LARGE SYNOPTIC SURVEY TELESCOPE

**Large Synoptic Survey Telescope (LSST)
Data Management**

LSST Alerts: Key Numbers

M. L. Graham, E. Bellm, L. Guy, C. T. Slater, et al.

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Abstract

Abstract text.

Change Record

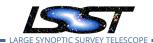| Version	Date	Description	Owner name
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Document source location: `https://github.com/lsst-dm/dmtn-102`

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LSST Alerts: Key Numbers

1 Introduction

This document is currently in development and contains a lot of detailed information for the purposes of internal discussion; to be reduced/clarified later. Text in red needs some discussion by DM-SST.

The LSST Data Management System's (DMS) Alert Production (AP) pipeline will process new data as it is obtained by the telescope. Difference Imaging Analysis (DIA) will be performed, and all sources with a signal-to-noise ratio $\texttt{transSNR} > 5$ in positive or negative flux will be considered "detected", instantiate a record in the source catalogs, and generate an alert (LSR-REQ-0101 **?**; DMS-REQ-0269, -0274 **?**). Each alert is a packet containing LSST data about the source such as coordinates, photometry, and image cutouts. For a full description of detected sources and alert packet contents, see **?**. The LSST alert stream will be delivered to several community-developed brokers, and also accessible to users via the LSST Science Platform's Alert Filtering Service (LAFS). Plans and policies for alert distribution are provided in **?**.

The purpose of this document is to quantitatively inform broker developers, and the broader scientific community planning to use alerts, on the key numbers regarding alert generation, distribution, and access via the LSST alert filtering service. The goals of this document are threefold: (1) to provide all of the key numbers regarding alert generation in one place; (2) to include any and all basis information, assumptions, and derivations that contributed to the key number; and (3) to be clear about whether each key number represents an estimate, a requirement, or a boundary.

In this work we use 8 bits per byte (B), and $1024\ \mathrm{B}$ per KB, $1024\ \mathrm{KB}$ per MB, and so forth.

The resources used in the preparation of this document are as follows:

- *LSST: From Science Drivers to Reference Design and Anticipated Data Products*, **?**

- LSST Science Requirements Document (SRD), **?**.

- LSST System Requirements (LSR), **?**.

- Observatory System Specifications (OSS) document, **?**.

- Data Management System Requirements (DMSR) document, **?**.

- Science Requirements and System Specifications Spreadsheet (SR&SSS), **?**.

- Data Products Definitions Document (DPDD), **?**

- Plans and Policies for LSST Alert Distribution, **?**

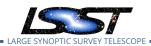- Data Management Science Pipelines Design, **?**

2   Alert Stream

The concept and existence of the LSST alert stream is introduced by the highest-level document: the Science Requirements Document (SRD) specifies that information about the detections of transient, variable, and moving objects be released as a data stream within 1 minute.

2.1   Alert Release Timescale

It is a formal requirement that the Data Management System (DMS) make available 98% of alerts for each visit within 60 seconds of the end of image readout.

Formal Requirements – Regarding the DMS's ability to generate alerts, the SRD states that *"data on likely optical transients … will be released with a latency of at most* 0TT1 *minutes"*, where 0TT1 is $1/2/0.5$ minutes (design/minimum specifications and stretch goal; **?**). The SRD's design specification value of 0TT1 flows down to a formal requirement in the LSR that specifies *"LSST shall meet the following specification for reporting of data on optical transients detected in single-visit data [in]* 0TT1*"*, and defines 0TT1 as *"the latency of reporting optical transients following the completion of readout of the last image of a visit"* (LSR-REQ-0101, **?**). The LSR also makes a formal requirement that the DMS's *"algorithm shall be applied and the alert transmitted within the specified latency for at least a fraction* 0TR1 *of instances … [and] remaining transients … be identified and recorded at the next processing opportunity"*, where 0TR1 is 98% (LSR-REQ-0025, **?**). The LSR requirement on 0TT1 also flows down to more specific formal requirements in the OSS and DMSR, which both state that *"Alerts shall be made available within time* 0TT1 *from the conclusion of readout of the raw exposures used to generate each alert to the distribution of the alert to community distribution mechanisms"* (OSS-REQ-0127, **?**; DMS-REQ-0004, **?**).

Proposed Updates to Formal Requirements – RFC-XXXX proposes to standardize the language regarding `0TT1` in the OSS and DMSR, and to flow-down `0TR1` from the LSR to the OSS and DMSR.

Additional Notes – `0TT1` covers only the time that the Data Management System has control over: from the end of camera readout to the time the alert packet "crosses the border" of NCSA and becomes publicly available for the brokers (i.e., `0TT1` does not include the time it takes for a broker to receive or ingest the alert). It is sometimes colloquially said that *OTT1* starts *at the time of shutter close*, but it actually starts 2 seconds later *at the end of readout* (or longer if slower reads are adopted).

Requirement Breach Protocol – With regards to `0TR1` $= 98\%$, LSR-REQ-0025 states that *" the remaining transients so detectable must still be identified and recorded at the next processing opportunity"*, but this is not this flowed down to DMSR, and it is unclear what *"the next processing opportunity"* means. For the $(100\% - 0TR1) = 2\%$ of alerts allowed to be transmitted with $> 0TT1$ seconds, how will they be identified as delayed? E.g., with a flag in the alert packet? This is not mentioned in the DPDD.

2.2   Number of Alerts per Visit

It is a formal requirement that the Data Management System can sustain the generation of an average of at least 10000 alerts per visit, and an instantaneous maximum of at least 40000 alerts per visit.

Formal Requirements – Regarding the DMS's ability to generate alerts, the SRD states that *"The system should be capable of reporting such data for at least `transN` candidate transients per field of view and visit,"* where `transN` is $10^4/10^3/10^5$ (design/minimum specifications and stretch goal; **?**). The design specification value of `transN` flows down to a formal requirement in the LSR, which describes `transN` as *"the minimum number of optical transients for which data can be reported per visit"*, with a note that *"it is unclear whether the SRD specification of `transN` refers to the number of alerts that can be generated for a single visit (i.e. an instantaneous limit), or the number per visit averaged over time"* (LSR-REQ-0101, **?**). The OSS does clarify: *"The LSST Data Management system shall be sized to accommodate an average value of at least `nAlertVisitAvg` alerts generated per standard visit while meeting all its other requirements,"* where `nAlertVisitAvg` is 10^4 (OSS-REQ-0193 in **?**). No corresponding requirement is flowed down to the DMSR, but the SR&SSS also uses the same minimum average value, and furthermore uses 40000 as the *peak*
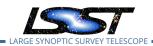
number of alerts per visit, with a note that it was chosen as a number in between the SRD's minimum of 10^4 and the stretch goal of 10^5 [**?**].

Proposed Updates to Formal Requirements – RFC-XXXX proposes to update the DMSR to express these requirements as `nAlertNightAvg` and `nAlertVisitMax`.

Requirement Breach Protocol – Visits that generate > 40000 alerts may have `>OTR1=98%` of the alerts delayed beyond `OTT1`, but it remains unclear whether these alerts will be flagged (as also mentioned in § 2.1).

Sizing Estimate (Science Drivers) – The value of `transN` $= 10000$ alerts per visit is a formal requirement on the Data Management System, and not a scientific estimate of the intrinsic rate of transients and variables in the universe. However, we can also provide here a summary of the science driver for `transN`. The number of alerts is expected to be lower/higher in extra/galactic fields. Estimates for the most common transients and variables are as follows, as derived from the Science Book (**?**):

- Variable Stars: LSST is predicted to observe a total of ~ 135 million variable stars. Making the simple assumption that $20/80$% are in extra/galactic fields, and that of the ~ 18000 $\deg^2$ surveyed by LSST $80/20$% of the fields are extra/galactic, and that 10% of all variable stars are detectably variable at any given time, then a typical extra/galactic field would yield $\sim 1800/28800$ alerts per visit. Averaged over all fields, and weighted by $80/20$% of the fields being extra/galactic, this is 7200 alerts per visit.

- Supernovae: LSST is predicted to observe a total of 10 million supernovae in 10 years, or 1 million per year. Since SNe are typically only visible for a few months, there might be ~ 0.3 million detectable at any given time. Over 15000 deg^2 of extragalactic survey area, that's ~ 20 $\mathrm{SNe}\,\deg^{-2}$ or ~ 200 SNe per visit.

- Active Galactic Nuclei: LSST is predicted to observe millions of AGN. If ~ 10% of them are detectably variable at any given time, then the estimate is ~ 0.1 million alerts over 15000 $\deg^2$ would generate ~ 7 $\mathrm{alerts}\,\deg^{-2}$ or ~ 70 alerts per visit for AGN.

- Moving Objects: The predicted number of Solar System objects that LSST is predicted to observe is dominated by the 5.5 million main-belt asteroids. Assuming that they are spread evenly over the ~ 18000 $\deg^2$ survey area (they're not, as they're found primarily along the ecliptic) leads to ~ 3000 alerts per visit due to moving objects.

Therefore, astrophysical estimates for the occurrence rates of alerts caused by the most common types of transients and variables yield $\sim 5100/32000$ alerts per visit in extra/galactic fields, with an average of ~ 10500 alerts per visit.

2.3 Alert Packet Size

The size of an individual alert packet is estimated to be $\lesssim 82$ KB **(without schema,** $+44$ KB**, or compression,** -17 KB**).** Eric is working on improved alert packet simulations for a more accurate sizing estimate, which would go in the red text below.

Formal Requirements – There are no formal requirements regarding the alert packet size.

Sizing Estimate – Alert packet contents will include all of the LSST science data for the triggering detection, including a ~ 12 month historical record of detections, plus image stamp cutouts. Alert contents are described in more detail in Section 3.5 of **?**. Simulated alert packets based on the Apache Avro format are at most $\sim 82/126$ KB, without/with the schema, respectively. This volume represents an alert packet for a variable star with a full 12 month history of detections. For example, a new unassociated source with only a single detection would be $\sim?$ KB, and a ~ 1 month long transient followed by ~ 11 months of forced photometry would be $\sim?$ KB. The application of gzip compression can further reduce the size of an alert to ~ 65 KB (JIRA ticket DM-16280). Cutout stamps included in the alert will be at least 30×30 pixels and contain flux (32 bit/pix), variance (32 bit/pix), and mask (16 bit/pix) extensions for both the template and difference image, plus a header of metadata [**?**]. The stamps alone will contribute $\gtrsim 18$ KB to the total size of the uncompressed alert packet (i.e., $\sim 20\%$).

Alternative "Lite" Packet Options – Brokers which plan to do their own source association, compile source catalogs based on alerts, or not use the image stamps might prefer a stream of packets with appropriately reduced information. The LSST DM team currently expects that some options will be possible, and brokers may propose an option that works for them during the selection process [**?**]. As previously mentioned, removing the image stamps would reduce packet size by $\gtrsim 18$ KB. Removing the historical records of past detections would reduce all alert packets to be equivalent in size to a new unassociated source. A few of these options might also be available to users of the LSST alert filtering service (§ 3).

2.4   Alert Stream Data Rate

The *time-averaged* **data rate of the alert stream is estimated to be** $\sim 25 \text{ MB/sec}$ **(for alert packets without schema or compression), potentially with bursts of up to** 640 MB/sec**.**

Formal Requirements – There are no formal requirements regarding the alert stream data rate.

Sizing Estimate – The size of a single LSST alert will be $\sim 82 \text{ KB}$ (including image stamps but not schema nor compression). Using an average of ~ 10000 alerts released per ~ 30 second image $+2$ second readout, this leads to a *time-averaged* alert stream data rate of $\sim 25 \text{ MB s}^{-1}$. As discussed in § 2.2, the number of alerts per field will vary in extra/galactic fields from ~ 2000 to $\lesssim 40000$, which would produce *time-averaged* alert streams of ~ 5 to $\lesssim 100 \text{ MB s}^{-1}$. However, in order to release alerts within $\text{OTT1} = 60$ seconds of image readout (§ 2.1), the stream will not be continuous in time, but periodic, with potential bursts. For example, if all 10000 alerts are issued within the last 5 seconds of OTT1 this would produce a data rate of 160 MB s^{-1}; in galactic fields with $\lesssim 40000$ alerts this could be as high as 640 MB s^{-1}.

2.5   Number of Selected Brokers

The DM team estimates that resources will allow for the delivery of the alert stream to 4**-**7 **brokers.**
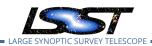
Formal Requirements – There are no formal requirements on the number of brokers.

Sizing Estimate – As described in Section 2.2.3 of **?**, *"An allocation of 10 Gbps is baselined for alert stream transfer from the LDF, with an estimated packet size of 82 KB and up to 10000 alerts per visit. For illustration, based on these numbers up to 7 brokers could receive the full stream if 5 seconds is budgeted for outbound data transfer."*

2.6   Alert Database Volume

The estimated maximum upper limit is $\lesssim 3 \text{ PB}$ **(without schema or compression).**

Formal Requirements – There are no formal requirements on the alerts database volume.

Sizing Estimate – An upper estimate is derived by starting with a maximum of ~ 1000 visits per night, and ~ 10000 alerts per visit, which amounts to ~ 10 million alerts per night. Assuming the upper estimate of $\sim 82\,\mathrm{KB}$ per alert (§ 2.3), that leads to a total of $\sim 782\,\mathrm{GB}$ per night. An extreme upper limit is 365 nights per year for 10 years, which would amount to $\sim 2.7\,\mathrm{PB}$ *at the very most*. Therefore we quote an extreme upper limit on the alerts database as $\lesssim 3$ PB. Compression could drastically lower this, as could reformatting: every alert contains a ~ 12 month historical record and links to the most recent DIAObject and DR Object catalogs. The set of alerts for the same transient/variable would contain a significant amount of redundant information which could be reformatted (i.e., removed from the individual alerts and compiled elsewhere in an alerts database).
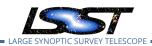
2.7   Delayed/Failed Alert Distribution

It is a formal requirement that $< 1\%$ **of all science visits have any fraction of their alerts experience a distribution delay** > 60 **seconds.**

It is a formal requirement that $< 0.1\%$ **of all science visits experience a failure in alert generation and distribution, integrated over all stages of data handling.**

Formal Requirements – The SRD does not say anything on the topic of alert distribution delays or failures. As mentioned in § 2.1, the LSR defines `OTR1` as the *"fraction of detectable alerts for which an alert is actually transmitted within latency `OTT1`"*, where `OTR1` $= 98\%$ (LSR-REQ-0025; **?**). The OSS does not state any requirements on the fraction of failed alerts per visit, but does specify that *"no more than* `sciVisitAlertFailure` *% of science visits … shall fail to be subjected to alert generation and distribution"*, where `sciVisitAlertFailure` $= 0.1\%$, and that *"no more than* `sciVisitAlertDelay` *% of science visits … shall have their alert generation and distribution completed later than [*`OTT1`*]"*, where `sciVisitAlertDelay` $= 1\%$ (OSS-REQ-0112; **?**). The OSS furthermore makes the distinction that if any number of the alerts for a given visit are distributed later than `OTT1`, it counts towards *sciVisitAlertDelay*. The DMSR makes no statements about the fraction of alerts per visit with delayed/failed distribution, or the fraction of visits with failed/delayed alert distribution.

Proposed Updates to Formal Requirements – RFC-XXXX proposes to include `OTR1` in the definition of `sciVisitAlertDelay`, such that only visits for which $>$`OTR1` % of the alerts are delayed count towards `sciVisitAlertDelay`. RFC-XXXX also proposes to specify that a visit counts towards `sciVisitAlertFailure` if even a single alert that is generated is, for some reason, not

made available (the current wording indicates that a visit only counts towards `sciVisitAlertFailure` if no alerts are generated or made available).

Requirement Breach Protocol – It remains unclear whether delayed alerts will be flagged (as also mentioned in § 2.1).

2.8   Alert Stream Completeness and Purity

It is a formal requirement that DM derive and supply threshold values for a `spuriousness` **parameter which can be used to filter all alerts into a subsample with a completeness and purity.**

Formal Requirements – The SRD makes no statements about alert stream purity or completeness, but does quote that the *"minimum signal-to-noise ratio in difference image for reporting detection of a transient object"* has a design specification of `transSNR` = 5 [**?**]. The LSR contains essentially the same definition for `transSNR`, *"the signal-to-noise ratio in single-visit difference images above which all optical transients are to be reported"* (LSR-REQ-0101; **?**). There is no minimum specification or stretch goal associated with `transSNR`. However, as described in the DPDD, detections with `transSNR` > 5 but *"with high probability of being instrumental non-astrophysical artifacts may be excluded"* (Section 3.1, **?**), and a limited number of `transSNR` < 5 sources might be allowed to generate alerts (e.g., sources near a gravitational keyhole which could make an asteroid potentially hazardous; Section 3.2.1, **?**). Regarding the alert stream completeness and purity, the OSS requires that *"there shall exist a spuriousness threshold* `T` *(also known as real/bogus), for which the completeness and purity of selected difference sources are higher than* `transCompletenessMin` *and* `transPurityMin`*, respectively, at the SNR detection threshold* `transSampleSNR`*. This requirement is to be interpreted as an average over the entire survey"* (OSS-REQ-0353; **?**). In other words, the DMS must be able to provide the value for a spuriousness threshold `T`, below which all alerts detected with a signal-to-noise ratio `transSampleSNR` = 6, over the entire LSST survey, have `transCompletenessMin` = 90% and `transPurityMin` = 95%. (For moving objects there is a separate specification for a threshold pertaining to `transSampleSNR` = 5, `mopsCompletenessMin` = 99%, and `mopsPurityMin` = 50%; OSS-REQ-0354, **?**). This spuriousness threshold `T` will allow users to filter their stream to a fiducial completeness and purity, thereby reducing the fraction of false positives (sources detected that are not astrophysical in origin). Brokers may request a pre-filtered stream that includes a restriction on spuriousness.

3   The LSST Alert Filtering Service

It is a formal requirement that the LSST provide a simple alerts filtering service for users (individuals with LSST data rights and access to the Science Platform), which is hereafter referred to as the LSST alert filtering service (AFS).

Formal Requirements – The SRD specifies that *"users will have an option of a query-like pre-filtering of [the alert] data stream in order to select likely candidates for specific transient type"* and that *"several pre-defined filters optimized for traditionally popular transients, such as supernovae and microlensed sources, will also be available"* [**?**]. Neither the LSR nor the OSS have a formal requirement on this capability, as it is a product of the DMS. The DMSR has a formal requirement that *"a basic, limited capacity, alert filtering service shall be provided that can be given user defined filters to reduce the alert stream to manageable levels"*, and that this service include *"a predefined set of simple filters"* (DMS-REQ-0342, -0348; **?**).

3.1   Number of Simultaneous AFS Users

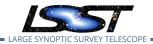It is a formal requirement that the AFS support a minimum of 100 simultaneous users.

Formal Requirements – The DMSR specifies that the LSST *"alert filtering service shall support* `numBrokerUsers` *simultaneous users"*, where `numBrokerUsers` $= 100$ (DMS-REQ-0343; **?**).

3.2   Number of Alerts per Visit Returned per User-Defined Filter

It is a formal requirement that the AFS return 20 alerts per visit per user.

Formal Requirements – The DMSR specifies that within the LSST alert filtering service *"each user [shall be] allocated a bandwidth capable of receiving the equivalent of* `numBrokerAlerts` *alerts per visit"*, where `numBrokerAlerts` $= 20$ (DMS-REQ-0343; **?**).

Note that in a footnote of **?**, it says that the *"requirement on the number of simultaneously connected users and number of passed alerts is largely driven by outbound bandwidth limitations from the DAC at NCSA. We are investigating approaches that would support larger numbers of active filters"* (page 12; **?**).

3.3   Alerts Database Query Latency

It is a formal requirement that all alerts be stored in a database and available for query (by users with data rights and access to the science platform).

Formal Requirements – The OSS states that *"All published transient alerts ... shall be available for query"* (OSS-REQ-0185; **?**). Like all other Prompt data products, the Alerts Database will be updated within $\mathtt{L1PublicT} = 24$ hours (LSR-REQ-0104, **?**).