Transient Alerts in LSST

Jeffrey Kantor
Large Synoptic Survey Telescope

1 Introduction

During LSST observing, transient events will be detected and alerts generated at the LSST Archive Center at NCSA in Champaign-Illinois. As a very high rate of alerts is expected, approaching 10 million per night, we plan for VOEvent-compliant Distributor/Brokers (http://voevent.org) to be the primary end-points of the full LSST alert streams. End users will then use these Distributor/Brokers to classify and filter events on the stream for those fitting their science goals. These Distributor/Brokers are envisioned to be operated as a community service by third parties who will have signed MOUs with LSST. The exact identification of Distributor/Brokers to receive alerts will be determined as LSST approaches full operations and may change over time, but it is in our interest to identify and coordinate with them as early as possible.

LSST will also operate a limited Distributor/Broker with a filtering capability at the Archive Center, to allow alerts to be sent directly to a limited number of entities that for some reason need to have a more direct connection to LSST. This might include, for example, observatories with significant follow-up capabilities whose observing may temporarily be more directly tied to LSST observing. It will let astronomers create simple filters that limit what alerts are ultimately forwarded to them. These user defined filters will be possible to specify using an SQL-like declarative language, or short snippets of (likely Python) code. We emphasize that this LSST-provided capability will be limited, and is not intended to satisfy the wide variety of use cases that a full-fledged public Event Distributor/Broker could. End users will not be able to subscribe to full, unfiltered, alert streams coming directly from LSST.

In this paper, we will discuss anticipated LSST data rates and capabilities for alert processing and distribution/brokering. We will clarify what the LSST Observatory will provide versus what we anticipate will be a community effort.

2 LSST Transient Science

The Large Synoptic Survey Telescope (LSST; http://lsst.org) is a planned, large-aperture, wide-field, ground-based telescope that will survey half the sky every few

nights in six optical bands from 320 to 1050 nm. It will explore a wide range of astrophysical questions, ranging from discovering killer asteroids, to examining the nature of dark energy.

The LSST will produce on average 15 terabytes of data per night, yielding an (uncompressed) data set of over 100 petabytes at the end of its 10-year mission. Dedicated HPC facilities will process the image data in near real time, with full-dataset re-processings on annual scale. A sophisticated data management system will enable database queries from individual users, as well as computationally intensive scientific investigations that utilize the entire data set.

LSST will support many areas of scientific research, as indicated in the LSST Science Book [1]. Of particular interest to the target audience of this paper are the sections on Transient Science and Solar System Science. LSST will detect and alert on an average of approximately 10 million transient events per night, where an event is defined as a significant, measured change in flux over a particular location.

LSST requirements are defined in the LSST Science Requirements Document (SRD) [2]. The following is an extract of the requirements related to transients and covers the contents, throughput, and filtering.

The fast release of data on likely optical transients will include measurements of position, flux, size and shape, using appropriate weighting functions, for all the objects detected above transSNR signal-to-noise ratio in difference images (design specification: 5). The data stream will also include prior variability information and data from the same night, if available. The prior variability information will at the very least include low-order light- curve moments and probability that the object is variable, and ideally the full light curves in all available bands. Specification: The system should be capable of reporting such data for at least transN candidate transients per field of view and visit (Table 1).

The users will have an option of a query-like pre-filtering of this data stream in order to select likely candidates for specific transient type. Users may also query the LSST science database at any time for additional information that may be useful, such as the properties of static objects that are positionally close to the candidate transients. Several pre-defined filters optimized for traditionally popular transients, such as supernovae and microlensed sources, will also be available, as well as the ability to add new pre-defined filters as the survey continues.

In normal survey mode, LSST will operate by capturing two back-to-back, 15-

Quantity	Design Spec	Minimum Spec	Stretch Goal
transN	10^4	10^5	10^6

Table 1: The minimum number of candidate transients per field of view that the system can report in real time.

second exposures for each pointing. The two exposures are referred to as snaps (aka exposures). They are combined to a visit, which is the basic input image product for transient alert processing, i.e. alerts are issued for each visit, not each snap. The primary purpose of the snaps is to enhance cosmic ray rejection. They are not to be confused with 30 to 90 minute revisits, scheduled to support Solar System science. The LSST Data Products Definition Document [3] is a readable description of LSST data products. Used to communicate with the science community, and to support the formal requirements flow-down. Describes the processing as well as the data products:

- Level 1 Data Products: Section 4
- Level 2 Data Products: Section 5
- Level 3 Data Products: Section 6
- Special Programs DPs: Section 7

Level 1 Data Products include the transient alerts.

LSST computing is sized for 10M alerts/night (average), 10k/visit (average), 40k/visit (peak). The DM System design includes, dedicated multi-gigabit/second networks for moving data from Chile to the US.

At the LSST Archive Center at the University of Illinois National Center for Supercomputing Applications (NCSA) dedicated computing infrastructure executes image differencing pipelines with improved algorithms for image calibration, detection, and alert generation. Solar System objects will be identified and linked together based on compatibility of their observed positions with motion around the Sun. An enhanced variant of the Pan-STARRS Moving Object Processing System (MOPS) algorithm has been used to develop an advanced prototype of the system. The fully developed algorithm will be used to identify and link observations of Solar System objects; measure their orbital elements; and measure their photometric properties. For each detected DIASource, LSST will emit an Event Alert within 60 seconds of the end of visit (defined as the end of image readout from the LSST Camera). LSST will measure and transmit with each alert:

- position
- flux, size, and shape
- light curves in all bands (up to a year; stretch: all)
- variability characterization (eg., low-order light-curve moments, probability the object is variable)
- cut-outs centered on the object (template, difference image)

Also, LSST will make available within 60 seconds fast moving objects (trailed) and known SSO's which suddenly develop activity (i.e. they show a non-point-source PSF). The goal is to transmit nearly everything LSST knows about any given event, enabling downstream classification and decision making without the need to call back into LSST databases (thus introducing extra latency).

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In conclusion, LSST will generate millions of transient alerts of interest to transient and solar system scientists every night, and will support public distribution of these alerts on 60 second time frames.

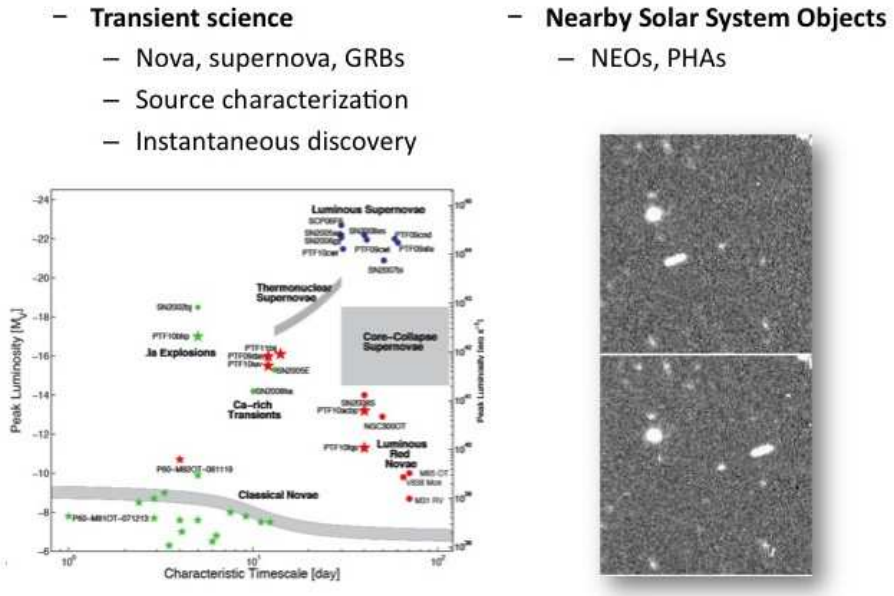

Figure 1: Transient Science with LSST

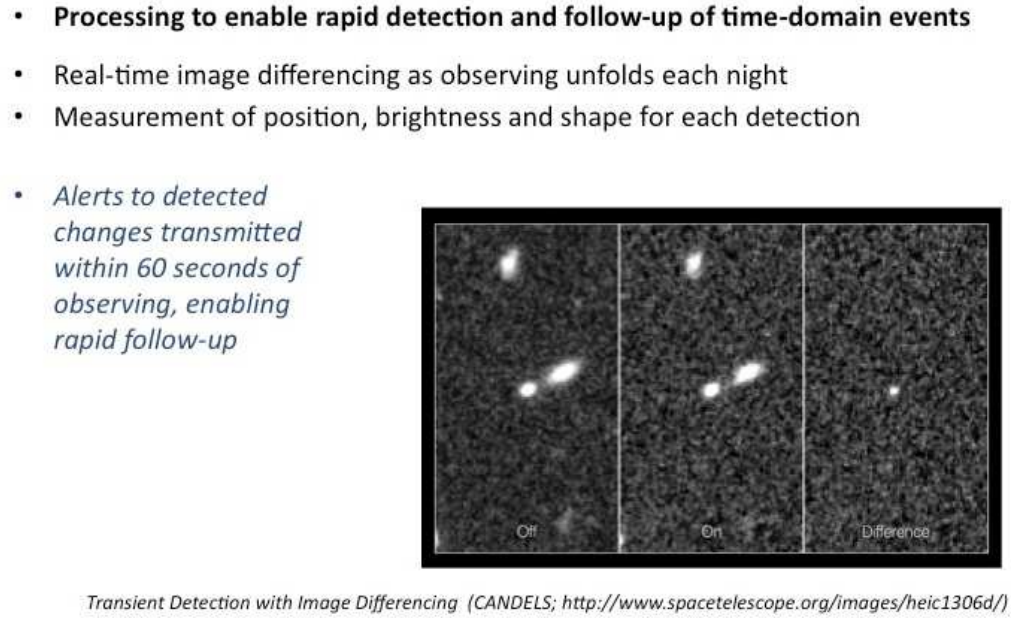

Figure 2: Transient Detection with Difference Imaging (CANDELS:http://www.spacetelescope.org/images/heic1306D/)

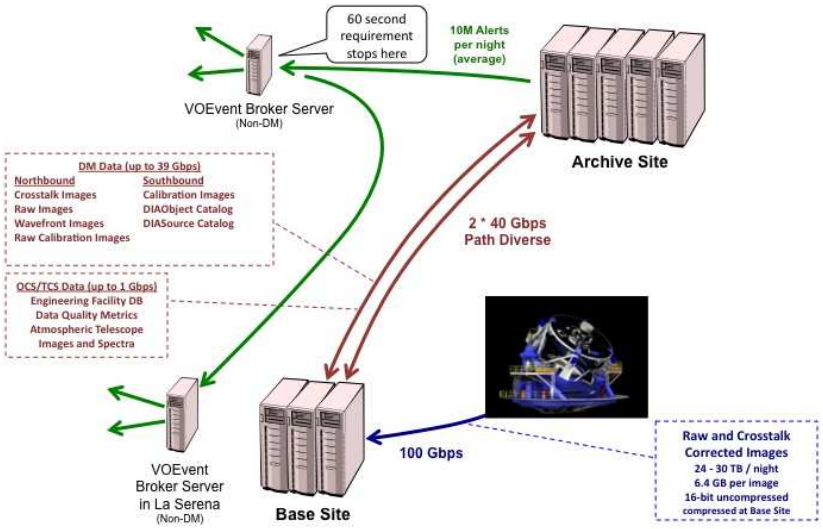

Figure 3: LSST Nightly International Data Flows

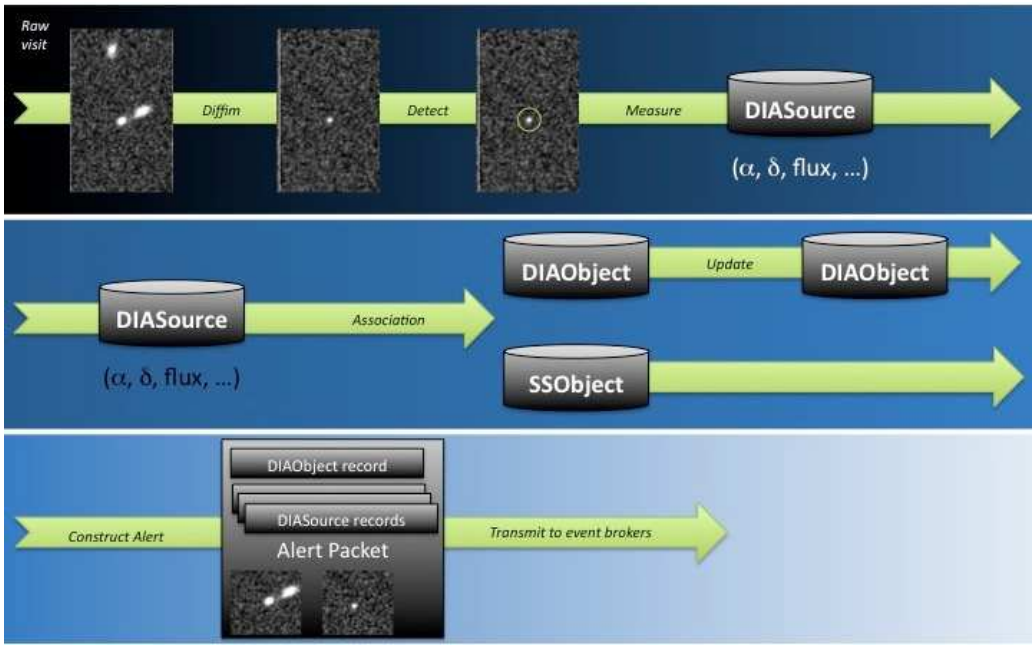

Figure 4: Level 1 Alert Production Outline

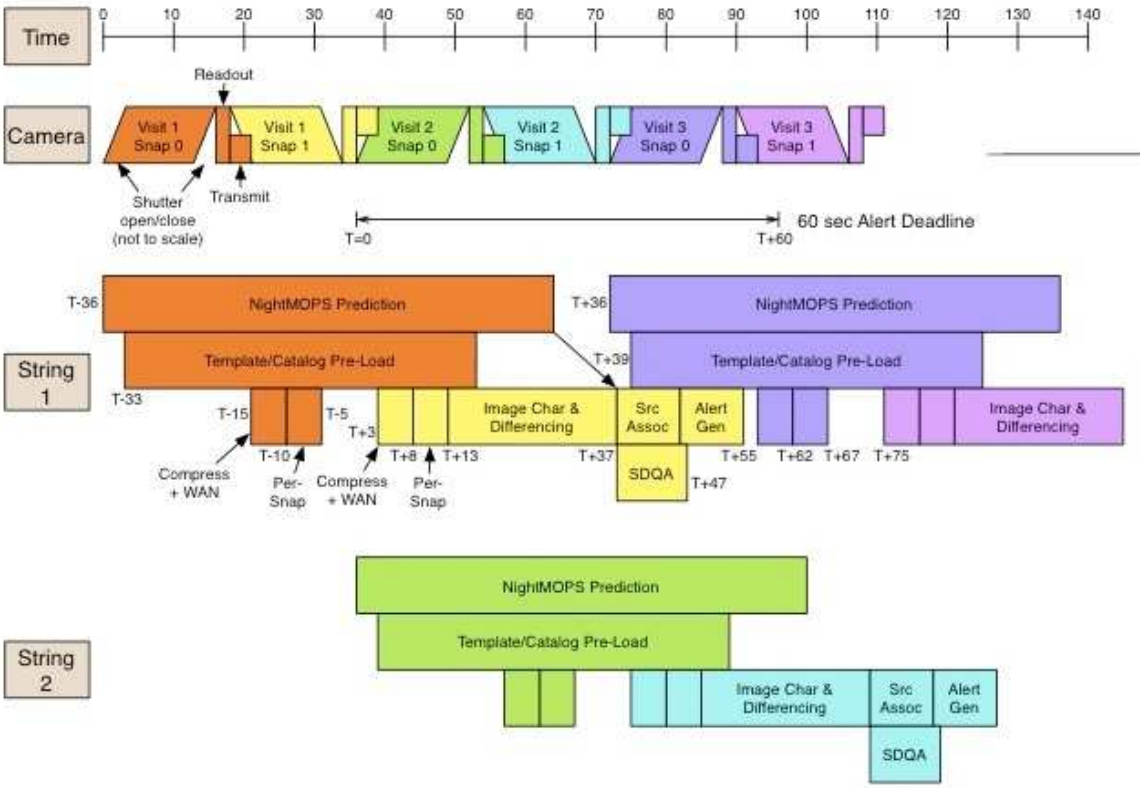

Figure 5: Level 1 Alert Production Timeline

References

[1] LSST Science Collaborations. (2009). LSST Science Book (2nd ed.). Tucson, Arizona: LSST.

[2] Ivezic, Z. and the LSST Science Collaboration. (2011). LSST Science Requirements Document (5th ed.). Tucson, Arizona: LSST.

[3] Juric, M., Lupton, R.H., Axelrod, T., Bosch, J.F., Dubois-Felsmann, G., Ivezic, Z., Becker, A.C., Becla, J., Connolly, A.J., Freemon, M., Kantor, J., Lim, K-T, Shaw, D., Strauss, M., Tyson, J.A. (2013). LSST Data Products Definition Document. LSST Data Management. Tucson, Arizona: LSST.