LARGE SYNOPTIC SURVEY TELESCOPE

Large Synoptic Survey Telescope (LSST)
Data Management

LSST Alerts: Science-Driven Options for Packets and their Distribution

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D R A F T

Abstract

EXTREME DRAFT STATE. DO NOT CITE. DO NOT READ. LOOK AWAY.
A review and discussion of the variety of options for alert packets and their distribution, such as latency timescale, packet contents, pre-stream filtering, and so forth.

Change Record

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1 Introduction

The purpose of this document is to consider the science motivation for, and impact of, various options for alert packet contents and their distribution timescale. The contents and delivery of alert packets will play a major role in the scientific impact of LSST, in part because they are the only LSST data product that is both world public, as they are exempt from any proprietary period, and publicly accessible because they are distributed to community brokers, and not solely available via the LSST Science Platform (LSP). In comparison, although the contents of the Prompt products database (PPDB) from which alerts are generated are also world public, access to the PPDB is restricted to individuals with data rights [LDO-013] who have authenticated accounts in the LSP.

It is a requirement that the DMS be capable of supporting the transmission of at least 5 full alert streams within 60 seconds of image readout. This is based in part on estimates of the alert stream data rate and the bandwidth allocated to alert distribution in the LSST data facility. Reducing the packet size or increasing (slightly) the latency could enable the stream to be delivered to more brokers, and thereby increase the amount of alerts-related science done by the community. The alert packets, as described in LSE-163, were designed to include all the relevant LSST data about a source that a broker might need to assess, classify, and prioritize the alert for follow-up observations *within minutes* (i.e., on order the timescale of the 60 second alert distribution latency). Reducing the contents should only be done if that information is easily and quickly obtainable elsewhere. numStreams DMS-REQ-0391

Document Overview — § 2 discusses how removing stamps and histories from alerts could be scientifically beneficial for some brokers, as long as stamps are made publicly available with similar latency, and proposes additional alert elements to better identify potential transient host galaxies. § 3 find that most alerts-related science goals would be satisfied with a ~5 minute alert timescale, but that the quickly evolving fields of fast radio bursts and gravitational wave events may soon provide more robust motivation for a 60 second latency. § 4 lists the expected types of pre-filtered streams that could improve brokers' scientific productivity, and § 5 argues that when alerts are delayed, the scientifically optimal response would be to flag and distribute them as soon as possible (and not, e.g., send them directly to an archive).

2 Alert Packet Contents

The section explores the science impacts of various options for alert packet contents, such as the ~12 month history of `DIASource` records, the image stamps, and the static-sky `Object` catalog associations. Reducing the size of an alert packet might be scientifically beneficial if it enables the stream to be transmitted to more community brokers, thereby leading to more science being done with alerts. It might also be beneficial if it enables brokers to spend less time developing software or spend less of their computational resources to remove parts of the alert packet they do not need prior to processing, and spend more on developing and running algorithms for various alerts-related science goals. § 2.1 and 2.3 consider reducing the size of alert packets by relocating some data or compressing the packets, respectively. A small increase to the size of the alert packet is not necessarily going to be scientifically detrimental if the information added enables science, and § 2.2 considers some small additions regarding the association of `DIASources` with the data release `Object` catalog.

2.1 Removing Histories and/or Stamps

The size of a fully-loaded individual alert packet is estimated to be $\lesssim$82 KB, based on simulations of the planned content of the alerts as described in Section 3.5 of LSE-163 (see also DMTN-102). The two largest components of the alert packet which could be considered "optional" are the history and the postage stamps. The history is the past ~12 months of `DIASource` records, previously released as alerts. The postage stamps are, at minimum, 30×30 pixels and contain flux, variance, and mask extensions for both the template and difference image, plus a header of metadata [LSE-163]. The history accounts for ~27KB of the alert packet (~33%) and the stamps contribute $\gtrsim$18 KB (~20%).

Brokers that save all alerts, build their own a database of alerts contents, or have an automated interface with the LSST Prompt products database or Alerts database might not need the historical records to be included in the alert packets. Brokers which do not use the image stamps – or would need them for only a subset of the alerts and could feasibly query a stamps database – might not need them included in the alerts packets. Individual broker teams may indicate which information they require (or would like removed from the packets in their stream) during the broker proposal process [LDM-612; LDM-682; LDM-723]. During the first stages of the proposal process, and at the LSST Community Brokers Workshop[1] in

[1] `ls.st/cbw`

June 2019, there was some indication that at least a few brokers were interested in alerts without historical records and/or postage historical records.

2.1.1 `DIASource` Record History

Including the `DIASource` record history in every alert allows for the *instant assessment* — without the need to cross-match or query catalogs — of changes in the objects's location, size, shape, or brightness, provides context for the latest detection (i.e., anomalous or typical), and enables a robust assessment of the likely physical nature of the object (e.g., light curve fits indicating supernova type become more reliable with more observations).

To remove the `DIASource` record history from an alert would slightly inhibit the scientific assessment of transient/variable objects for brokers that build their own database of alert contents, due to the time required to cross-match with the database. Removing the `DIASource` record history would completely inhibit this kind of analysis for brokers that do not have such storage or processing capabilities. There is also the issue that the association of `DIASources` into `DIAObjects` may change over time, for some objects. For example, rare cases such as multiply-imaged strongly-lensed supernovae, or two unassociated transients/variables that are superimposed along the line of sight, might be blended/separated in poor/good seeing. In such cases, the set of all associated `DIASources` might be improved between one alert and the next.

Summary – The `DIASource` record histories should not be removed from all alert packets, but could be optionally removed at the request of a broker. However, if the record histories are removed, a list of all `DIASource` identifiers (the `diaSourceId`, as in Section 3.3.1 of LSE-163) which are currently associated with the `DIAObject` to which the alert-spawning `DIASource` is associated should be provided (note that this list is *not* part of the `DIAObject` record).

2.1.2 Forced Photometry History

When forced photometry (`DIAForcedSource` record history) is included in an alert packet, it is "historical" in the sense that it is based on past images and not the image which spawned the alert. However, it is not always redundant information that was previously released in an alert, like the `DIASource` record history. There are two main cases where forced photometry is performed, as described in LSE-163. (1) For all new `DIAObjects`, forced "pre-covery" photometry is done in the past 30 days of difference images within 24 hours, stored in the DIAForcedSource catalog, and included in all future alert packets associated with that DIAObject. (2) For all DIAObjects that are not detected[2] in a given difference image, but had a detection in the past ∼12 months, forced photometry is done on that difference image. The result is stored in the DIAForcedSource catalog, and included in all future alert packets associated with that DIAObject. The forced photometry is scientifically valuable because, for example, pre-covery forced photometry provides context for the first detection of a transient/variable, and low-SNR detections can help with photometric classification and prioritization for follow-up observations.

If a given DIAObject is never again detected in a difference image, then the DIAForceSource records are never included in an alert packet, but are available to individuals or brokers with access to the PPDB via the LSST Science Platform. If a given DIAObject is repeatedly detected in new difference images, then the same DIAForcedSource records will be redundantly included in all future alerts (after the first one containing the pre-covery or non-detection forced photometry). For the "historical" DIAForcedSource records, alert content redundancy could be avoided by only including previously undistributed DIAForcedSource data in an alert packet. To do this, the Prompt pipeline would have to either compare with the contents of the most recent alert and remove redundant data from the new alert, or flag the DIAForcedSource data as "released" and only add "unreleased" forced photometry to a alert packet. Both of these options would add processing times to the alert generation pipeline, which is undesirable.

Summary – If the decision is made to remove the historical DIASource records from alert packets, the DIAForcedSource records of forced photometry should always be added to all alerts. This will cause some redundancy in alert contents, but if not included there would be no public access to this scientifically valuable information.

2.1.3 Postage Stamps

Including the postage stamps in the alert packet allows for the instant assessment of the DIASource in the difference and template images, which has a variety of scientific applications. For example, although real/bogus classification of the difference-image sources will be done prior to alert generation, some brokers may still wish to run additional algorithms on the images – especially in the case of first detections. Brokers might also employ algo-

[2] The detection threshold is a signal-to-noise ratio ≥ 5.

rithms to classify transients and variables based on the images instead of the photometry (e.g., Carrasco-Davis et al. 2019). From the postage stamp images, scientifically useful information can be derived about the trails left by moving objects, or from the 2-dimensional luminosity distribution of spatially evolving objects such as comets, which might not be entirely captured by the `DIASource` elements (see Table 1 in LSE-163). The images also provide context for the `DIASource`, such as host-galaxy morphology or field crowdedness, that can assist with follow-up observations.

If postage stamps were not created during alert production, the only option would be for users to wait until the images are made available (within 24 hours) in the LSP, which would significantly inhibit alerts-based science goals. However, postage stamps are unlikely to be needed for most `DIASources`, the majority of which — 95%, according to the breakdown in DMTN-102 — will be stars or asteroids: point sources for which context is not a significant part of their immediate evaluation. An efficient compromise might be for the Prompt pipeline to create the postage stamps during alert generation, and then store them in a publicly accessible database (i.e., outside the LSP) where they can be obtained (via `diaSourceId`) with a latency similar to the alert distribution timescale by anyone, from anywhere, at anytime.

The expected maximum download rate from this stamp database is estimated by assuming that all 5 community brokers download ~500 stamp sets per visit: ~2500 stamp sets every ~35 seconds. At 18 KB per stamp set, that's a data rate of 10.5 Mbps (for comparison, that's ~5% of one full alert stream).

Summary – The postage stamps could be removed from all alert packets, but they should still be created during Prompt processing and stored in a publicly accessible database where they can be obtained with a latency similar to the alert distribution timescale.

2.1.4 Pros and Cons of Multiple Alert Formats

The above options could either apply to all alert packets, or brokers could choose from the menu and subscribe to a stream with the options they want. The latter means that LSST distributes multiple types of alert packet formats, and there are benefits and drawbacks to this "menu" approach. The LSST currently expects to deliver alert streams to five brokers, and there are four alert packet formats on the table: (i) with histories and stamps, (ii) with histories but without stamps, (iii) without histories but with stamps, and (iv) without histories or stamps.

From a science perspective, the benefits to allowing brokers to customize their alert packet is that it potentially enables unique science to be done by brokers (e.g., custom stamp-analysis algorithms), and could enable LSST to support >5 brokers which might lead to more alerts-related science in general. One drawback might be that in times of heavy load, full-sized packet streams might be more likely to be delayed, which would be unfair to brokers requiring full-size packets, and could disproportionately affect some science goals more than others. The fact that not all alert packets are identical might cause some additional bookkeeping considerations for downstream brokers who ingest from multiple community brokers, but should not be detrimental to their science goals.

The technical considerations of how many different alert packet formats it is feasible to create and transmit within the required latency time is left for other work.

2.2 Additional `Object` Association Information

The contents of the alert packet as defined in LSE-163 includes the following with respect to associations with `Object` catalog from the most recent data release:

- `nearbyObj` (`unit64[6]`), the *"closest* `Objects` *(3 stars and 3 galaxies) in Data Release database"*
- `nearbyObjDist` (`float[6]`), the *"distances to* `nearbyObj`*"* in arcseconds
- `nearbyObjLnP` (`float[6]`), the *"natural log of the probability that the observed* `DIAObject` *is the same as the nearby* `Object`*"*

For the latter, there is a footnote that says *"This quantity will be computed by marginalizing over the product of position and proper motion error ellipses of the* `Object` *and* `DIAObject`*, assuming an appropriate prior"*.

The current definitions of `nearbyObj`, `nearbyObjDist`, and `nearbyObjLnP` are not as useful as they could be for transients in host galaxies. For extragalactic transients, the three nearest galaxies are not always the three most likely host galaxies, and the distance in arcseconds matters less than a separation distance that accounts for the galaxy's luminosity profile. Furthermore, the definition of `nearbyObjLnP` is only appropriate for static variable point sources (stars): for transients in host galaxies, the observed `DIAObject` will never be "the same as the nearby `Object`".

Statistically, the most likely host for a given transient is the galaxy which contributes the most optical flux at the transient's location. This is usually estimated by calculating an offset distance from the nearby galaxies to the transient that is expressed in terms of the galaxy's spatial luminosity profile, and assuming the galaxy with the lowest offset distance is the host. The following are several options for estimating which nearby galaxy is the most likely host of an extragalactic transient.

Effective Radius – Calculate a separation distance that is the radial distance from the core of the galaxy to the location of the transient, divided by the effective radius of the galaxy (i.e., `kronRad90` in the `Objects` table; LSE-163). The nearby galaxy with the lowest separation distance is the most likely host. This will account for the relative sizes of the potential host galaxies, but not their position angles.

Second Moment – Calculate a separation distance, as in Sullivan et al. (2006), based on the two-dimensional luminosity profile of the galaxy. Where $x_{\rm trans}$, $y_{\rm trans}$ is the location of the transient, and $x_{\rm gal}$, $y_{\rm gal}$ is the center of the galaxy (the first moment; `radec` in the `Object` table), the separation distance is $R^2 = C_{xx}x_r^2 + C_{yy}y_r^2 + C_{xy}x_r y_r$, where $x_r = x_{\rm SN} - x_{\rm gal}$ and $y_r = y_{\rm SN} - y_{\rm gal}$. The ellipse parameters C_{xx}, C_{yy}, and C_{xy} can be calculated directly from the second moments of the galaxy luminosity profile (`Ixx`, `Iyy`, and `Ixy` in the `Object` table), e.g., as described in Section 10 of E. Bertin's Source Extractor manual[3]. The nearby galaxy with the lowest separation distance is the most likely host. This option accounts for both the relative sizes and position angles of the potential host galaxies, and requires only a little more processing.

2D Algorithms – There are also other, more complicated methods for identifying the most likely host for a given transient. For example, the nearby galaxy with the smallest fraction of light interior to an isophot through the transient's location, where the isophot shape is given more degrees of freedom and not constrained to concentric ellipticals as in the second moment method above. Another example is to use an algorithm that provides deblended footprints for nearby extended objects, and can estimate the fraction of light in given pixel that should be attributed to each (e.g., the SCARLET deblender, Melchior et al. (2018)). The most likely host galaxy would be the one which contributes the most flux at the pixel location of a transient.

Generally, nearby galaxies with separation distances >3, or >99% of the luminosity profile, are not assigned as hosts and the transient is considered "hostless". While this cutoff has been

[3] Version 2.3: `https://www.astromatic.net/pubsvn/software/sextractor/trunk/doc/sextractor.pdf`

appropriate for past samples of ∼hundreds of transients, it will not be appropriate for the LSST sample size, and no such cut should be applied when evaluating potential host galaxies for `DIAObjects`.

All of the above host galaxy identification methods can also make use of priors if the transient type is known; for example, the established correlation between core-collapse supernovae and star formation. However, such a robust level of host associations are beyond scope for the Prompt pipeline, and the main goal is to provide brokers with sufficient information to assess the potential host association, and decide whether it is useful to the classification and/or prioritization of alerts for follow-up.

Summary – For the ten nearest `Object` catalog galaxies, a separation distance should be calculated with respect to the transient location, preferably using the second moments of each galaxy's luminosity profile. Two new `DIAObject` catalog elements should be added: `nearbyPotHost`, containing the `objectId` for the three galaxies with the lowest separation distances, and `nearbyPotHostSepDist`, containing the separation distances. An analog for the existing element `nearbyObjLnP`, representing the probability, is not necessary. This would add `unit64[3]` and `float[3]` to the `DIAObject` catalog and to each alert, but this both tiny and worthwhile.

2.3 Compressing the Alert Packets

The application of gzip compression could further reduce the size of a full alert to ∼65 KB (80%; JIRA ticket DM-16280). Naively, this seems like it would allow 1 more full stream to be transmitted to a broker, and thereby enable more science. However, the time and computational resources required to compress the alert packets needs to be considered. For example, gzip compression at 50 MB/s to compress ∼10000 alerts would take ∼10000 ×0.08 MB per alert /50 MB/s, or ∼16 seconds. This is significant, considering the alert distribution latency requirement is 60 seconds. Furthermore, compressing the alert packets forces brokers to then decompress the alerts on arrival, which would incur further delay. Science goals requiring very low-latency alerts distribution might be negatively impacted by compression – see § 3 for a deeper discussion of the science drivers for low-latency alerts.

OTT1
LSR-REQ-0101
OSS-REQ-0127
DMS-REQ-0004

Summary – Since packet compression could induce an additional latency, perhaps it should only be done if, e.g., an algorithm could provide a compression rate of ≲10 MB/s (requiring only a few seconds to compress a visit's worth of alerts), or if the alert distribution latency requirement is relaxed from 1 minute (see § 3). Otherwise, compression would have no impact on alerts-related science goals and so this should be primarily a technically-driven decision.

3 Alert Distribution Latency

It is a requirement that the DMS be capable of supporting the distribution of at least 98% of alerts for each visit within 60 seconds of the end of image readout. OTT1 OTR1 LSR-REQ-0101 LSR-REQ-0025 OSS-REQ-0127 DMS-REQ-0004

If it is possible to relax this requirement to, e.g., 5 minutes – *without risk to the science goals* – then it might be possible to support more community brokers and/or repurpose the human and computational resources that would otherwise be dedicated to delivering 1 minute alert distribution. This section attempts to gather the science goals which might potentially require 1 minute alert distribution and could not be satisfied with a longer latency.

Generally, for science goals that require alerts on timescales shorter than ∼5 minutes, this need stems from targets that are fast-evolving or short-lived (or both) and require follow-up on timescales shorter than ∼15–30 minutes. Most observing strategies for the WFD main survey do not revisit fields on timescales shorter than ∼15 minutes (strategies that do pair visits aim for closer to ∼22 minute gaps). Thus, any science goals driving the need for alerts on timescales shorter than ∼5 minutes *must also be able to confidently identify their targets with single-epoch single-filter LSST photometry*, or be using additional information (such as host galaxy characteristics or coincidence with another survey's data).

Target of Opportunity – It is important to note that for rapid ToO observations with LSST (if they occur), there might not be time to pre-cache slow database queries (e.g., loading slices of the PPDB catalogs) when upcoming pointings are not known in advance, as would happen during regular survey observations. This might mean that a 1 minute alert distribution timescale for alerts from ToO imaging surveys cannot be guaranteed. While this should be kept in mind as a possibility, for the purposes of this study of the *scientific* impacts of the alert latency it assumed to be technically solvable issue.

3.1 TVS Survey Results Regarding Alerts Timescales

The Transients and Variable Stars (TVS) science collaboration surveyed the science needs of their members with respect to alert latency, and the results[4] are shown in Table 1. The survey asked respondents to choose the maximum tolerable and ideal average delay between the alerts being produced by the LSST data reduction pipeline and the alert information becoming

[4] Results courtesy of TVS co-chair Rachel Street.

available through the broker service. This is not exactly the same as the alert distribution timescale OTT1, but these responses will inform the need for <1 minute alert distribution. Respondents were asked to provide a short summary of their science goals for alerts if they reported needed access within 15 minutes. Note that the pool of respondents is probably not representative of the wider collaboration, and is likely biased towards individuals with science interests that do require faster access to alerts.

Only 20% (10%) of respondents report that <10 minutes (≤1 minute) is an ideal average delay, and whereas 70% report that >30 minutes would be a sufficient average latency. The three science drivers associated with <5 minute alert access are the electromagnetic counterparts to gravitational wave events (EM-GW; kilonovae), young supernovae (early short-lived light curve features such as shock breakouts), and gamma-ray bursts (GRB). The fact that these three are also listed as science drivers for longer-latency alert is mainly due to the diversity within the science drivers and the fact that the events have both short- and longer-timescale features. Each of these science drivers is discussed in turn below, along with two other science cases that rely on rapid access to LSST alerts: fast radio bursts (FRBs) and solar system objects (SSOs).

TABLE 1: Table of results from a TVS survey which asked "how fast do you really need alerts?". The total number of respondents was 20. The science driver acronyms are: EM-GW (electromagnetic counterparts to gravitational wave events), YSNe (young supernovae, including e.g., shock breakouts), GRBs (gamma-ray bursts).

Latency	Maximum Tolerable	Science Driver(s)	Ideal Average	Science Driver(s)
1 min or less	1	EM-GW, GRB	2	EM-GW, YSNe, GRB
1-5 min	0		1	
5-10 min	1	EM-GW, YSNe	1	YSNe
10-30 min	2	YSNe	2	EM-GW, GRBs
30-60 min	2		7	EM-GW
1-6 hours	4	EM-GW, GRBs	1	
6-12 hours	2		1	
12-24 hours	3	EM-GW	1	EM-GW
1-3 days	1		0	
>3 days	4		4	

3.2 EM Counterparts to GW Events

During LSST Operations, target-of-opportunity imaging follow-up sequences might be executed in the error ellipse of a gravitational wave (GW) detection to search for the electromagnetic (EM) optical counterpart. Such a search yielded a fast-evolving "kilonova" which decayed from 22 to 28th magnitude in the g-band in just 6 days (faster in the bluer and slower in the redder filters Kasliwal et al., 2017). Although the kilonova light curves last only a few days, since there is so far only one event, GW170817, a day or two delay between the GW event and the optical detection still yields very scientifically valuable data – for now. During LSST Operations there will already exist a sizable collection of longer-latency follow-up, and it is likely that science will be moving in the direction of pushing to ever earlier detections. However, since kilonovae produce days-long optical afterglows, a 5 minute LSST alerts would likely suffice.

There are two theoretical predictions for prompt optical emission that would require very rapid access to alerts. One of them is a potential faint, $<$1 hour, UV/optical transient that occurs at the time of jet-break out for a short gamma-ray burst associated with a binary neutron star merger (§ 3.3). Another that predicts emission of a similar color, luminosity, and timescale is the spin-down energy of a long-lived (10^2–10^4 s) neutron star formed from a binary neutron star merger before its eventual collapse to a black hole (Siegel & Ciolfi, 2016). As described in § 3.3, very few events could be detected by serendipitous coincidence by the LSST WFD main survey, and targeted follow-up of well-localized GW events with more appropriate facilities such as space-based UV/optical imagers is much more likely to yield detections of this very short lived emission.

There are two additional issues related to ToO for EMGW events which might make 1 minute alerts necessary or impossible. First, as described above, for a ToO imaging survey with LSST there might not be time to pre-load catalogs for the targeted fields. The second is that, at least for run O3, the GW event detection system itself issues preliminary alerts within 1–10 minutes, and these preliminary alerts are often retracted and do not always have the sky localization. Even now, many imaging follow-up surveys wait for the initial alert (or retraction) to be sent after a round of human vetting of the GW event signal, and this can take several hours. With such latencies, the question of 1 *vs.* 5 minute LSST alert timescales becomes inconsequential.

3.3 Gamma-Ray Bursts

For short gamma-ray bursts (sGRBs) which are thought to be the mergers of two neutron stars, or a neutron star and a black hole, as the jet propagates through the ejecta material a hot cocoon is formed. When cocoon and jet break out, along with sGRB can can be observed as a blue transient with an absolute peak brightness of -12 to -15 magnitudes that lasts for 10^3–10^4 seconds (e.g., Gottlieb et al. 2018). For an LSST detection limit of $r \sim 24$ mag, a detection limit of $r \lesssim -12$ ($r \lesssim -15$) mag corresponds to distances of $\lesssim 160$ ($\lesssim 630$) Mpc, or redshifts $z \lesssim 0.035$ ($z \lesssim 0.14$). Observing the diversity of cocoon emission will require multi-band follow-up within 10^3 seconds, or 15 minutes, and in this particular case a 5 minute alert distribution latency is too long to include the shorter events (or the fainter events for which only the peak would be visible).

The rate of short GRBs in the local volume (<200 Mpc) is estimated to be quite low, $<$4 yr^{-1} (Mandhai et al., 2019). Scaling this up to the co-moving volume within 630 Mpc is $\sim$240 yr^{-1}, all-sky. In the baseline main survey, about a sixth of the sky can be observed in a given night, which is $\lesssim$0.1 event in the WFD main survey area per night. With $\sim$1000 visits per night, and $\sim$10 visits every 5 minutes, there's a 10^{-3} chance that the location of a sGRB will be serendipitously observed within 5 minutes of the event on a given night. So this could happen once every 3 years, or $\sim$3 times over the 10-year LSST main survey.

For this particular science case, LSST seems to be the wrong tool for the job. As described by Gottlieb et al. (2018), a rapid search at the location of sGRBs with a UV satellite such as ULTRASAT would be ideal.

3.4 Young Supernovae

Photometric data obtained during the first few hours to days of a supernova can constrain the progenitor radius and circumstellar material in the immediate environment, which in turn provides information about the progenitor star, its system, and its final stages of evolution before the explosion. For example, Bersten et al. (2018) model the optical photometric data of the post-shock breakout cooling peak for a massive star's core collapse supernova to constrain the radius and mass of its outer envelope; Bloom et al. (2012) used the first day of photometric observations of a nearby Type Ia (thermonuclear detonation) supernova to show that their progenitor stars must be a compact degenerates; and rare "blue bumps" in the first few days of a Type Ia supernova's light curve might betray the presence of a non-degenerate companion star (e.g., Kasen, 2010; Hosseinzadeh et al., 2017).

For young supernovae, follow-up observations within a couple of hours are required, and the related science goals are unlikely to be impacted if the alert latency was 5–10 minutes instead of 1 minute.

3.5 Fast Radio Bursts

One of the strongest – but also most mysterious – transients that might significantly benefit from the 60 second alert timescale are fast radio bursts (FRBs): a millisecond long pulse of coherent emission in the GHz range. The emission is dispersed by the inter-galactic medium (IGM), such that the pulse's observed arrival time is frequency dependent. Observed FRB dispersion measures of $\mathrm{DM} \approx 100$ to $1000\ \mathrm{pc\ cm^{-3}}$ indicate that they originate at cosmological distances, with redshifts $z \approx 0.1$ to 1 (Shannon et al., 2018).

If an optical counterpart is generated by this coherent emission, the time delay between the optical detection and the radio detection is on the timescale of minutes for frequencies $\nu < 500\ \mathrm{MHz}$, as shown in Figure 1. This leaves open the possibility for triggering radio follow-up of an optical counterpart candidate serendipitously detected by LSST – if such counterparts exist and are detectable. A millisecond-long event in the optical would have to be quite bright to be detected by LSST, but studies show that LSST detections are feasible (Lyutikov & Lorimer, 2016). Yang et al. (2019) demonstrate that two theoretical sources for coherent optical emission from FRBs would not be detectable by LSST, but that inverse Compton scattering processes could lead to optical detections with LSST (e.g., from pulsars or masers). Searches for FRB counterparts in optical images that were serendipitously obtained (near-) coincidentally with an FRB detection have only just recently become possible thanks to current wide-field imaging surveys. No transient optical counterparts have yet been detected (Tingay & Yang, 2019), but individual host galaxies for FRB events have been identified (Keane et al., 2016). Since the rate of FRBs is estimated to be quite high (thousands per day; Champion et al. 2016) even after radio detection efficiency is factored in there could be many within the observed LSST volume.

For example, if there are 1000 FRB occurring across the full sky every 24 hours, and LSST observes one sixth of the sky during a night's 10 hours of darkness, then there would be ~ 70 FRB occurring in that area during that time. Assuming that both the FRB and the LSST visits are distributed randomly in time and location (although the visits are correlated, obviously), there's a $\sim 6\%$ chance that in any given night one visit will be serendipitously coincident with the short lived time-delayed optical counterpart of an FRB. If such a source could be recognized as an FRB optical counterpart within a minute, and radio follow-up could begin as soon as possible to detect the radio component and measure the time delay (Figure 1). However, it is (or rather, MLG is) currently unclear whether (a) there is strong theoretical support for such optical counterparts, and (b) radio telescopes can perform ToO follow-up on <15 minute timescales.

If FRBs are associated with superluminous supernovae (SLSNe) and young magnetars, then potentially an LSST alert regarding a change in behavior of known SLSNe could be used to trigger radio follow-up. However, this case is unlikely to be as sensitive to the LSST alert distribution timescale as the optical emission would be released over a longer time window (Law et al., 2019).

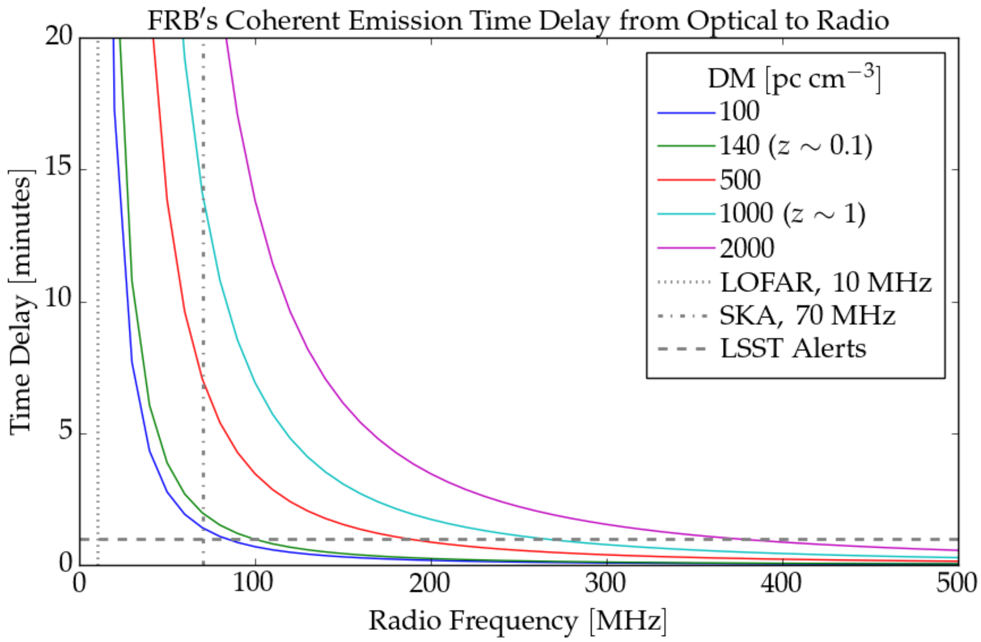

FIGURE 1: The delay time (for coherent emission) between the arrival of the optical and radio photons due to cosmological dispersion, as a function of the frequency of the radio detector. The *lowest* frequency bands of the Square Kilometer Array (SKA) and the Low-Frequency Array (LOFAR) are marked with vertical dotted and dash-dotted lines, and the 1 minute timescale for LSST alert distribution with a horizontal dashed line. The delay time is $\Delta t = k_{\rm DM}\, DM\, (\nu_{\rm low}^{-2} - \nu_{\rm high}^{-2})$, where $k_{DM} = 4.149\ {\rm GHz}^2\ {\rm pc}^{-1}\ {\rm cm}^3\ {\rm ms}$, ${\rm DM}$ is the dispersion measure in ${\rm pc\ cm}^{-3}$, ν is the low and high frequency bands of the observation, and Δt is in ${\rm ms}$. We have used the range of FRB dispersion measures as observed by Shannon et al. (2018).

3.6 Solar System Objects

MLG: in Lynne's talk on the SSSC needs for alerts brokers at the CBW in June 2019, slide 4 says that a needed broker capability was "API or other 'push' notification (e.g., trailed detections) [minutes may count]". Follow-up on the SS use case for alerts on very short timescales.

3.7 Stellar Variables

Return to the road map or science book? Surely there must be some stellar use-cases for 1 minute alerts. E.g., microlensing peaks can be real sharp.

3.8 Summary

There does not, currently, seem to be an unambiguous need for alerts on latency timescales of 1 minute compared to 5 minutes. However, it is not unambiguous that such a need will not evolve out of the still emergent fields of fast radio bursts and gravitational wave events.

4 Pre-Filtered Alert Streams

This section explores the scientific motivation and impact of offering brokers pre-filtered alert streams. Pre-filtering could reduce the overall bandwidth of alert distribution and potentially allow streams to be transmitted to more brokers, thereby enabling more alerts-related science. Providing pre-filtered streams could also lessen the load and resources used by the brokers, enabling more alerts-related science by allowing brokers to spend a smaller fraction of their budget computational resources.

The types of pre-filters that a broker would use are mainly driven by the science goals of that particular broker; some examples follow. A broker might only find it useful to receive alerts for `DIASources` that are likely to be stellar variables, moving objects, or extragalactic transients. A broker might only want to receive alerts that could potentially be observed by its associated follow-up resources – `DIASources` brighter than a given limit or located in a particular region of sky. A broker might employ a suite of algorithms that all require, e.g., at least two detections by LSST before any further action is taken, and so would not need any single-detection alerts. A broker might be specialized in a science area that is not done with the wide-fast-deep main survey, but with a special program such as the deep drilling fields or target-of-opportunity imaging surveys. Finally, a broker might not be interested in alerts obtained during poor weather conditions (e.g., an image quality or sky background violating some limit) – although, this type of filter might not be entirely science-driven.

For the above science drivers, the types of pre-filters that are likely to be scientifically useful – some of which have been suggested by brokers already – include:

- **Apparent Magnitude:** only `DIASources` brighter than a specified apparent magnitude (for each of the LSST filters *ugrizy*) are transmitted.
- **Region of Sky:** only `DIASources` in a given sky area (or areas; defined by, e.g., limits in right ascension or declination), are transmitted.
- **DIAObject History:** only `DIASources` associated with `DIAObjects` that have at least N previous detections are transmitted, where N can be ≥ 1.
- **SSObject Association:** only `DIASources` that are associated with a `SSObject` are transmitted. (Potentially including new, unassociated `DIASources`, because they might also be moving objects).

- **Object Association:** only DIASources associated with DIAObjects that are, in turn, associated with a data release Object that meets some specification are transmitted (e.g., associated with a stellar point source).
- **Observation Metadata:** only alerts from images obtained with a given set of metadata, e.g., a special observing program or meeting sky condition thresholds, are transmitted.

All of these potential science-driven pre-filters are based on the information contained in the alert itself, and do not impose any additional processing on the Prompt pipeline.

Provide estimates for how much the alert stream volume would be reduced by each of these potential pre-filters using nominal limits.

4.1 LSST Alert Filtering Service

As described in LSE-163 the LSST will provide an alert filtering service with limited capacity, by which individuals with LSST data rights and access may receive alerts via pre-defined filters and/or create and apply their own filters to the stream [LPM-17; LSE-61]. It is a requirement that the LSST alert filtering service be able to support at least 100 simultaneous users, and capable of returning 20 full-sized alerts per visit per user. User-generated filters may be comprised of, e.g., a series of if statements applied to the alert packet elements. There are no requirements on the latency of filter execution, which may depend on the complexity of the filter and available resources.

numBrokerUsers
DMS-REQ-0343
numBrokerAlerts
DMS-REQ-0343

From a science perspective, it would be beneficial to offer any and all of the pre-filtered streams listed above as options for user-generated filters. Individual users running small follow-up programs are more likely to have access to smaller-aperture telescopes and thus desire an initial apparent magnitude cut. It would save on compute resources to avoid a situation in which, e.g., 50 user-generated brokers all start with an if statement to filter the stream to, e.g., $m_r < 20$ mag.

5 Graceful Degradation

The LSST specifications for the DMS require that it support the distribution of at least 40,000 alerts per single standard visit, and that for visits producing ≤40,000 alerts no more than 1% of them fail to have at least 98% of its alerts distributed within 60 seconds of image readout. It is furthermore specified that alert distribution "degrade gracefully" beyond that limit, meaning that visits resulting in an excess of 40,000 of alerts should not cause any DMS downtime [LSE-30; LSE-61].

transN
LSR-REQ-0101
nAlertVisitAvg
OSS-REQ-0193
nAlertVisitPeak
DMS-REQ-0393
sciVisitAlertDelay
sciVisitAlertFailure
OSS-REQ-0112
DMS-REQ-0392

This leaves the open question of what, from a science perspective, is the optimal way of dealing with delayed alerts that also meets the DMS specification of a “graceful degradation"? We leave the aspects of technical implementation of a “graceful degradation", such as distributing delayed alerts and alert archive storage access, for elsewhere and here just consider the science implications for a delayed timescale.

Next-opportunity distribution via the alert stream. As discussed in Section 3, there remains plenty of science goals that do not absolutely require alert distribution in 1 minute. Distributing delayed alerts via the stream would still enable plenty of science. The brokers might prefer to have delayed alerts clearly flagged to properly process them (e.g., some filtering and processing done by brokers might only be appropriate for alerts delivered within a given latency).

Next-morning distribution via the alert stream. This refers to an option to collect all delayed alerts during the night and then releasing them (perhaps on a new “topic") in the morning after survey operations have ended for the night. From a science perspective this is not as useful as next-opportunity distribution, but if it is preferred for technical reasons it would enable more science than the option below.

Do not distribute delayed alerts; send directly to archive. There is no scientific merit in not distributing delayed alerts, and two further drawbacks: the alert archive update timescale is 24 hours, significantly slower than next-morning distribution, and the alert archive might only be accessible by brokers with data rights since it is part of the LSST Data Facility. L1PublicT

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