Vera C. Rubin Observatory
Data Management

Data Management and LSST Special Programs

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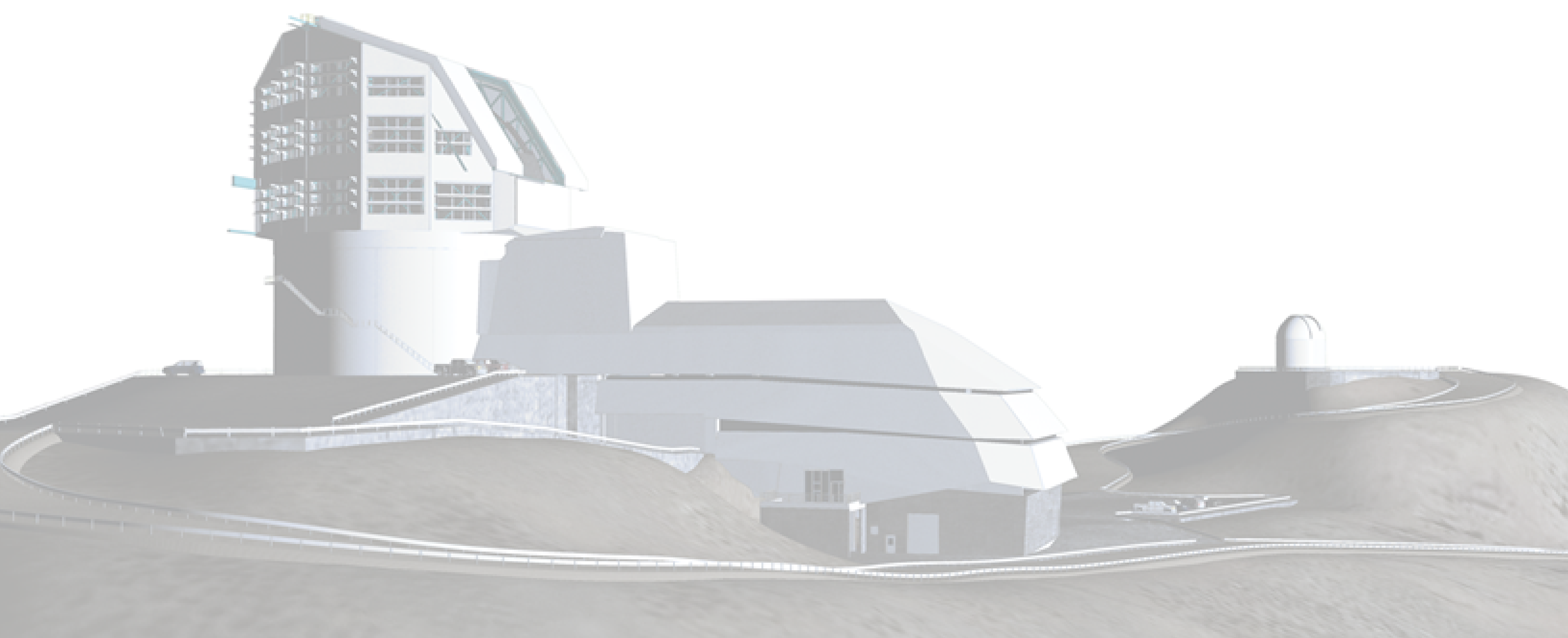

Abstract

The core LSST science goals will be met by the Wide-Fast-Deep (WFD) Main Survey, which is expected to be accomplished with 85–90% of the observing time. The remaining 10–15% of the time will be spent on Special Programs: additional survey areas and/or observing strategies that are driven by specific science goals which build on, or are beyond, the core science pillars of the LSST.

This document provides a summary of the Special Programs being considered, the potential diversity of data they might produce (e.g., shorter or longer exposure times), and the role of Rubin Observatory in reducing, processing, and serving data products from Special Programs. The latter includes a discussion about the relevant system requirements, the needed capabilities of the LSST Science Pipelines and the Rubin Science Platform, and the cases in which Special Programs data products would be User-Generated.

The specialized, science-specific aspects of Special Programs processing and analysis that are best left to the science community are also described, and illustrated with case-study examples.

The main target audience of this document is Rubin Observatory staff – the construction-era Data Management (DM) team and the operations-era Data Production (RDP) team – but members of the science community who are planning to use Special Programs to reach their science goals may also find this document useful.

Change Record

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0	2017-11-14	Status: internal working document.	Melissa Graham
1	2018-06-17	Updated to finalize and issue.	Melissa Graham
2	2021-12-01	Updates per DM-20375.	Melissa Graham

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Contents

Data Management and LSST Special Programs

1 Terms and Definitions

1.1 Wide-Fast-Deep (WFD) Main Survey

The WFD Main Survey is the core science program of the LSST, designed to achieve the science goals defined by the Science Requirements Document (SRD; LPM-17). As of the Phase 1 SCOC recommendations in PSTN-053, the WFD Main Survey is thought of as several contiguous areas that cover at least ~18000 deg^2 with $\gtrsim$800 visits per field, and is expected to be accomplished with ~85% of the observing time. These areas include the low-dust-extinction survey area (the largest area), the higher-extinction high stellar density Galactic Bulge, and the Magellanic Clouds.

1.2 Mini-Surveys

As of the Phase 1 SCOC recommendations in PSTN-053, the term "mini-survey" refers to additional areas that are adjacent to the WFD but are covered with a few hundred (100-300) visits per pointing. They are expected to be accomplished with ~10% of the total survey time. Mini-surveys include the North Ecliptic Spur (NES), the remainder of the Galactic Plane, and the South Celestial Pole. Boundaries, re-visit cadences, and depths for all WFD areas remain to be determined [PSTN-053].

1.3 Special Programs

Special Programs are survey areas and/or observing strategies, aside from the WFD and mini-surveys, that are driven by specific science goals which either build on, or are outside of, the core science pillars of the LSST. Special Programs will fill the remaining ~5% of the available survey time, and include both "deep drilling" fields and "micro-surveys".

1.3.1 Deep Drilling Field (DDF)

A DDF is a single pointing for which many exposures are obtained during the night. The five DDFs (below) are expected to take ~5% of the total available time. Generally, the LSST observing strategy for a DDF is to obtain some or all of these exposures consecutively, and to maintain a high inter-night cadence over a short season (e.g., returning every two nights over four months, Ivezić et al. 16) – but the exact strategies and total time for the LSST DDFs remain to be determined [PSTN-053].

- Elias S1 (00:37:48, -44:00:00)
- XMM-LSS (02:22:50, -04:45:00)
- Extended Chandra Deep Field-South (03:32:30, -28:06:00)
- COSMOS (10:00:24, +02:10:55)
- Euclid Deep Field South (04:04:58, -48:25:23)[1]

1.3.2 Micro-Surveys

As of the Phase 1 SCOC recommendations in PSTN-053, the term "micro-survey" refers to either new sky areas observed with a WFD-like survey, or sky areas within the WFD but observed with a specialized strategy. Micro-surveys are expected to take up the remaining ~10% of the total available survey time over LSST's 10 years, and those which would use >0.3% of the time and are currently being considered by the SCOC are listed below (see also PSTN-053).

- short-exposure twilight visits (for near-Sun and near-Earth objects; NEOs)
- a static short-exposure (5 sec) map of the sky in $ugrizy$ in the first year (for calibration)
- an extended short-exposure survey of the sky in $ugrizy$ (for transient detection and static-sky calibration)
- target-of-opportunity (ToO) follow-up (to identify optical counterparts to gravitational wave sources)

[1] https://www.cosmos.esa.int/web/euclid/euclid-survey

- coverage of the Roman microlensing bulge field (potentially as a DDF)
- deeper g-band imaging of 10 local volume galaxies
- a high-cadence survey of 2 fields in the SMC (for microlensing)
- annual week-long surveys of the Carina nebula and surrounding star-forming regions
- a limited-visit (i.e., shallow) "northern stripe" survey to declination $<$+30 degrees
- a survey of the Virgo cluster to WFD depth

Note that there remains some grey area between what is a mini-survey within the WFD, and what is a WFD-like micro-survey. For example, the last two on the list above (the northern stripe and the Virgo cluster) could also be (or might be in the future) called WFD mini-surveys, and not Special Programs micro-surveys.

1.4 Visit Types

A visit is an observation of a single pointing at a given time, of which there are three types as listed below. As of the Phase 1 SCOC recommendations in PSTN-053, most WFD and DDF visits would be standard or alternative standard visits. However, non-standard visits with longer exposure times are being considered, especially for u-bands, and several of the micro-surveys are considering shorter exposure times. The full potential for diversity in Special Programs data is reviewed in Section 2.2.

- Standard Visit – Composed of 2×15 second exposures (commonly referred to as "snaps").
- Alternative Standard Visit – Composed of a single 30 second exposure.
- Non-Standard Visit – Any other exposure time(s) or number of snaps.

2 Reduction and Processing for Special Programs Data Products

2.1 Requirements Related to Special Programs

A detailed list of the requirements related to Special Programs is provided in Appendix A. The most important requirements are summarized below.

2.1.1 Data Products

Rubin Observatory and the LSST system (the observatory and the data management systems) are required to process Special Programs data to produce unique and separate data products "whenever possible" (LSR-REQ-0121).

The term "whenever possible" includes cases where the original or reconfigured versions of the LSST Science Pipelines can be run, and excludes cases where the development of new algorithms or the allocation of significant additional computational resources are required (LSR-REQ-0121).

The statement "to produce unique and separate data products" typically refers to producing the same kinds of data products as will be generated by the Prompt and Data Release pipelines (processed visit images, coadded images, difference images, and catalogs of sources and objects for those images).

It is a requirement that the cumulative size of the Special Programs data products generated by Rubin Observatory be no more than ∼10% the size of the Data Release data products (i.e., proportional to the fraction of survey time spent; LSR-REQ-0121).

It is a requirement that these Special Programs data products be distinct, and joinable with (in other words, they can be federated or cross-matched with) the Prompt and Data Release data products (DMS-REQ-0322).

The derivation of value-added data products, such as HiPS or MOC maps, for Special Programs remains an open question (DMS-REQ-0379, 0383).

2.1.2 Metadata

In order to support Special Programs processing, the LSST system is required to store metadata that includes program information for every raw image, such as identifiers for images obtained as part of the Main Survey or a Special Program (DMS-REQ-0068).

It is required that this metadata be sufficient for Special Programs to trigger their own real-time data processing recipes "whenever possible" (DMS-REQ-0320), and be included in alert packets (DMS-REQ-0274).

2.1.3 Processing

It is a requirement that any Special Programs processing done with the Prompt pipeline (or a reconfigured version of it) is subject to the same timescales and latency constraints of 24 hours for the release of Prompt data products and 1 minute for the transmission of Alert packets (DMS-REQ-0344).

It is also a requirement that Special Programs processing be done on timescales intermediate to the Prompt and Data Release processing, "whenever possible" and whenever necessary to enable the intended science goals of the Special Program (LSR-REQ-0032).

It is a requirement that the LSST system be able to process non-standard visits with short exposure times as low as 1 second, with a discussion note that such short exposures might have degraded image quality (LSR-REQ-0111).

Processing for Special Programs by Rubin Observatory is expected to use no more than $\sim$10% of computational and storage capacity of the Rubin data processing cluster (i.e., proportional to the fraction of survey time spent and the size of the Rubin-processed Special Programs data products; Section 6 of the DPDD).

2.1.4 User Processing

In cases where the science goals of a Special Program require that new algorithms or software be developed, User-Generated pipelines and data products will be needed.

The 10% of the total data processing capacity that Rubin Observatory is required to reserve for all User-Generated processing includes that applied by users to Special Programs data – in other words, there is no additional capacity *for users* that will be reserved only for Special Programs data (LSR-REQ-0041).

2.2 The Potential Diversity of Special Programs Data

As discussed in Section 1, most of the Special Programs that are currently under consideration will use standard or alternative standard visits. However, some are likely to require non-standard visits with shorter exposures (5 sec). Furthermore, some are likely to acquire images with a significantly brighter sky background (e.g., twilight images) than most nighttime survey images.

The cadence and patterns of Special Programs might also differ from the WFD, such as long series of exposures obtained of the same field (e.g., DDFs), or a strategy optimized to find very fast-moving objects (e.g., NEOs).

It does not appear that any of the currently-proposed Special Programs are likely to violate boundaries imposed by the Rubin Observatory hardware, but there remain a few open questions about boundaries on data processing imposed by the LSST Science Pipelines.

2.2.1 Hardware Boundaries

Appendix B lists all of the hardware boundaries that might constrain the potential diversity of Special Programs data.

The minimum exposure time is 1 second (stretch goal: 0.1 seconds), and there is a potential hardware boundary that limits the readout rate to 1 every 15 seconds. This would affect the image acquisition rate and increase the overheads of the proposed short-exposure micro-surveys.

Special Programs which required the *exact same* field pointing and rotation for *every exposure* (to sub-arcsecond levels) might run into hardware boundaries on pointing and tracking, but none of the currently-proposed programs seem likely to be affected by this potential boundary.

Hardware imposes no other boundaries on how data can be obtained, but Special Programs that request a high number of filter changes and/or long slews could be inefficient due to large overheads.

2.2.2 Processing Boundaries

Appendix C describes the boundaries on what types of visits can be processed and calibrated by the LSST Science Pipelines, which are designed to process standard (or alternative standard) visits.

Very short (<2 sec) exposures could be difficult to reduce due to an incompletely-formed PSF, and very short or very long (>150 sec) exposures could be difficult to calibrate due to having too few (or too few unsaturated) stars. As mentioned above in Section 2.1, the LSST system is required to be able to process exposure times as low as 1 second, and it is known that such short exposures might have degraded image quality.

It is currently unclear whether images with very bright sky backgrounds (twilight images) can be processed with the LSST Science Pipelines, or whether user generated pipelines will be needed.

The full reduction and calibration of images obtained with non-sidereal tracking, in which the stars are streaked, is currently beyond the scope of the LSST Science Pipelines, and will require a user generated pipeline.

2.3 Including Special Programs Data in the WFD Main Survey's Data Products

Instances where the Special Programs data might be included in the Prompt and/or Data Release data products alongside data from the WFD Main Survey – i.e., the data products described by LSE-163 – are preliminarily described.

Generally, Rubin Observatory might incorporate Special Programs data into the data products for the WFD Main Survey whenever this is (1) possible and (2) scientifically beneficial. **Decisions about when and whether to include Special Programs data in the WFD Main Survey's data products are left to the discretion of the Rubin Operations Data Production and System Performance teams.**

2.3.1 Prompt

It is expected that all Special Programs data that *can* be processed by the Prompt processing and Alert Production pipelines *would* be, alongside the standard visits from the WFD Main Survey, as this would be scientifically beneficial to the science pillars of the LSST.

Non-standard visits that can be processed with the Prompt pipeline in accordance with the relevant requirements might also be included.

Very short and very long exposure times might be excluded if they would need specialized algorithms or templates[2]. Visits in sky regions that Rubin had not previously observed would not be able to contribute to Alert Production until a template could be generated.

The data products from Special Programs images would thus contribute to all of the Prompt data products described in Section 3 of the DPDD [LSE-163]. Images and catalog rows would be tagged with a program identifier indicating their Special Program of origin, so that the associated data products can be discovered and extracted by users.

There are two potential issues which might complicate Prompt processing for Special Programs which obtain a sequence of images without slewing, such as the Deep Drilling Fields. (1) As alert packets contain the full records of all associated `DIASources` from the past 12 months, alerts for `DIAObjects` in the DDFs might become very large. (2) The association of *new* `DIASources` into `DIAObjects` will be somewhat compromised for a DDF sequence. The processing for the second image begins when the processing for the first image is only halfway done – when the `DIAObject` catalog has not yet updated with the new `DIASources` detected in the first image. Thus, the `DIASource` from images one and two for a new transient would not be associated with a single `DIAObject`, but instead would each instantiate a new `DIAObject`.

As a side note, no User-Generated pipeline may contribute Alerts to the LSST Alert Stream, and since the latency on image availability is "within 24 hours" (`L1PublicT`) no User-Generated L1PublicT
pipeline would be able to obtain and process Special Programs data on a timescale similar to the Alert Stream (60 seconds, `OTT1`). OTT1

[2]If a Special Program's science goals do require specialized templates and Prompt processing, the DMS will have the capability to load and use an alternative template for some regions, based on the image metadata. However, there would not be enough memory to hold alternative templates for the whole sky region.

2.3.2 Solar System Processing

Since Solar System Processing takes `DIASources` as input, so any Special Programs images that can be run through the Alert Pipeline can also be incorporated into Solar System Processing.

2.3.3 Data Release

It would be both possible and scientifically beneficial to include all standard and alternative standard visits from Special Programs in *some aspects* of the Data Release processing – such as the repository of processed visit images and the `Source` and `Forced Source` catalogs – alongside the standard visits from the WFD Main Survey. Images and catalog rows would be tagged with a program identifier indicating their Special Program of origin, so that the associated data products can be discovered and extracted by users.

However, some of the core LSST science goals require a WFD Main Survey data products of *uniform depth*. Whether and how to include any Special Programs data in the deep image coadds and the corresponding `Object` catalog is left to the discretion of the appropriate Rubin teams in Operations.

For example, perhaps Special Programs images will only be included when they bring additional area to the same depth as the rest of the WFD Main Survey, or when they suppress edge effects or low-order modes in the all-sky photometric solutions.

2.4 Anticipated Rubin- and User-Generated Special Programs Data Products

As mentioned in Section 2.1, Rubin Observatory and the LSST system are required to process Special Programs data to produce unique and separate data products whenever the original or reconfigured versions of the LSST Science Pipelines can be used.

Cases where the development of new algorithms, or the allocation of significant additional computational resources, are required in order to produce unique and separate data products will require User-Generated processing.

The anticipated divisions between what will be Rubin- versus User-Generated for the variety of anticipated "unique and separate" Special Programs data products, which are designed to meet the specific science goals of the Special Programs, are *preliminarily* described. **Decisions about when and whether Rubin Observatory will generate Special Programs data products are left to the discretion of the Rubin Operations Data Production and System Performance teams.**

For Special Programs which will require User-Generated pipelines and data products, note that users will have access to all of the LSST Science Pipelines and its data processing infrastructure, as well as dedicated computational resources next-to-the-data (via the Rubin Science Platform; LSE-319). Details of the planned "User Batch" facility for data processing are described in DMTN-202. However, very computationally intense processing might require external resources.

Furthermore, it is expected that some User-Generated pipelines and data products might be "adopted" or "federated" into the LSST Science Pipelines and the Prompt and Data Release data products. Details regarding this process are to be provided elsewhere.

Appendix D provides more detailed, step-by-step data processing examples for some potential Special Programs as further illustration.

2.4.1 Deep Drilling Fields

As the DDFs will likely be observed with standard or alternative standard visits, it is likely that Rubin Observatory will be able to reconfigure existing pipelines to process the DDF data and produce "unique and separate" DDF data products.

Rubin-generated data products might include:
- nightly-coadded images (24 h)
- nightly-coadded difference images (24 h)
- deeply-coadded images (all images to date; yearly)
- templates for the nightly-coadded difference images (yearly)
- Source- and Object-like catalogs for the night and deep coadds (yearly)
- DIASource- and DIAObject-like catalogs for the nightly-coadds (24 h)

User-Generated data products might include, for example, DDF images coadded on other timescales, or using algorithms outside of the LSST Science Pipelines.

2.4.2 Short-Exposure Surveys

Short-exposure images obtained during twilight, which will have a very bright sky background unlike other LSST images, might require User-Generated algorithms to subtract the high sky background. Short-exposure images obtained during the night would have fewer stars for astrometric and photometric calibration, and might require User-Generated processing pipelines.

If the Rubin Operations team decides that the LSST Science Pipelines can be reconfigured and used for short exposures, then the Rubin-generated data products would likely be similar to the Data Release data products (Section 4, LSE-163). For example, a separate repository of processed visit images and coadded images, and separate (but joinable) `Source`, `Forced Source`, and `Object` catalogs.

2.4.3 GW Target-of-Opportunity

As the science goals of any target-of-opportunity program are the immediate processing and discovery of new transient phenomena, it is very likely that all ToO programs would be designed to use standard or alternative standard visits and Prompt processing data products such as Alerts. Prompt processing would proceed automatically for all ToO for which an LSST template image exists.

Options for Rubin Observatory to assist with or expedite the processing of ToO programs, especially during the first year of Operations when the template coverage will be low, are discussed in more detail in RTN-008.

Other science-driven data products from ToO programs, such as custom deep stacks and difference images to find $<5\sigma$ transients in the fields on intermediate timescales in cases where the optical counterpart was not detected, would require User-Generated processing.

2.4.4 Micro-Surveys

Potential micro-surveys include additional sky areas, in some cases covered to a depth that is different from the WFD Main Survey, such as the proposed micro-surveys for the Roman bulge field; deeper g-band imaging of 10 local volume galaxies; the SMC; the Carina nebula; the northern stripe; and the Virgo Cluster.

In all of these cases, if the Rubin Operations team decides that the LSST Science Pipelines can be reconfigured and used for the visits associated with these micro-surveys – which is likely if they're using standard or alternative standard visits – then the Rubin-generated data products would be similar to the Data Release data products (Section 4, LSE-163). For example, separate repositories of processed visit images and coadded images, and separate (but joinable) `Source`, `Forced Source`, and `Object` catalogs would be created for all of these micro-surveys.

In cases where data for the micro-survey is obtained throughout the year, then the separate data products would also be produced on a yearly basis. In cases where the data might be all obtained within a week (e.g., Carina nebular survey), such data products would likely be generated on a shorter (intermediate) timescales.

Micro-surveys with time-domain science goals that aren't met by the Prompt pipelines – for example if they require difference imaging with coadded images on an intermediate timescale (e.g., a weekly stack) – might require User-Generated processing.

3 Enabling the Discovery and Analysis of Special Programs Data Products

3.1 "Discoverability Considerations" (Visit Labels)

- needs for labelling
- survey characterizability, selection biases
- provenance and origin
- not just for separate data products but all regions
- what if someone puts a micro survey in NES? labeling useful

3.2 Anticipated Rubin Science Platform Capabilities for Special Programs

- discoverability of SP data when browsing an all-sky map
- to query data by tag of WFD, WFD mini-survey, or Special Program (e.g., DDF field, micro-survey identifier)

3.3 Computational Resources for User (Re-)Processing

As mentioned in Section 2.1.4, Rubin Observatory will reserve 10% of its total data processing capacity for users. This component would include *all* user processing and re-processing of any and all LSST data, including Special Programs.

As described in Section 2.4 this processing capacity will be accessed via Rubin Science Platform, with a supported software environment and infrastructure for batch processing [DMTN-202].

Very computationally intense processing (e.g., shift-and-stack for faint moving objects) will likely require external resources[3].

[3] For more details about the boundary between what Rubin Observatory will provide (in terms of data products and processing resources) and what will be left to the expertise of the science community, see `https://www.lsst.org/about/dm/data-products`

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A Documentation Review for Requirements Related to Special Programs

Below are described mentions of Special Programs in Rubin documentations, with a focus on requirements and specifications.

Updates to Rubin documents related to Special Programs – motivated by past versions of this DMTN – were made via LCR-1309 and LCR-2265.

A.1 Science Requirements Document (SRD)

Version 5.2.4 (revision 2018-01-30), [LPM-17].

Section 3.4 "The Full Survey Specifications" states the SRD's assumption that 90% of the total available survey time would be spent on the main survey, and that the remaining 10% would be spent *"to obtain improved coverage of parameter space ... [or to] observe special regions"*.

A.2 LSST System Requirements (LSR)

Version 7.1 (revision 2020-03-05), LSE-29.

Note that Version 5 (2018-06-26) was an update for LCR-1309, which added requirements, specifications, and discussions regarding the processing of Special Programs data based on earlier versions of this DMTN.

In Section 1.5.1.3, "Processing Data from Special Programs", LSR-REQ-0122 is a requirement that the LSST system *"shall deliver unique and separate data products for visits from Special Programs"* whenever possible, and that they *"shall be delivered on timescales intermediate"* to the Prompt and Data Release timescales *"when this enables the intended science of the Special Program"*. The discussion clarifies that *"the term 'whenever possible' includes cases where the Data Management System can run original or reconfigured versions of existing pipelines, and excludes cases where the development of new algorithms, or the allocation of significant additional computational resources, are required"*. LSR-REQ-0122

In Section 2.4.1.1.2, "Non-Standard Visit", LSR-REQ-0111 requires that the LSST system *"be ca-* LSR-REQ-0111 *pable of obtaining and processing exposures not taken in a standard visit mode including those with a minimum exposure time of"* 1 second (`minExpTime`). The discussion notes that *"non-standard visit exposures may possibly be degraded in some aspects of performance (e.g. cosmic ray rejection on visits consisting of a single exposure), and might be incompatible with difference imaging and alert production (e.g., short exposures in which the PSF is not fully formed)"*. minExpTime

The above requirement indicates that the LSST system shall be able to process non-standard visits from Special Programs, but that the image quality might be degraded. Improvements that require algorithms or processing outside of what the LSST Science Pipelines can provide would be left to the science community and require User-Generated pipelines and data products.

The requirement in Section 1.5.1.3 is echoed in Section 2.6.1.1, "Organization of Data Products", in which LSR-REQ-0032 is a requirement that the data processing system provide the means for three 'classes' of data products on different timescales (Prompt, Data Release, and User-Generated), and also to provide a means for processing Special Programs data because the *"science goals of Special Programs may require that their processed data products be made available in an additional fourth class, and possibly with intermediate timescales"*. LSR-REQ-0032

In Section 2.6.1.1.3, "Level 3 Data Products", LSR-REQ-0041 specifies that the LSST system *"shall support"* User-Generated data products. The discussion clarifies that "*there will be technical limits on DM's ability to meet this requirement, such as cases where an intensive amount of additional computational resources is required, because only 10% of the total computational system is allocated for user processing"*. This level of support applies also to user processing of Special Programs data. See also the reference to LSR-REQ-0055 below. LSR-REQ-0041

Section 2.6.1.1.4, "Data Products for Special Programs", LSR-REQ-0121 specifies that the LSST system *"shall produce unique and separate Data Products as the result of processing data from Special Programs whenever possible, on a timescale that enables the intended science goals of the Special Program. The cumulative size of the online Special Programs data products shall be no more than 10% of the size of the DRP data products from the most recent data release"*. The discussion clarifies that *"the term 'whenever possible' includes cases where the Data Management System can run original or reconfigured versions of existing pipelines, and excludes cases where the development of new algorithms, or the allocation of significant additional computational resources, are required. The cumulative size of the Special Programs data products is capped at 10% of the most recent DR because this matches the expected fractional survey area of Special Programs* LSR-REQ-0121 *compared to the main survey"*.

In Section 2.7.1.6, "Community Computing Services", LSR-REQ-0055 requires that the LSST system *"shall provide and maintain an amount of computing capacity equivalent to at least"* 10% (`userComputingFraction`) *"of the total LSST data processing capacity (computing and storage) for the purpose of scientific analysis of LSST data and the production of"* User-Generated data products. The discussion clarifies that the scope of this service remains to be determined. This level of computational resources includes user processing of Special Programs data. LSR-REQ-0055 userComputingFraction

In Section 3.1.3.1, "Survey Time Allocation", LSR-REQ-0075 requires that the *"survey performance requirements shall be met utilizing approximately 90% of the historically available observing time, leaving the remaining time available for yet to be defined special programs"*. LSR-REQ-0075

In Section 1.3.1.3, LSR-REQ-0124, the discussion specifies that an image quality parameter related to ellipticity applies only to main survey data. LSR-REQ-0124

A.3 Observatory System Specifications (OSS)

Version 19.1 (revision 2021-07-30), LSE-30.

Note that Version 13 (2018-06-26) was an update for LCR-1309, which added requirements, specifications, and discussions regarding the processing of Special Programs data based on earlier versions of this DMTN.

In Section 2.2.3.1, "Standard Operating States", OSS-REQ-0044 specifies that *"the LSST observatory system shall be designed and constructed to support ... manual observing - used for specific non-scheduler driven observing to support system verification and testing or specialized science programs"*. Although most Special Programs will be executed via the survey scheduler as part of *"fully automated observing"*, manual observing might be necessary for, e.g., target-of-opportunity Special Programs. OSS-REQ-0044

Section 3.1.5.1.2, "Data Products Handling for Special Programs", OSS-REQ-0392 is essentially a flow-down of requirements from the LSR (0122, 0075, and 0121), and specifies that *"the handling of data products from Special Programs shall be compliant with the approach defined in LSE-163"*. OSS-REQ-0392

In Section 3.2.5.3, OSS-REQ-0403 is a flow-down of LSR-REQ-0124 related to the ellipticity correlation function distribution. OSS-REQ-0403 LSR-REQ-0124

In Section 3.6.1.3, "Continuous Exposures", OSS-REQ-0319 requires that *"The Observatory shall be capable of continuous operation throughout a night with the interval between successive visits equal to the FPA readout time"*. The discussion clarifies that *"this mode of observing is needed to support observations when the telescope is not being re-pointed"*, such as deep drilling fields or other Special Programs. OSS-REQ-0319

In Section 3.6.1.4, "Minimum Exposure Time", OSS-REQ-0291 specifies that *"the camera shall be able to obtain a single exposure with an effective minimum exposure time of no more than"* 1 second (`minExpTime`) *"with a goal of an effective minimum exposure time of"* 0.1 seconds (`minExpTimeGoal`). The discussion clarifies that *"if the exposure is shortened from the 15 second nominal, the spacing between successive exposures should be extended to maintain the average readout rate consistent with a 15 second exposure"*, which may increase the overheads of Special Programs using short exposure times. The discussion also clarifies that *"if the exposure is lengthened from the 15 second nominal, the thermal stability may be affected, which may affect photometric accuracy"*. OSS-REQ-0291 minExpTime minExpTimeGoal

In Section 3.6.1.5, "Publish Visit Type", OSS-REQ-0384 specifies that *"the OCS [Observatory Control System] shall configure the [Data Management System] DMS (in particular Prompt Processing) with the type of visits to be processed: Standard, Alternate, or a specific type of Non-Standard"*. The discussion clarifies that this allows the Prompt processing pipeline to be reconfigured on-the-fly in order to incorporate non-standard visits from, e.g., Special Programs. The time required for reconfiguration might introduce some latency or cause some images to not be processed by the Prompt pipeline. OSS-REQ-0384

In Section 3.6.2.1.2, "Maximum time for operational filter change", OSS-REQ-0293 specifies that *"the camera system shall provide the capability of changing the operational filter with any other internal filter in a time less than"* 120 seconds (`tFilterChange`). This would impose a large overhead on, e.g., a Special Program that changes filters often without slewing. See also OSS-REQ-0295, Appendix B of this document, and/or the filter change memorandum (`ls.st/spt-494`), for more information about the total lifetime number of filter changes. OSS-REQ-0293 tFilterChange OSS-REQ-0295

In Section 3.6.3.1, "Absolute Pointing", OSS-REQ-0298 specifies that *"the LSST shall point to a defined set of sky coordinates with an RMS accuracy of"* 2 arcseconds (`absPointErr`). OSS-REQ-0298 absPointErr

In Section 3.6.3.3, "Rotator tracking Time, OSS-REQ-0301 specifies that *"the LSST shall be able to maintain field rotation tracking over a period of at least"* 1 hour (`rotTrackTime`). The discussion clarifies that this *"is driven by the need to conduct extended 'deep drilling' observations on a single field"*. There do not seem to be any constraints on the speed of the rotator or the minimum distance between successive visits. OSS-REQ-0301 rotTrackTime

In Section 3.6.3.5, "Offset Pointing", OSS-REQ-0302 specifies that *"the LSST shall be capable of offset pointing within a single field-of-view with a precision of no more than"* 0.2 arcseconds (`offsetPointingErr`). OSS-REQ-0302 offsetPointingErr

In Section 3.6.3.6, "Open Loop Tracking", OSS-REQ-0303 specifies that *"The LSST shall be capable of open loop tracking without the assistance of real time optical feedback to an accuracy of"* 1.0 arcseconds (`openTrackErr`) *"over any 10 minute duration during normal night time operations"*. Note that the open loop tracking requirement is *without guiding*. OSS-REQ-0303 openTrackErr

In Section 3.6.3.8, "Guiding", OSS-REQ-0305 specifies that *"the LSST system shall improve the tracking of the optical system to the sky by means of active guiding over the whole accessible sky"*. OSS-REQ-0305

In Section 3.6.3.10, "Non-Sidereal Tracking", OSS-REQ-0380 specifies that *"the LSST system shall be capable of tracking in an arbitrary direction on the sky along a parametric RA(t) and DEC(t) trajectory, at angular rates of up to"* 220 arcseconds per second (`nonsiderealAngularRateEl` and `nonsiderealAngularRateAZ`) *"with a tracking error not to exceed"* 0.5 arcseconds per minute (`nonsiderealTrackingError`). The discussion notes that *"this is standard capability for modern telescopes"*, but might be relevant to some Special Programs. OSS-REQ-0380 nonsiderealAngularRateEl nonsiderealAngularRateAZ nonsiderealTrackingError

A.4 Data Management Subsystems Requirements (DMSR)

Version 9 (revision 2021-02-12), LSE-61.

Note that Version 8.3 (2020-05-04) was an update for LCR-2265, which updated requirements, specifications, and discussions regarding the processing of Special Programs data based on earlier versions of this DMTN.

In Section 1.2.3, "Raw Science Image Metadata", DMS-REQ-0068 specifies that *"for each raw science image, the DMS shall store image metadata"* including *"Program metadata (identifier for main survey, deep drilling, etc.)"*. The discussion clarifies that *"the program metadata should be* DMS-REQ-0068 *sufficient to associate an image with a specific Special Program so that DMS-REQ-0320 and DMS-REQ-0397 can be satisfied"*.

In Section 1.3.13, "Alert Content", the discussion for DMS-REQ-0274 explains that the *"program and/or scheduler metadata"* included in an alert packet *"should be sufficient to identify whether the image is associated with a Special Program (such as an in-progress Deep Drilling Field)"*. DMS-REQ-0274

In Section 1.4.18.1, "Produce All-Sky HiPS Map", the discussion for DMS-REQ-0379 raises the point that generating separate HiPS maps for Special Programs (e.g., DDFs) remains an open question. DMS-REQ-0379

In Section 1.4.18.5, "Produce MOC Maps", DMS-REQ-0383 specifies that Data Release processing *"shall include the production of Multi-Order Coverage maps for the survey data"*, and that *"additional MOCs SHOULD be produced to represent special-programs datasets"*. It is noted that a separate technical note would be created to define these MOCs. DMS-REQ-0383

The bulk of the DMS's requirements related to Special Programs are in Section 1.6 of the DMSR.

In Section 1.6.1, "Processing of Data From Special Programs", DMS-REQ-0320 specifies that *"it shall be possible for special programs to trigger their own data processing recipes, during the night instead of the nightly Alert Processing (but the recipes may still issue Alerts), or on alternative timescales"*. The discussion clarifies that the *"LSST will provide these recipes ... when possible, which includes cases where DM can run original or reconfigured versions of existing pipelines, and excludes cases where the development of new algorithms, or the allocation of significant additional computational resources, are required. An example of an alternative timescale is a nightly trigger to coadd all the deep-drilling field images. Decisions about which recipes are applied to which Special Programs will be made by the Operations team, after consideration of the scientific goals, computational resources, and data rights policy"*. This requirement is derived from OSS-REQ-0392, which is essentially a flow-down of requirements from the LSR (0122, 0075, and 0121). DMS-REQ-0320

In Section 1.6.2, "Prompt/DR Processing of Data from Special Programs", DMS-REQ-0397 specifies that *"it shall be possible for special programs data to be processed with the prompt and/or annual-release pipelines alongside data from the main survey"*. The discussion further clarifies that *"the data from Special Programs should only be included ... when it is (a) possible ... to do so without additional effort and (b) beneficial to the LSST's main science objectives. Decisions about* DMS-REQ-0397 *which data are included ... will be made by the Operations team"*. This requirement is also derived from OSS-REQ-0392, which is essentially a flow-down of requirements from the LSR (0122, 0075, and 0121).

In Section 1.6.3, "Level 1 Processing of Special Programs Data", DMS-REQ-0321 specifies that *"all [Prompt] processing from special programs shall be completed before data arrives from the following night's observations"*. This is essentially adding a quantifier to DMS-REQ-0397, to specify that *"when it is (a) possible ... to do so"* means when it is possible to complete the processing before the next night's observations. This requirement is also derived from OSS-REQ-0392, which is essentially a flow-down of requirements from the LSR (0122, 0075, and 0121). DMS-REQ-0321

In Section 1.6.4, "Constraints on Level 1 Special Program Products Generation", DMS-REQ-0344 specifies that *"the publishing of [Prompt] data products from Special Programs shall be subject to the same performance requirements of"* 24 hours (`L1PublicT`) for the release of Prompt data products and 1 minute (`OTT1`) for the transmission of Alert packets. This is essentially a more detailed version of DMS-REQ-0321 which includes the Alert production timescale. This requirement is also derived from OSS-REQ-0392, which is essentially a flow-down of requirents from the LSR (0122, 0075, and 0121). DMS-REQ-0344 L1PublicT OTT1

In Section 1.6.5, "Special Programs Database", DMS-REQ-0322 specifies that *"data products for special programs shall be stored in databases that are distinct from those used to store standard [Prompt] and [Data Release] data products"* and that *"it shall be possible for these databases to be federated ... to allow cross-queries and joins"*. This requirement is also derived from OSS-REQ-0392, which is essentially a flow-down of requirements from the LSR (0122, 0075, and 0121). DMS-REQ-0322

In Section 4.1.16, "Level 2 and Reprocessed Level 1 Catalog Access", DMS-REQ-0313 specifies that *"the DMS shall maintain ... versions of the most recent catalogs generated from Special Programs data"*. As with all LSST data, *"there is no requirement for older data releases to be queryable"*. DMS-REQ-0313

A.5 Data Management Applications Design (DMAD)

Version 4.3 (revision 2020-11-10), LDM-151.

The DMAD is not a requirements document. Instead, it describes the scientific design of the

LSST Science Pipelines: the algorithms and software that will be implemented to meet the requirements for processing the LSST data.

Special Programs are only mentioned a few times, either as a potential source of single-snap visits or as a potential source of reference images or catalogs (e.g., training sets).

As described above (e.g., LSR-REQ-0122), the LSST system shall deliver unique and separate data products for visits from Special Programs whenever this (1) enables the intended science of the Special Program and (2) can be accomplished using the original or reconfigured versions of the LSST Science Pipelines. For cases in which the development of new algorithms or the allocation of significant additional computational resources are required to produce Special Programs data products, User-Generated pipelines and processing will be necessary.

The DMAD can be used as the reference document to decide whether a given Special Program will require User-Generated pipelines and processing.

A.6 Data Products Definitions Document (DPDD)

Version 3.6 (revision 2021-12-17), LSE-163.

Section 6 describes the data products for Special Programs. The DPDD is not a requirements document; Section 6 summarizes the requirements presented above and does not introduce any new constraints or new information about Special Programs.

B Potential Hardware Boundaries on Data Diversity

The potential boundaries on the diversity of data products that could be imposed by limitations from the Rubin Observatory hardware – camera, telescope, and/or site – are considered.

B.1 Filter Changes

The maximum time for filter change is 120 seconds: 30 seconds for the telescope to reorient the camera to its nominal zero angle position on the rotator, and 90 seconds to the camera subsystem for executing the change (OSS-REQ-0293; LSE-30). Assuming that most Special Programs would be designed to keep overheads <100% and would be using standard 30 second visits, the filter change time indicates that it is likely that at least 4 exposures in a given filter would be obtained between filter changes, but this is not actually a hardware boundary. The filter change mechanism is designed to undergo a total of 100000 changes over its lifetime, and each filter is designed to support up to 30000 changes over its lifetime, where lifetime is 15 years. That is an average of ∼27 changes per day, some of which would occur in they day during calibrations (estimate, ∼10) and the rest at night. As stated in the filter change memorandum (`ls.st/spt-494`), *"the system could support as many changes involving the 5 filters loaded in the carousel as desired, without any practical limitation"*.

B.2 Filter Carousel Loads

The filter carousel can hold five of the six LSST filters at a time. The system is designed to support 3000 loads in 15 years (`ls.st/spt-494`). Filter loads are only done in the day, and there will never be data in more than five filters in a given night.

B.3 Exposure Times

The minimum exposure time is 1 second, with a stretch goal of 0.1 seconds (OSS-REQ-0291; LSE-30). The maximum exposure time is not restricted.

B.4 Readout Time

The readout time is 2 seconds, and would be significant overhead on short exposures.

B.5 Inter-Image Time

Images with exposure times < 15 seconds *might* still have to be separated by 15 seconds for thermal tolerance; i.e., the minimum readout rate might be one image every 15 seconds, regardless of exposure time (OSS-REQ-0291; LSE-30).

As discussed in Jira ticket DM-12573, the main issue is thermal and is related to the shutter, both the motors and the brakes; an elevated Camera skin temperature would affect image quality. As of 2022, early tests suggest that a sustained (30 minutes) sequence that increases the heat load by large factors would not work, but further functional testing of the system once the Camera was fully assembled are needed for full characterization of the issue.

This potential 15 interval between images is also a potential hardware boundary on the potential diversity of data products.

B.6 Telescope Slew

As described in Document-28382, large slews would have considerable overheads, but there are no hardware boundaries on the size of a single slew or the accrued slew distance.

B.7 Pointing and Sidereal Tracking

The specifications for the telescope's pointing and tracking in LSE-30 indicate that <0.2 arcsecond precision in field pointing (OSS-REQ-0302) and <1 arcsecond in open-loop tracking (OSS-REQ-0303) would not be possible, but guiding would improve the latter (OSS-REQ-0305). Furthermore, obtaining the *exact same* alignment of the pixel grid in RA-Dec *"would put demands on the camera rotator that were not planned"*[4].

B.8 Non-Sidereal Tracking

The requirement that the LSST system be able to perform non-sidereal tracking is set by OSS-REQ-0380 in LSE-30. This capability will include angular rates of up to 220 arcseconds per second in both azimuth and elevation.

B.9 Camera Rotation

The requirements on the rotator's capabilities do not set any limits on the per-night or total lifetime rotation (OSS-REQ-0301, -0300; LSE-30) which might put boundaries on the distance between successive visits or the ability to jump between two widely separated fields. Currently, there are no hardware boundaries imposed by camera rotation constraints on the potential diversity of data products.

[4] As per C. Claver's comments in ticket DM-12573.

C Potential Processing Boundaries on Data Diversity

The capability of the LSST Science Pipelines to process diverse data is explored below.

Note that processing boundaries might ultimately be defined not by what is technically possible, but by the resulting image quality parameters (e.g., the number of stars with sufficient flux for photometric calibration). Furthermore, the processing boundaries might not be fully constrained until the final performance of the LSST Science Pipelines, as described in the Data Management Applications Design, LDM-151) document, is fully characterized.

Summary of the conclusions below:
Very short (<2 sec) exposures could be difficult to reduce due to an incompletely-formed PSF, and very short or very long (>150 sec) exposures could be difficult to calibrate due to having too few (or too few unsaturated) stars. It is currently unclear whether images with very bright sky backgrounds (twilight images) can be processed with the LSST Science Pipelines, or whether user generated pipelines will be needed. The full reduction and calibration of images obtained with non-sidereal tracking, in which the stars are streaked, is currently beyond the scope of the LSST Science Pipelines, and will require a user generated pipeline.

C.1 Exposure Times

Images which deviate significantly from the 15 second duration for the WFD main survey may encounter issues in the instrument signature removal routine, in the correction for differential chromatic refraction, in the difference imaging analysis pipeline, and/or in the photometric and astrometric calibrations due to a differently sampled set of standard stars per CCD.

C.1.1 Short Exposures (Non-Standard Visits of $<$30 sec)

The LSST System Requirements document states that *"The LSST shall be capable of obtaining and processing exposures not taken in a standard visit mode including those with a minimum exposure time of* `minExpTime`", which is 1 second (stretch goal 0.1 seconds; LSR-REQ-0111 in LSE-29).

However, for exposure times there are other considerations, as changing the exposure time also affects the photometric and astrometric calibrations. Assuming that 1 second exposure can be reduced and calibrated, its detected point sources will span a dynamic range of $r\approx$ 13–21 magnitudes. A template image built on 15 second exposures will saturate at $r\approx$15.8 mag, but this still leaves stars between 15.8–21.0 magnitudes to be used in the PSF-matching (and all other filters have a similarly large overlap).

In order for an image to be successfully PSF-matched to the template, the PSF must be well formed (no speckle pattern), and have a spatial variance that the pipeline is capable of modeling (be smoothly varying on some minimal scale). As a simple demonstration, Figure 1 shows that perhaps exposure times shorter than 2 seconds do not have a well-formed PSF (using the centroid of a 2D Gaussian fit as a proxy for "well-formed").

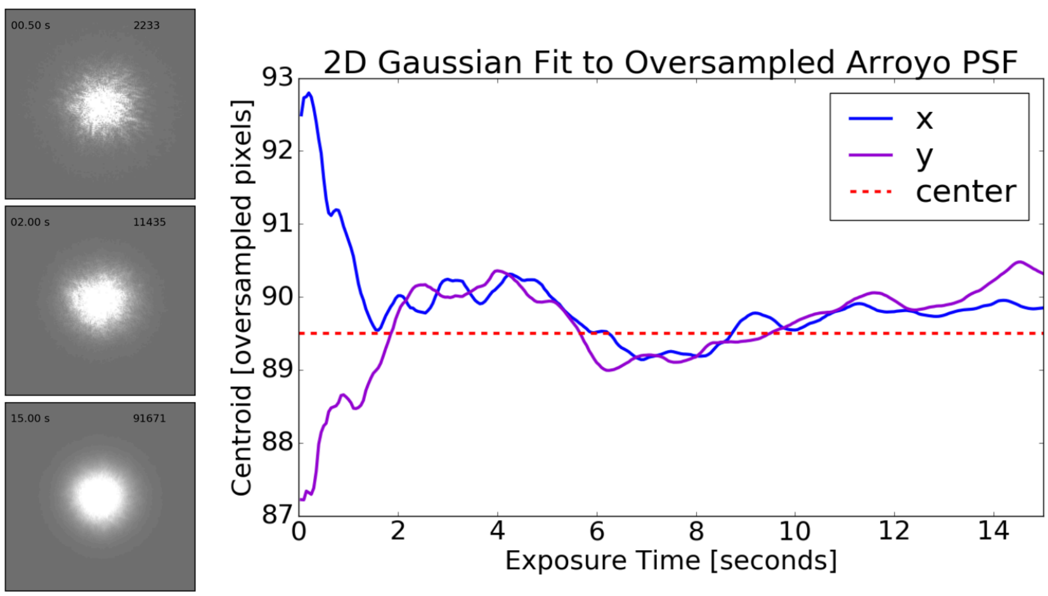

FIGURE 1: At left, Arroyo atmosphere-only simulated PSF for LSST (with oversampled pixels) with exposure times of 0.5, 2, and 15 seconds (top to bottom), courtesy of Bo Xin. At right, blue and purple lines show the location of the centroid derived from a 2D Gaussian fit to the PSF as a function of exposure time, with the red dashed line showing the true center. We can see that for exposure times greater than 2 seconds, the centroid converges near its true value.

C.1.2 Long Exposures (Non-Standard Visits of $>$30 sec)

There is no maximum exposure time specified for an LSST image. Given that the template image will be a stack of at least a year or two of data, processing a 5–10 times deeper single image through the difference imaging pipeline should be fine. However, a $2{\times}150$ second exposure would saturate at $r \approx 18.3$, perhaps leaving too few stars overlapping with e.g., templates or WFD images, for astrometric and photometric calibrations. Furthermore, cosmic-ray rejection completeness might be reduced for longer exposures (unknown), which could impact the quality of a difference image and the detected sources. Additionally, any system qualities that vary on short (but > 30 second) timescales could inhibit photometric calibration (e.g., tracking).

C.2 Twilight Images with a Bright Background

Images obtained during twilight for scientific purposes are also likely to have shorter exposure times, and so the issues described in Section C.1 also apply here. Whether or not bright-background images can (or shall) be fully processed – reduced, calibrated, background-subtracted, and delivered with astrometric and photometric solutions – or whether this will require a user generated pipeline, remains to be determined (see also the example in Section D.3). This may depend on the exposure time and the number of stars available in the image.

C.3 Images Obtained with Non-Sidereal Tracking

Non-sidereal tracking leads to images in which stars are streaked, but the moving object appears as a point source. Full processing – providing reduced, calibrated, background-subtracted images that are delivered with astrometric and photometric solutions – of these images is beyond the scope of the DM pipelines as it would require the development of new algorithms, and will need to be done as a user generated pipeline. The first steps of such a pipeline, such as Instrument Signature Removal, will probably be possible to achieve by reconfiguring the relevant DM software tasks.

D Special Programs Processing Examples

This section has not been updated since 2018.

For further insight to the DM-related needs of potential Special Programs, we can write out all of the data acquisition and processing steps, in order, that some of the proposed Special Programs might use. Note that we are not including any analysis in these descriptions, only processing and products. These are not necessarily complete and may even be incorrect in some places, as we are not experts in the science needs of these potential Special Programs;

they could use some more thought and input.

Basic steps that we use to describe a processing case study:
Step 1. Data Acquisition.
Step 2. Inclusion in the Prompt Pipeline and Alert Generation.
Step 3. Delivery of LSST Processed Images.
Step 4. Reconfigured Processing Pipelines and Separate Data Products.
Step 5. Inclusion in the DRP Data Products for the WFD Main Survey.
Step 6. User-Generated Pipelines and Products.

D.1 Searching for TNOs with Shift-and-Stack

This Special Programs processing summary is based on Becker et al. (2011) white paper to find TNOs with shift-and stack (SAS) [Document-11013].

Step 1. Data Acquisition.
The observational sequence is triggered. In a single night, the 9 adjacent fields in a 3x3 grid are observed with 336×15 second r-band exposures. This sequence is always repeated 2-3 nights later. This re-visit sequence is repeated 3 more times: 1.5 months, 3 months, and 13.5 months later. Data obtained in the g-band filter is also acceptable. [Document-11013]

Step 2. Inclusion in the Prompt Pipeline and Alert Generation.
Each 2×15 second visit is processed in the Prompt pipeline and Alerts are released within 60 seconds.

Step 3. Delivery of LSST Processed Images.
The raw, reduced, and calibrated exposures and difference images from the Prompt pipeline are made available within `L1PublicT` (currently 24 hours; LSR-REQ-0104), but this is not very relevant for this program, which requires a year of dispersed observations before the processing pipelines for SAS can be run.

Step 4. Reconfigured Processing Pipelines and Separate Data Products.
Shift-and-stack processing is beyond the scope of DM's algorithms.

Step 5. Inclusion in the DRP Data Products for the WFD Main Survey.

As with all Special Programs data, they might be included in the products of the WFD main survey if DM decides it is beneficial. However, since these images are much deeper than stacks made from the WFD survey, and the strict timing of the observations might lead to their acquisition in sub-optimal conditions, it is unlikely that they would *all* be incorporated.

Step 6. User-Generated Pipelines and Products.
The User-Generated pipeline running the shift-and-stack processing will be set up and submitted for batch processing by the user through the Science Platform or on an external processor. Pipeline inputs will be the 336 processed exposures per field per re-visit sequence. The DRP difference imaging routine will be used with the same template tract/patch for all. Custom, User-Generated algorithms will shift the exposures and create difference images, then DRP routines can stack and do source detection and characterization and generate an object database. Custom code will derive orbital parameters for the detections and add them to a `SSObjects`-like database.

D.2 Searching for Supernovae in Deep Drilling Fields

Step 1. Data Acquisition.
On a single deep drilling field, the scheduler obtains e.g., 5, 10, 10, 9, and 10 visits with 2×15 second exposures in $grizy$ (or similar for the night's filter set) and a small dither pattern between visits.

Step 2. Inclusion in the Prompt Pipeline and Alert Generation.
Each 2×15 second visit is processed by the Prompt pipeline's DIA, and Alerts are released within 60 seconds. They are flagged to denote the image source is a DDF and that source association might be compromised.

Step 3. Delivery of LSST Processed Images.
The raw, reduced, and calibrated exposures and difference images from the Prompt pipeline are made available within `L1PublicT` (currently 24 hours; LSR-REQ-0104).

Step 4. Reconfigured Processing Pipelines and Separate Data Products.
The required data products for this science goal can be met by reconfiguring the DM pipelines. First, a template image for the field will be made using DM stacking algorithms. On nights when this DDF is observed, at the end of the sequence of observations, DM algorithms are used to create a nightly deep stack, PSF-match it with the template, create a deep difference

image, run source detection on the differences, and create separate databases of `DIAObject`, `DIASource`, and `Object` that are unique to this DDF. The LSST codes for alert packet and transport could be used to distribute the detected objects e.g., to the same brokers that receive the Alert Stream, or alternative destinations. However, these packets would not be distributed via the LSST `Alert Stream`, and would need to be identified as, e.g., DDF Alerts.

Step 5. Inclusion in the DRP Data Products for the WFD Main Survey.
As with all Special Programs data, they might be included in the products of the WFD main survey if DM decides it is beneficial.

Step 6. User-Generated Pipelines and Products.
For the science goal of searching for supernovae in nightly stacked DDF images, no separate User-Generated software appears necessary.

D.3 A Twilight Survey with Short Exposures

Several kinds of twilight surveys with short exposures have been or might be proposed: to put brighter stars (or transients such as supernovae) that saturate in a 15 second image onto the LSST photometric system and/or to observe the Sweetspot, 60 degrees from the sun, for near-Earth objects. The processing case study for these is currently limited by unknowns about the first step: the reduction of processed single visit images.

Step 1. Data Acquisition.
At a specified time (or e.g., 6 degree twilight), the scheduler begins dither pattern of short exposures. Location and exposure times are set by the sky brightness and desired saturation limits.

Step 2. Inclusion in the Prompt Pipeline and Alert Generation.
Pending studies of short-exposure suitability for DIA (see Section C) and scalable processing capabilities to incorporate a faster image-input rate than 1 every 30 seconds, these data could *potentially* be incorporated and spawn Alerts.

Step 3. Delivery of LSST Processed Images.
Pending the issues mentioned above, the raw, reduced, and calibrated exposures and difference images from the Prompt pipeline are made available within `L1PublicT` (currently 24 hours; LSR-REQ-0104).

Step 4. Reconfigured Processing Pipelines and Separate Data Products.
This is officially not determined, but so long as the short-exposure images can be processed and have enough stars for photometric and astrometric calibration, reconfigured DM pipelines will probably be sufficient for creating image and catalog products from this kind of data.

Step 5. Inclusion in the DRP Data Products for the WFD Main Survey.
These short-exposure, high sky background images would not contribute to the DRP data products created for the WFD survey.

Step 6. User-Generated Pipelines and Products.
If short-exposure images cannot be processed with the existing DM algorithms, a User-Generated processing pipeline might be needed to reduce the raw data.

Side note: A short-exposure survey of the bright stars of M67, described in Chapter 10.4 of the Observing Strategy White Paper [20], suggests using the stretch goal of 0.1 second exposures or, if that is not possible, *"custom pixel masks to accurately perform photometry on stars as much as 6 magnitudes brighter than the saturation level"*. This would be considered a User-Generated algorithm.

D.4 The Galactic Plane Survey for Variable Stars and/or Exoplanets

Step 1. Data Acquisition.
The schedule incorporates fields in the Galactic Plane, and executes 2×15 second visits in these fields (or shorter, for a shallower depth than the WFD main survey).

Step 2. Inclusion in the Prompt Pipeline and Alert Generation.
Each 2×15 second visit is processed in the Prompt pipeline and Alerts are released within 60 seconds. Extremely crowded fields might have to be skipped if they take longer to process and violate the 60 second latency for Alerts.

Step 3. Delivery of LSST Processed Images.
The raw, reduced, and calibrated exposures and difference images from the Prompt pipeline are made available within `L1PublicT` (currently 24 hours; LSR-REQ-0104).

Step 4. Reconfigured Processing Pipelines and Separate Data Products.
The image and catalog products needed for science with the Galactic Plane are very similar

to the products of the Prompt and DRP pipelines, so it seems that not much reconfiguration would be needed. The biggest difference might be the incorporation of a user-supplied deblender algorithm optimized for very crowded fields.

Step 5. Inclusion in the DRP Data Products for the WFD Main Survey.
It is quite likely that images from the Galactic Plane will be included into the products of the WFD main survey, as they could e.g., reduce edge effects and help with global photometric classification, but this will depend on deblender performance, and left to the discretion of DM.

Step 6. User-Generated Pipelines and Products.
It seems likely that science users will want to deploy their alternative deblending algorithms on this data set and create their own catalogs.

D.5 Gravitational Wave Event Follow-Up

For a description of how target of opportunity data to search for the optical counterparts of gravitational wave events would be processed, see RTN-008.

E Previously Proposed Special Programs

This section has not been updated since 2018.

In this section we compile information about the science goals and observational methods for Special Programs that have been previously proposed or discussed in the Science Community. We use these to infer the potential deviations from standard visit images, and to get a basic idea of the DM processing needs that would be required to enable the science. The main resources from which we have collected information about the Community's Special Program are: [15]; [14]; the LSST Deep Drilling Field white papers from 2011[5]; presentations by Niel Brandt and Stephen Ridgway at the LSST Project and Community Workshop in August 2016[6]; [11]; and Chapter 10 of [20].

[5] https://project.lsst.org/content/whitepapers32012

[6] https://project.lsst.org/meetings/lsst2016/sites/lsst.org.meetings.lsst2016/files/Brandt-DDF-MiniSurveys-01.pdf and https://project.lsst.org/meetings/lsst2016/sites/lsst.org.meetings.lsst2016/files/Ridgway-SimulationsMetrics_1.pdf

So far, only one aspect of the LSST Special Programs are set: the locations of the four chosen deep drilling fields[7]. There are three mini-survey areas that have been discussed extensively by the Science Community: the North Ecliptic Spur (NES), the South Celestial Pole, and the Galactic Plane (see Figure 8 of [15]). In Table 1 we list the four extragalactic deep drilling fields have already been specified, along with an *incomplete* list of potential mini-surveys that have been openly discussed in the Science Community. In Section **??**, we create detailed DM Processing Case Studies for several of these Special Programs in order to identify any potential issues with reconfiguring the DM pipelines to create specific data products for these programs.

TABLE 1: Approved DDF and Incomplete List of Potential Special Programs.

Name	Coordinates	Description
DDF Elias S1	00:37:48, -44:00:00	approved, cadence TBD
DDF XMM-LSS	02:22:50, -04:45:00	approved, cadence TBD
DDF Extended Chandra Deep Field-South	03:32:30, -28:06:00	approved, cadence TBD
DDF COSMOS	10:00:24, +02:10:55	approved, cadence TBD
North Ecliptic Spur		solar system objects (find and characterize)
Galactic Plane		more intensive stellar surveying
South Equatorial Cap		S/LMC and more Galactic science
Twilight		short exposures (0.1s) for bright stars
Mini-Moons		finding mini-moons
Sweetspot		60 deg from Sun for NEOs on Earth-like orbits
Meter-Sized Impactors		detection a week before impact
GW Optical Counterparts		search and recovery
Old Open Cluster M67	dec +12	compact survey above Galactic plane

Here we consider a variety of scientific fields in turn, the Special Programs that have been discussed in that Science Community so far, and the implications of these Programs for the diversity of data and data products. Generally, the types of LSST Special Programs that are open for proposals include: (i) additional deep drilling fields; (ii) refined observing strategies for deep drilling fields; (iii) optimized survey areas for the NES, South Pole, and Galactic Plane; (iv) refined observing strategies for the NES, South Pole, and Galactic Plane; and (v) additional mini-surveys (areas and observing strategies).

A Nominal DDF Observing Strategy – Ivezić et al. (2008, [15]; Section 3.1.2) describes a nominal DDF data set as ~ 50 consecutive 15 second exposures in each of four filters, repeated every two nights for four months. Each exposure would have a 5σ limit of $r \sim 24$; the nightly stack would have a limit of $r \sim 26.5$; and the final deep stack of all exposures would have a limit of $r \sim 28$. This description does not comment on the processing mode, but, depending

[7] https://www.lsst.org/scientists/survey-design/ddf

on the science goals the exposures could be done as either a series of 50 non-standard visits (1×15 seconds) or 25 standard visits (2×15 seconds).

Solar System Objects (SSO) – Four of the mini-surveys in Table 1 have science goals related to studies of SSO. Observations of the North Ecliptic Spur area could yield more ≥ 140 m near-earth objects (NEOs) for the final LSST sample (reference: Brandt's talk). The Mini-Moons Mini-Survey aims to find and study the temporarily captured satellites of the Earth (Section 10.2, [20]). The Sweetspot Survey would use twilight fields to find NEOs in Earth-like orbits (i.e., these objects are never in opposition fields, but overhead at sunrise/sunset; Section 10.2, [20]). The Meter-Sized Impactors program would find and track meter-sized impactors < 2 weeks before impact (Section 10.2, [20]). **Summary:** most of these science goals do not seem to require non-standard visits or exposure times, with the exception of the Sweetspot survey which occurs during twilight and thus may require shorter exposures. The cadence and patterns of these mini-surveys may differ from the WFD main survey, especially when very fast-moving objects are sought. From a processing perspective, it seems that many of these science goals will be achievable by using the products of Solar System Processing, which runs on the Prompt Pipeline's `DIASource` catalogs after they are updated each night. The exception is finding faint SSOs (e.g., Trans-Neptunian Objects Trojans, asteroids, long-period comets, dwarf planets) through shift-and-stack (SAS) processing [Document-11013], because SAS is not a capability being built within the DM system and cannot be done solely by reconfiguring DM pipelines. An example of user-generated pipeline for SAS is described in Section **??**.

Stars in the Milky Way and Magellanic Clouds – As described in [Publication-141], mini-surveys of the Galactic Plane can better distinguish faints stars from faint red galaxies by including at least 3 filters of coverage (e.g., izy; similar to WFD), and could mitigate losses from proper motion and increase the detection rate of stellar flares by obtaining all the images in short time span (i.e., a more concentrated cadence than the WFD). As described in [Publication-145], applying the nominal DDF observing strategy over the full area of the Large and Small Magellanic Clouds can characterize stellar variability to $M_V < 6.5$ on timescales from 15 seconds to 3 days. For this, special co-adds may be required, e.g., *"to reach variability levels of 0.1 to 0.005 mag will require co-adds depending on the timescale of the particular variables"* [Publication-145]. The Twilight survey in Table 1 proposes short exposures to enable bright stars to be put on the same photometric system as the deeper LSST WFD main survey catalog, and enable science that is based on their long monitoring baselines from historical observations. In Chapter 10.4 of [20], a proposed short-exposure survey of M67 would use the camera's stretch goal of 0.1 second exposures or, if that is not possible, *"custom pixel masks* *to accurately perform photometry on stars as much as* 6 *magnitudes brighter than the saturation level".* **Summary:** while some of these science goals can be accomplished with standard visits, MW & L/SMC science goals are likely to request shorter exposure times, perhaps down to 0.1 seconds. These science goals are also likely to propose cadence and filter distributions that are significantly different from the WFD main survey. From a processing perspective, the science goals depending on shorter exposures will only be able to be met by reconfiguring the DM pipelines if the short exposures can be shown to successfully be processed (with, e.g., instrument signature removal); the science goals can likely be met with data products in the same format as the Prompt or DR Pipeline (i.e., `Source` and `Object` catalogs, single visits and deep CoAdds). Although it is not mentioned in the above paragraph, the MW & L/SMC science community is also most likely to require special processing to extract information from saturated stars, which is outside the scope of DM. See Section D.4 for more detailed DM processing case studies.

Exoplanets – As described in Section 3.1.2 of [15], transiting exoplanets could be detected with the nominal DDF plan, which would allow for 1% variability to be detected over hour-long timescales; a DDF field at Galactic latitude 30 degrees would yield 10^6 stars at $r < 21$ that would have SNR > 100 in each single exposure of the sequence. [11] describes how transits can be extract from a wider-area survey of the Galactic Plane, and how microlensing candidates can be found with ~ 22 mag imaging over the Galactic Plane region every 3-4 days (since microlensing events are slower; these would then require follow-up with external facilities). Dealing with the more crowded fields would be mitigated by the shallower images, in this case. One of the main points of [11] is that the Galactic Plane can yield a lot of science despite the fact that its eventual deep co-adds would be uselessly confusion limited, and therefore should not be skipped. **Summary.** Some of these science goals appear possible with standard visit images, and some might request shorter exposures to avoid confusion in crowded fields when the science can be done with brighter stars. From a processing perspective, the science goals are likely to be achievable with reconfigured DM pipelines, but this depends heavily on performance in crowded fields. See Section D.4 for a more detailed DM processing case study for Galactic Plane regions.

Supernovae – The nominal DDF plan described in [15], which builds nightly stacks with a limit of $r \sim 26.5$ out of standard visit images, would extend the SN sample to $z \sim 1.2$ and provide more densely sampled light curves for cosmological analyses. The optimal exposure time distribution might be 6, 5, 10, 10, 9, 10 in $ugrizy$ [Publication-144]. High-cadence observations of DDF would be the only way to detect fast transients, particularly extragalactic novae, some tidal disruption events, optical counterparts to gamma-ray bursts, and peculiar SNe [6]. Generating the best-possible individual SN light curves for cosmological analyses requires building special, deep-as-possible, SN-free host galaxy images and using them as a template. This will also be necessary for studying SNe that appear in the template image; i.e., that last > 1000 days. These are mostly Type IIn, probably explosions of massive stars into dense circumstellar material, which are not used for cosmology but rather to study late-stage stellar evolution and mass loss. SN-free images will also be needed to measure correlated properties for cosmology and to do host-galaxy science. The latter, specifically the ”characterization of ultra-faint SN host galaxies”, is also mentioned in the Galaxies DDF WP [Publication-142]. Short-exposure observations of bright, nearby SNe may also be useful to include near-peak photometry in the LSST magnitude system, and enable full light-curve analyses. **Summary.** All of these science goals appear possible with standard visit images (with the exception of a target-of-opportunity short-exposure program to observe bright SNe). From a processing perspecitve, the science goals appear to be accessible with reconfigured DM pipelines to stack and difference the data. In particular, the DRP codes to create ”transient-free CoAdds” will be suitable for generating the SN-free templates for DDF, as they will do for the Main Survey images. See also Section D.2 for a DM processing case study to find SNe in a DDF.

Galaxies – The additional depth of a DDF may provide access to a larger collection of low-μ objects. [Publication-142] mentions ”identification of nearby isolated low-redshift dwarf galaxies via surface-brightness fluctuations” and ”characterization of low-surface-brightness extended features around both nearby and distant galaxies”. The DDF stacks could also be used to characterize of high-z clusters, although this ability might depend on deblending extended objects. Also, the DDF observations, when combined with the WFD, allow for AGN monitoring on a variety of timescales in well-characterized galaxies [Publication-142, Publication-143]. **Summary.** As with the SN science goals, these use standard visit images and reconfigured DM pipelines to make deep CoAdds and extract sources. In addition, it seems likely that user-generated algorithms that are optimized to detect and characterize particular types of faint extended sources will be needed, and these are beyond the scope of DM.

Weak Lensing – The deeper imaging from DDFs can help with shear systematics and the effects of magnification in the analysis of WFD data (community forum, Jim Bosch). **Summary.** As with the SN and Galaxies DDF-related science goals, these use standard visit images and reconfigured DM pipelines can be used to make deep CoAdds and extract sources, as Jim notes.