LARGE SYNOPTIC SURVEY TELESCOPE

Large Synoptic Survey Telescope (LSST)

Data Management and LSST Special Programs

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LDM-nnn

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Abstract

WORKING DRAFT but intended to be an overview of any and all potential requirements on data management from special programs such as the deep drilling fields or mini-surveys. We summarize how the special programs might be integrated into the wide-fast-deep survey (Levels 1 and 2). It is the intent that this document evolve to become a community resource for future special program white papers, change requests to the DM Level 1 and 2 pipelines and products, and preparations for Level 3 pipelines. **Preliminary recommendations and action items are listed in Section 1.1.**

Change Record

Version	Date	Description	Owner name
1	2017-04-??	Initial release of preliminary investigation.	Melissa Graham

Contents

1 Introduction

The current status of this work is that it is an internal, ongoing study with several interim preliminary recommendations so far (Section 1.1).

The purpose of this document is to:
(1) summarize the current plans of the DM pipelines with respect to special programs,
(2) summarize any special programs processing that is required to enable science, and
(3) analyze whether any glaring problems exist and how they might be repaired.

This will be accomplished by:
(1) starting with the DPDD, whitepapers, etc., and compiling relevant information,
(2) discussing initial issues internally with DM (Mario), and then
(2) getting in touch with Neil Brandt and the SC heads for additional input.

1.1 Current Recommendations and Action Items

(1) Special programs images should be included as Level 1 whenever possible. This means that they are differenced with the WFD survey template images and generate alerts in the standard 60 second turn-around time. There are probably some exposure time thresholds for which this is possible, and a study should be done to determine this range (e.g., 20–40 seconds, 15–120 seconds). (Section 2)
(2) Query the community about all special program science goals that require 60 second alert latency from non-standard exposure times. (Section 3.1)
(3) Database schema for `DIASource` needs to have an element added that contains information about the template that was used to create the difference image (e.g., `tractId` or `patchId`). (Section 3.2)
(4) Clarify whether `Object.prv_inputID` will identify whether an object is an externally provided coordinate for forced photometry. (Section 3.2)
(5) Consult with the Science Collaborations for input on the database characterization parameters for variability across a range of cadences, and extended object shapes for e.g., low-surface brightness features. Be sure to first compile and provide a list of planned parameters from the schema. (Section 3.2)
(6) Assess the science use-cases for auto-generated template images with e.g., constant Δt, and whether this will require additional database elements. (Section 3.3)

1.2 The Existing Community Forum

Recall that there is already a community forum on this topic:
`http://community.lsst.org/t/deep-drilling-fields-and-data-management/1115`.

The questions opened up on that forum are:
(1) What additional processing beyond that currently planned by the DM team (alerting relative to an annually created template) would greatly enhance the DDF science goals?
(2) Are there DDF or Mini-Surveys specific aspects of the Level 3 system that would add significant value if provided? "Level 3" is the LSST-provided capability that enables non-DM, user-driven, processing of LSST data at the LSST Archive center (or remotely).
(3) Are there aspects of the Science User Interface and Tools (SUIT) that need to be developed in order to enhance the usefulness of DDF data products.
(4) To what degree should the DDF or Mini-Survey imaging could/should be incorporated into the main survey's deep stacks and associated data products (as opposed to being processed as separate data products)?

2 A Summary of Current DM Plans for Special Programs

In this section we review what is said in official documents with regards to LSST processing of special programs. The resources used here are the Data Products Definitions Document [11], the LSST Data Management Applications Design [10], and Mario's Brain.

DPDD – Data Products Definitions Document [11] specifies that the data products of the DDF and MS will "be created using the same software and hardware as Levels 1 and 2". Section 7 is devoted to the data products of "Special Programs", which encompasses DDF and MS. The current plan is to have both the Level 1 and 2 processing pipelines run on the DDF/MS in the same way that they run on the WFD, and produce all of the same data products and alerts – but to have the DDF/MS products kept in separate (joinable) databases that have identical schema as the WFD databases. It is specified that DDF/MS processing will be limited to not use more than 10% of the DM computational and storage facilities. During the telecon on Wed Mar 29, KT Lam reviewed the computational budget but it seemed mainly for WFD with only passing mention of DDF or special programs.

LDM-151 – LSST Data Management Applications Design [10] outlines the steps that will happen in the processing of images in the AP, DRP, and MOP. It makes only passing reference to the existence of DDF or special programs, so there are currently no plans for any DDF/MS-only processing algorithms.

Incorporating SP data into Level 1 and the Alert Stream.
All SP images that can be incorporated into the Level 1 processing for the WFD survey should be included. This probably means all images with an exposure time of ~ 30 seconds that can be differenced with the WFD template to decent results. "Incorporate into the Level 1 processing" means alerts are produced in 60 seconds, and the sources are added to `DIASources` and `DIAObjects`.
Recommendation: SP images should be included as Level 1 whenever possible. This means that they are differenced with the WFD survey template images and generate alerts in the standard 60 second turn-around time. There are probably some exposure time thresholds for which this is possible, and a study should be done to determine this range (e.g., 20–40 seconds, 15–120 seconds).

Incorporating SP data into MOPS.
Needs and capabilities are currently undefined.

Incorporating SP data into the Level 2 DRP.
The core science needs for uniform-depth images and catalogs for the WFD main survey probably means this will not happen, but identical Level 3 data pipelines and products may be used instead, and special programs processing might include WFD images where possible.

What qualifies as Level 3?
Level 3 pipelines that are assembled and provided by the Science Collaborations can be installed and run in real time by the LSST, with a projected latency of (at most) tens of minutes (as opposed to the 60 second guaranteed for WFD). The community will hopefully use existing LSST codes and schemas.

3 Questions and Potential Issues.

In this section we list questions or potential problems identified only from reading LSST documents [11, 10], or issues raised also in Gregory's AHM 2016 slides[1].

Another useful resource is the LSST Database Schema Browser: `http://lsst-web.ncsa.illinois.edu/schema/index.php?sVer=baseline`.

3.1 Alert Stream

• Alerts on a `DIASource` will link to the associated `DIAObject`, but in cases where a special program obtains a sequence of images without switching fields, will the `DIAObject` catalog have had enough time to be updated to include the `DIASource` from the previous image?
→ Immediate updates of the `DIAObject` catalog is an expected capability, although it is currently uncertain how it will be accomplished, technically.

• Special program images that are processed as Level 1 with 60 second latency can naturally contribute to the Alert Stream, but what about real-time (tens of minutes) processing of Level 3 pipelines for special programs? Could they be set up to contribute to the same Alert Stream?
→ Have not yet tried to answer this question.

• If we find that e.g., ≤ 5 second exposures could be included in Level 1 (i.e., differenced with the standard template), then this $6\times$ higher data acquisition rate might cause a back-up at NCSA. Is there a science need for 60 second latency on short exposures, or will the standard Level 3 tens-of-minute processing be OK?
→ Have not yet tried to answer this question, as it will be driven by the science community.
→ **Recommendation: query the community about all special program science goals that require 60 second alert latency from non-standard exposure times.**

• LDM-151, Section 3.3.4 'Alert queuing and persistance' mentions that the *"event message stream and the AlertDB will be synchronized at least once every 24 hours"* and that *"Prior to the start of the subsequent night's observations, the message queue will be flushed and synchronized with the AlertDB. It is possible to persist the message queue on longer timescale but it is a requirement that synchronization be performed within 24 hours of the observations."* Since this is for the

[1] "DM Considerations for Deep Drilling", LSST AHM Aug 2016 presentation by Gregory Dubois-Felsmann `https://zenodo.org/record/61402#.WNVk6hIrIUF`

main survey in which new alerts are issued for a given field 2–3 times per night, check that this is fine in the case of doing e.g., 200 alert bursts on the same field in a single night.
→ Have not yet tried to answer this question.

3.2 Databases and Schema

• Images obtained during special programs might be used with one or more different types of templates – the same images could be used as multiple surveys. Is it feasible to have separate databases for each?
→ Yes, Level 3 pipelines can create as many separate databases as necessary. There should at least be a separate database for each kind of template image. These databases can have the same base schema, and elements of the schema can be "turned off" if the survey will not use them, to save processing time and disk space.

• Data from special programs might be incorporated into the Level 1 and/or 2 databases; if so, how will it be flagged in these databases?
→ In the schema for `DIASource` and `Source` there is an element for `ccdVisitId`, and the database `CcdVisit` has entry for `visitId`, and the database `Visit` has an entry for `programId`, which is currently an `integer` containing the *"Observing program id (e.g., universal cadence, or one of the deep drilling programs, etc.)."*.

• The database schema for `DIASource` needs to have an element added to identify the template image that was used; this is relevant for the Main Survey WFD Level 1 and also all Level 3 differencing products.
→ **Recommendation: Database schema for `DIASource` needs to have an element added that contains information about the template that was used to create the difference image.**

• LDM-151 mentions that forced photometry will be done for externally defined targets (Section 3.2.5), and this may be a particular interest to special programs, but it is unclear how such targets will be identified or flagged as such in the databases.
→ This is definitely a promised Level 1 product, but it is unclear whether we need to add

an element to the database schema. Currently, the `Object` database contains an element `prv_inputId` which is an `integer`, and is described as the *"Pointer to prv_InputType. Indicates which input was used to produce a given object."* Is that all we need?
→ **Recommendation: Clarify whether `Object.prv_inputID` will identify whether an object is an externally provided coordinate for forced photometry.**

• Will the special programs databases for be able to incorporate forced photometry from the main survey images and/or the WFD databases? Will WFD be able to incorporate forced photometry from special program images, e.g., deep nightly stacks of DDF images? Will this apply to the 30-day precovery data supplied in the 60 second alerts?
→ Have not yet tried to answer this question, but database joins should be straightforward to add?

• Will the following element sizes be enough the characterize the different kinds of variability that could be measured with cadences that are quite different from the main survey (i.e., longer or shorter cadenced special programs)?
`Object` and `DIAObject.lcPeriodic` = `float[6 x 32]` = Periodic features extracted from light-curves using generalized Lomb-Scargle periodogram
`Object` and `DIAObject.lcNonPeriodic` = `float[6 x 32]` = Non-periodic features extracted from light-curves using generalized Lomb-Scargle periodogram
→ Note that these elements could be differently populated in the Level 3 databases in order to meet the science goals of a given special program.
→ **Recommendation: Contact the Science Collaborations for input on the characterization parameters for variability.**

• Low surface-brightness features and/or objects are required for some galaxy science, and will show up more in e.g., a DDF than the WFD stack. Will the related shape parameters such as extendedness that will be included in the `Object` database be sufficient to describe the extra level of detail in low-surface brightness features afforded by e.g., DDF stacks?
→ As above, these elements could be differently populated in the Level 3 databases in order to meet the science goals of a given special program.
→ **Recommendation: Contact the Science Collaborations for input on the characterization parameters for extended objects.**

3.3 Templates

• Typically we think of a single template from the last DRP, or a template created e.g., $\Delta t \geq 1$ year ago, being used for all difference imaging. However, would enabling the auto-creation and use of a template with constant Δt be scientifically necessary? E.g., $\Delta t = 7$ days to mitigate proper motion induced issues in a difference image for a Galactic plane mini-survey.
→ This is obviously Level 3, but the feasibility of such an evolving template situation is unknown.
→ **Recommendation: assess the science use-cases for auto-generated template images with e.g., constant Δt, and whether this will require additional database elements**. This is extra motivation for the recommendation to add template type to the `DIASource` database.

• Is there ever a need for image-image differencing instead of image-template differencing, and would this need require DM to produce those differences?
→ Probably OK to leave until a science goal truly motivates this.

• Reminder: the type of template used to generate a difference image needs to be included in the database elements for e.g., *DIASource*, in Level 1 and any relevant Level 3.

3.4 Snap Handling

• LDM-151 says (Section 3.2.4.1) that the image differencing pipeline will measure the PDF flux on snap difference images for all `DIASources`, but is there a lower limit to exposure time for this? E.g., would not apply to a 1s twilight survey?
→ I don't know what's up with snaps these days.

3.5 Calibrations

The follow questions might already have answers in the Level 2 Calibrations document LSE-180 [9], I have not gone through and checked.

• In the case where a special program uses a different exposure time than the WFD images (e.g., the 1s Twilight survey), it should be reviewed whether the calibration algorithms and products in LDM-151 are still appropriate (e.g., dark frame processing, brighter-fatter correc-

tions).

• A Twilight Short Exposure survey would need good on-the-fly sky subtraction of a rapidly changing sky background during twilight; has this scenario been incorporated into the calibrations pipeline?

• Special programs might use a special dither pattern (or no dither pattern); it should be reviewed to confirm that no calibration technique is compromised by this (e.g., is charge build-up a problem with the CCDs? is artifact recognition and removal more difficult with some patterns?)

• Might there be issues with absolute astrometry in a very deep or very shallow field with a different number of stars available for the solution than expected for the WFD images?

• Multiple special programs request short-exposure survey, which would provide less/different stars for photometric classification; will there be enough stars to characterize the images and determine all the necessary photometric calibrations?

• Planting fake sources may be both more manageable and more important to some special programs. How will DM support this?

3.6 Custom Co-Adds

• Building deep co-adds with no transient contamination (e.g., SN hosts, cosmology uses host parameters correlated with intrinsic SN brightness).
→ Creating custom co-adds in general will be a solid Level 3 that could be done with LSST software.

• Plan to deep stack across filters for faint-object detection and then measurement in individual filters? Is this a separate database or same as `Objects`?
→ This would be a separate, Level 3 database.

3.7 Moving Object Processing System (MOPS)

• Does MOPS do shift-and-stack (SAS), and are the databases set up to include shift-and-stack output (e.g., real/bogus probability matrices or something)?
→ MOPS will not SAS. This is solidly Level 3..
→ However, people may want to SAS on difference images, which would require DM making these available for some time.

• Can MOPS link newly discovered `sources` to those discovered earlier on the same night (e.g., in a 4-visits-per-night scenario), or does it have a similar problem to `DIASource` and `DIAObject`?
→ MOPS does not run during the night in real time. This is not a problem..

• Can MOPS provide absolute astrometry immediately, do we need to confirm that alert astrometry is precise enough for follow-up? (I fully would expect it to be so).
→ MOPS does not run during the night in real time, so this is not a problem. Furthermore the SRD defines the required astrometry for e.g., discovering PAHs is an *"absolute accuracy not worse than 0.1 arcsec for sources detected with the signal-to-noise ratio SNR > 10."* So that is not a worry either.

4 Science Cases and their DM Requirements

In this section we review science documents from LSST and the community. We compile information about the nominal observing plans for special programs that are already written down (Section 4.1), and summarize the science motivations for special programs that have so far been proposed (Section 4.2). Potential issues for DM are inferred from these science motivations and have been incorporated into our list of issues in Section 3.

Resources:
- "LSST: from Science Drivers to Reference Design and Anticipated Data Products" [8]
- The LSST Science Requirements Document [7]
- "General Review of the Proposed DDF and MS", LSST AHM Aug 2016 presentation by Niel Brandt `https://project.lsst.org/meetings/lsst2016/sites/lsst.org.meetings.lsst2016/files/Brandt-DDF-MiniSurveys-01.pdf`
- "Simulations, Metrics and Merit Function for Mini-Surveys and DDF", LSST AHM Aug 2016 presentation by Stephen Ridgway `https://project.lsst.org/meetings/lsst2016/sites/lsst.org.meetings.lsst2016/files/Ridgway-SimulationsMetrics_1.pdf`
- "LSST's DC [Deep CoAdd] Bias Against Planets and Galactic-Plane Science" by A. Gould, [6] `https://arxiv.org/abs/1304.3455`
- Chapter 10 "Special Surveys" of the Observing Strategy White Paper [14]
- List of LSST Deep Drilling white papers: `https://project.lsst.org/content/whitepapers32012`

4.1 Nominal Observing Plans for DDF and MS

[8], Section 3.2.1 "Mini-Surveys": describes a nominal DDF data set as ~ 50 consecutive 15 second exposures in each of four filters in one hour per night, once every two nights, for four months. Each observation would have a limit of $r \sim 24.5$; a one-hour nightly stack would have a limit of $r \sim 26.5$; and and assuming a 60% completion rate (weather), the four-month ~ 40 hours stacked together with the ~ 180 main survey visits would yield a limit of $r \sim 28$. The LSST Science Requirements Document [7] doesn't contain the terms "deep drilling field" or "mini-survey"; I assume that the SRD is only for WFD survey.

Four extragalactic deep drilling fields have already been specified (Table 2). From a scouring of mainly the presentations of Brandt and Ridgway at the 2016 AHM, an *incomplete* list of

potential mini-surveys that people are thinking about in Table 2 also.

TABLE 2: Approved DDF and Incomplete List of MS.

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
DDF TBD		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

4.2 Science Descriptions (Not Comprehensive)

The following is a collection of rough notes on the science goals and potential data processing/product issues for some proposed special programs, classified by field. It is not comprehensive. The questions for DM that were inspired by considering the proposed special programs are still mingled in amongst these notes, but have also been incorporated into Section 3, and so the answers and solutions to any questions or problems are all in Section 3 also.

Solar System Objects

• Strategy would be to observe 3x3 grid of 9 fields centered on coordinate of an ecliptic latitude equal to 0 and a longitude at a conjunction of Trojan clouds of Jupiter and Neptune, 4 groups of 2 visits on a 2–3 day revisit schedule, with the 4 groups targeted at e.g., opposition, all done in r-band (g suitable too). (Is this within the North Ecliptic Spur?) [1].

• North Ecliptic Spur region will yield more ≥ 140 m NEOs (Brandt talk).

• Are the three SSO special programs described in Chapter 10.2 of [14] mandated by NASA?

• SSO science goals require enabling the discovery of faint SSO via shift-and-stack of images in specific fields where SSO discovery is maximized [1].

• Does MOPS processing do shift-and-stack, and/or is the MOPS database schema ready to incorporate a shift-and-stack output?

• Regarding shift-and-stack, [1] says that "the multi-fit algorithm ... naturally provides a base

infrastructure for this process. In particular, the marshaling of the pixels to attempt a given photometric measurement is non-trivial when tens of thousands of images are required. However, the multi-fit middleware is required to do exactly this, so we expect that this issue will be resolved by the time SAS is needed." True?

• To detect Earth impactors *"hours before impact"* using the four visits per night will require real-time linking of new `DIASources` – or maybe the MOPS handles this differently?

Stars in the Milky Way and Magellanics

• Special programs will provide images deeper than the main survey in order to identify useful stellar populations; getting the images over a short time span mitigates proper motion losses and increase flare detection rates [3].

• Target Galactic plane regions and/or open clusters, typically 1 to 3 filters needed for detections of e.g., faint stars already detected in z and y but needing i to distinguish from red galaxies [3].

• Characterize stellar variability over the full L/SMC galaxies to $M_V < 6.5$ on timescales from 15s to 3d [15].

• 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" [15].

• Light curve characterization parameters in the databases should include one for very short events like flares; ensure there's adequate space in the database for multiple variability parameterizations.

• How might LC-characterization parameters fail on e.g., an LBV-turned-SN?

• A Twilight Short Exposure survey would need good on-the-fly sky subtraction of a rapidly changing background; ensure plans are adeqaute?

• A short-exposure survey of M67, Chapter 10.4 of [14], suggests using *"custom pixel masks to accurately perform photometry on stars as much as 6 magnitudes brighter than the saturation level"*; feasible?

Exoplanets

• Transits. The nominal DDF plan described in [8] would allow for 1% variability detection over hour-long timescales, which is suitable for detecting transits. A DDF field at Galactic latitude 30 degrees would yield 10^6 stars at $r < 21$ that would have $\mathrm{SNR} > 100$ in each single exposure of the sequence. Microlensing events can also be detected with this data set. In both cases, follow-up is required. The Galactic Plane MS is proposed for this. [6] describes how transits

can be extract from the same data set.

• Microlensing. Slower than a transit, [6] suggests that ~ 22 mag imaging every 3-4 days (i.e., the WFD nominal cadence) can find microlensing candidates (for follow-up with e.g., LCO). However, more Galactic regions must be included, and this will require image differencing in crowded fields. [6] claims that imaging in the necessary regions of the galaxy has been disfavored by the project on the basis that the eventual deep co-adds would be uselessly confusion limited. I don't think DM could fix this fact, and deep co-adds (and all DRP) could possibly just be skipped for these regions. Otherwise, the already-planned AP should work fine for Galactic plane survey.

Supernovae:

• The nominal DDF plan described in [8] would allow for nightly stacks with a limit of $r \sim 26.5$, extending the SN sample to $z \sim 1.2$ and providing more densely sampled light curves for cosmological analyses.

• [2] doesn't say much specific.

• [12] describes their optimal exposure time distribution as 6, 5, 10, 10, 9, 10 in $ugrizy$, which adds up to < 60 minutes and could presumably be done with the standard 30s exposures.

• Template generation: e.g., supernovae will want a DDF template from > 30 days ago (minimum for SNeIa); > 100 days is better (SNII), and > 200 days safest (SLSNe, SNIIn). So, last DRP will be fine. But some last longer, thousands of days, and so users will want to know the date of the template.

• Building special, deep-as-possible, SN-free host galaxy images in order to measure correlated properties and make corrections to the LC, and do host science. The regular DRP will be inadequate for this (this could be a Level 3 tool to stack requested epochs only?). With short runs on a DDF this might be impossible, would have to revisit. [4] also mentions *"characterization of ultra-faint SN host galaxies"* in their Galaxies WP.

• A short-exposure survey could include nearby SNeIa on the same photometric system – but can we calibrate as well with the limited set of stars?

Galaxies:

• [4] 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"* – building a large collection of low-μ objects is a science driver but do these even get in the `Object` database (**check on the 'extendedness'-related parameters,**

e.g. GALFIT **modeling? to what** μ**?**), or is this assumed entirely Level 3?
• It seems that e.g., characterization of high-z clusters will depend on ability to deblend extended objects.
• AGN monitoring in well-characterized galaxies [4], and for a long-term DDF on many timescales [5]
• Effect of AGN on e.g., bulge-disk decomposition parameters?

Weak lensing:
• DDF can help with shear systematics and the effects of magnification in the analysis of WFD data (community forum, Jim Bosch)
• "Will need to process at least some deep drilling fields (high-latitude ones) in the same way we process a full data release production before running the full data release production, so we can use the results to build priors and/or calibrate shear estimates on the wide survey" (community forum, Jim Bosch)
• Will need to process various wide-depth subsets of some deep drilling fields (again, high-latitude ones) using the regular DRP pipeline. We'll definitely want best-seeing, worst-seeing, and probably a couple of independent typical-seeing subsets, but there may be other ways we'd want to subdivide as well. (community forum, Jim Bosch)
• photo-z are very important [13] and so perhaps the implemented method should be chosen with weak lensing science prioritized

5 Conclusions

Conclusions section.

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