different work packages to be integrated together before the end of LSST Commissioning Phase. These mechanisms are described in detail in the Project Management Plan [1], though summarised here.

- A communication plan has been developed to encourage regular and frequent communications within the UK team. In particular, the whole team meet (face-to-face or virtually) at least every three months, to coordinate cross-project activities, to update plans and to disseminate progress. In addition, several mailing lists have been created for day-to-day information sharing, and a Slack workspace has been set up to encourage more spontaneous and interactive discussions.
- Collaboration – building on good practice from other distributed development projects, various tools have been adopted to streamline and support collaboration. Most notably, there is a well-established project routine built around Atlassian Confluence and GitHub. All project documents and materials are stored in

Confluence [https://lsst-uk.atlassian.net/wiki] and software development is coordinated in GitHub [https://github.com/lsst-uk].

- Community engagement – mirroring the philosophy of LSST, the UK consortium has adopted an Open Source strategy for its work. Almost all the Confluence and GitHub materials are visible to the whole collaboration, who may then exploit the outputs of that work or use it as a basis to engage with the developers. Further, the project team regularly updates the community on its plans and progress, and software and data is released (where permitted) as Open Source.
- Stakeholder engagement – to be successful, the Consortium needs to actively engage with key stakeholders in a number of fields: the LSST:UK leadership team is represented on the STFC IRIS Delivery Board and Technical Working Group; the Consortium has an on-going dialogue with peer projects, such as Gaia, Euclid and SKA; and the DAC team are working collaboratively with other Rubin stakeholders including – at the time of writing – LSST:France, the Dark Energy Science Collaboration, and the LSST Alert team.

5.2 Integration of DEV Products into UK DAC

Some, but not all, of the Phase B DEV work packages will deliver products (software or datasets) that need to be integrated into the UK DAC. Funding was identified, in the Phase B award for WP2, to support engagement with any DEV work package planning integration with the UK DAC, but, in practice, only three of the DEV work packages (WP3.3, WP3.5 and WP3.11) have drawn on that effort, because:

- WP3.2, which considers the scientific exploitation of the LSST alert stream, has a dedicated DAC complement (WP2.3) which will address the integration of alert-stream services into the UK DAC platform and infrastructure.
- WP3.6 and WP3.10 are using DESC-provided computing resources in the US.
- WP3.7 is using Rubin computing resources, as it is developing software for integration with the data processing pipelines.
- WP3.9, which considers the sensor characterisation modelling of the point spread function for the LSST camera, will not directly contribute functionality nor datasets into the UK DAC.
- WP3.12 runs on the Zooniverse platform.

DAC engagement with the DEV work packages is an on-going activity, though has two particularly important stages:

- Early in the timeline of a DEV work package, to agree on how the DEV work package's products integrate into the DAC, and to agree the interfaces that should be employed between the DAC platform and the DEV products.
- Towards the end of each DEV work package, to validate the DEV outputs, finalise the integration of these outputs into the DAC platform, and to agree an operating model for DEV outputs in LSST:UK Phase C.

Agreeing and defining the form of the DEV view, for each of the relevant DEV work packages, has been a crucial task for the initial DAC interaction with each work package, along with an understanding of what technologies will support the interactions between the DEV view and the astronomer view.

The findings of this work are documented in an *Interface Requirements Document*—one for each DEV work package—which include, at least:

- Details of the datasets that are required by the DEV team, along with when the DEV team need them and how the DEV team will use them.

- Details as to how the DEV outputs (software, data, and documentation) will integrate into the UK DAC, and the interfaces that need to be provided by the DAC team for this.
- The interfaces and standards the DEV team need to adopt and develop against to make integration easy, aiming to make the software as portable as possible (e.g., between different IRIS infrastructure options or different DAC platforms).
- The approach to validate DEV team's products in the DAC, within the scope of the Phase B effort (effectively DEV commissioning).
- The infrastructure and support requirements, in production, to operate the DEV team's products.

At the time of writing, Interface Requirements Documents exist for WP3.5 and WP3.11; DAC team interaction with WP3.3 has, to date, been limited to provision of a containerised environment running on the Somerville cloud, but this may be expanded, and captured in an Interface Requirements Document, in due course.

6 Transition to Phase C

The first version of these operational plans, described in D2.1.1, envisaged a fully working UK DAC towards the end of Phase B, which integrated functionality and user-generated-product workflows from DEV activities, to enhance the capabilities for UK-based astronomers. As noted above, Covid-induced delays with the Rubin schedule have pushed the later Data Previews (as well as Data Release 1) into Phase C, with the result that UKDAC3, the final Phase B release of the UK DAC, will be a less mature system than was expected to be in place when Phase B planning began.

Plans for the final Data Previews should be released by the Rubin Observatory before the end of Phase B, so the DAC team will produce an updated roadmap prior to the start of Phase C. This will cover the transition of the WP2 staff from a development team, building a facility to a schedule set by the timeline for the Data Previews, to it performing a service-operation role, managing access to available (IRIS) infrastructure and supporting Rubin data rights holders to use the Data Access Centre; and operating/ refining the DEV workflows to produce UK-led User-generated products for the international LSST community, as part of the UK's in-kind programme. That plan will also generate forecast requirements for infrastructure, which will then be shared with the IRIS Delivery Board to influence their provisioning plans into Phase C and beyond.

The DAC team also aims to have a closer working relationship with other IDACs, during Phase C. At the time of writing, there are twelve confirmed IDACs and one confirmed Science Processing Centre (SPC) – where a Science Processing Centre is a contribution of computing resources to aid with large-scale analysis, though without significant storage for long-term hosting of Data Products. To this end, the UK team is helping organise a four-day IDAC workshop, scheduled for March 2023 (see announcement on Rubin Community Forum). This workshop will be split into two parts: the first two days will collect use cases from the community for early science (that is, Data Releases 1, 2, and 3 – plus Data Previews, if appropriate); the final two days will be a closed session, for IDAC representatives only, to consider how best to respond to these use cases and progress key elements of the orchestration and implementation of the IDAC network.

It is expected this workshop will be the first of several, providing an opportunity for IDACs and SPCs to coordinate activities and shared experience, and to lobby the Rubin Observatory on matters that require their attention, towards achieving a successful IDAC network.

7 References

[1] G. Beckett, *LSST:UK Science Centre Phase B Project Management Plan*, Version 1.6 (February 2020)

[2] LSE-163 – *LSST Data Products Definition Document*

[3] R.G. Mann, *LSST:UK Long-Term Plan*, Release 1.1 (May 2016)

[4] *LSST:UK DAC Roadmap*, https://lsst-uk.atlassian.net/wiki/spaces/LUSC/pages/921337857/Phase+B+DAC+Roadmap, (accessed 25th May 2020)

[5] IRIS, www.iris.ac.uk

[6] W. O'Mullane et al., *Guidelines for Rubin Independent Data Access Centers* (RTN-003), Version 1.3 (29/JUN/21).

[7] Firefly GitHub repository, https://github.com/Caltech-IPAC/firefly

[8] G. Dubois-Felsmann, *LSST Science Platform Portal Aspect Design and Maintenance Manual* (DMTN-136), (29/4/21)

[9] C. Banek, *Nublado v2 Architecture*, (DMTN-164) (2/10/20)

[10] *Somerville Service*, https://lsst-uk.atlassian.net/wiki/spaces/LUSC/pages/2756968452/Somerville+Service

[11] The Ceph Foundation, *Ceph, Democratising Data Storage*, digital report available at https://ceph.io/assets/pdfs/report-dec2021.pdf (December 2021)