

# Alert Production with the Vera C. Rubin Observatory

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## ABSTRACT

Describes the LSST Alert Production pipelines, data products, execution environment, and early performance.

### Todo list

7		
8	Eric: more	1
9	Eric: add some examples: FBOTS, ISOs, asteroids interior to venus, ...	2
10	Eric: VOEvent, GCN, SciMMA/HopSkotch, TNS	2
11	Eric: cites	2
12	Eric: confirm	2
13	Eric: cites throughout	2
14	Eric: brief summary of observations: commissioning, first alerts, ongoing data taking. What we expect to be in the PPDB.	2
15	Eric: cite	2
16	Eric: image release?	2
17	Eric: final date	2
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19	Eric: scheduler discussion/citation? link to survey-strategy.lsst.io? mention status dashboards at prompt-products.lsst.io?	2
20	appropriate citation	2
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## 1. INTRODUCTION

Time-domain measurements are among of the foundational techniques of astronomical science: repeated observations of the night sky enable discovery of transient, variable, and moving objects. The cadence of the observations, the intrinsic luminosities and timescales of the phenomena, and the spatial volume probed by the observations set the rate of discovery (Bellm 2016). In recent years, scientists have conducted dedicated optical time-domain surveys with large CCD mosaic cameras (e.g., PanSTARRS, DECam, ZTF, HSC, Gaia, Kepler, TESS) as well as distributed telescope networks (e.g., ASAS-SN, ATLAS, KMT-Net,

Eric: more

79 ). These have yielded large new samples of super-  
 80 novae, variable stars, active galactic nuclei, and solar  
 81 system objects. Additionally, they have uncovered the  
 82 first exemplars of rare new classes of objects

Eric: add some examples: FBOTS, ISOs, asteroids  
 interior to venus, ...

84 .  
 85 Frequently, time-critical followup observations are  
 86 necessary to classify and characterize objects discovered  
 87 in time-domain surveys. Historically, human-composed  
 88 circulars or telegrams were used to disseminate discov-  
 89 eries to the wider community. The increasing rate of  
 90 transient candidates as well as the desire for rapid au-  
 91 tomated followup motivated machine-readable alterna-  
 92 tives

Eric: VOEvent, GCN, SciMMA/HopSkotch, TNS

93 . These trends culminated in the public “alert stream”  
 94 paradigm employed by ZTF (Patterson et al. 2019), in  
 95 which hundreds of thousands of unfiltered difference im-  
 96 age sources are shipped along with historical lightcurves  
 97 and image cutouts to third-party alert brokers for clas-  
 98 sification, filtering, and followup. This approach has  
 99 enabled fully automated identification, reporting, and  
 100 followup of supernova candidates

Eric: cites

103 .  
 104 The Legacy Survey of Space and Time (LSST) to be  
 105 conducted by the Vera C. Rubin Observatory promises  
 106 an order of magnitude increase in transient discovery.  
 107 Rubin’s large collecting area, wide field of view, and fast  
 108 readout and slew will deliver nearly a thousand

Eric: confirm

109 exposures across a wide swath of the Southern Hemi-  
 110 sphere sky to unprecedented depths. This capability  
 111 motivated the development of a rapid data processing  
 112 pipeline to identify and publicize time-variable phenom-  
 113 ena in LSST images: the Rubin Alert Production Sys-  
 114 tem (AP). Along with the annual Data Release Process-  
 115 ing (DRP), these productions make use of the Rubin  
 116 Science Pipelines software as well as the larger systems  
 117 and infrastructure of Rubin Data Management (DM).

Eric: cites throughout

120 In this paper, we describe the design, implementation,  
 121 and initial performance of the Rubin Alert Production  
 122 system. In §2 we detail the alert-producing observations  
 123 taken to date. §3 presents the science data products re-  
 124 sulting from alert production and §4 describes the data

125 processing pipelines which produce them<sup>2</sup>. We summa-  
 126 rize the data processing environment and infrastructure  
 127 in §5. We characterize the early scientific and techni-  
 128 cal performance of alert production in §6. In §7 and §8  
 129 we describe how data are served to scientists and the  
 130 support channels available to users. We conclude in §9.

## 131 2. OBSERVATIONS

Eric: brief summary of observations: commissioning,  
 first alerts, ongoing data taking. What we expect to  
 be in the PPDB.

Unlike Rubin’s Data Releases (e.g., DP1, DP2

Eric: cite

132 ), which contain a fixed dataset acquired before the  
 133 processing begins, Alert Production provides a contin-  
 134 uous, ongoing release of data obtained by Rubin that is  
 135 released within seconds to days of observation. During  
 136 commissioning, alerts were transmitted to community  
 137 alert brokers for technical integration tests beginning  
 138 on 2025-09-05. Since data from this period are avail-  
 139 able in alert history and the Prompt Products Database  
 140 (PPDB; §7.3.4)

Eric: image release?

141 , we include them in this paper, although they were  
 142 not available publicly at the time of processing. Real-  
 143 time public alert release began on 2026-02-24. In this  
 144 paper we include data obtained until

Eric: final date

145 .  
 146 During the commissioning and early operations  
 147 phases, scientific data taking was intermixed with on-  
 148 going technical commisioning activities that did not  
 149 produce data suitable for alert production. Calibration,  
 150 delivered image quality, and pipeline processing were  
 151 under substantial development. Additionally, template  
 152 images were only available initially for a small subset  
 153 of the sky area. Accordingly, the quantity and quality  
 154 of early alerts produced are not representative of steady-  
 155 state performance, and not all data products are avail-  
 156 able. We specify the range of data included in our per-  
 157 formance analysis (§6).

Eric: consider a figure or histogram showing the  
 alert rate over time, perhaps a sky plot of alert den-  
 sity?? or colored by earliest alert date?

<sup>2</sup> Discovery of new solar system objects from daytime process-  
 ing of the prompt data products is not described here but is  
 presented in

appropriate citation

Eric: scheduler discussion/citation? link to survey-strategy.lsst.io? mention status dashboards at prompt-products.lsst.io?

### 3. PROMPT DATA PRODUCTS

Eric: Summary of relevant aspects of the DPDD (Jurić et al. 2023), including latency considerations and user access. Describe key requirements that drive technical decisions.

#### 3.1. Alerts

Alert packets are the primary data product for time-critical LSST science. Each alert packet is triggered by a single positive or negative detection on a difference image. This measurement is packaged with a variety of contextual information in order to enable downstream users to quickly identify events of interest without requiring followup queries to Rubin databases.

Each alert packet contains

- The triggering DIASource record
- The corresponding DIAObject or SSOBJECT record
- Any DIASource and DIAForcedSource records that exist, and difference image noise estimates where they do not, taken from the previous 12 months.
- Cutout images of the science, template, and difference images.

Eric: confirm contents

The cutout images are packaged in the FITS format using the `astropy CCDData` class and include mask and variance planes, an estimate of the PSF, a World Coordinate System, and other metadata. Most cutouts are  $30 \times 30$  pixels but are expanded to a larger size for extended sources. The maximum cutout size of  $102 \times 102$  pixels allows cutouts to contain trailed Near Earth Asteroids traveling slower than ten degrees per day while avoiding the performance impacts that would result from larger cutouts.

Alerts are transmitted and stored in Apache Avro<sup>3</sup> format, a strongly-schemaed compact binary serialization. However, the Avro standard includes its schemas as uncompressed ASCII. To conserve bandwidth, we therefore send alerts without including the schemas required to deserialize them. Instead, the schemas are stored in a separate schema registry and are referenced by a unique

identifier in the alert packet. (Patterson et al. 2024) describes the alert packaging and schema versioning used in the alerts. Avro alert schemas are programatically generated from the database schema definitions stored in the `lsst.sdm.schemas` package and can be found in the `lsst.alert.packet` repository<sup>4</sup>.

#### 3.2. Images

#### 3.3. Prompt Catalogs

Eric: point to schema browser. forward reference the PPDB.

#### 3.4. Data Rights

Blum & the Rubin Operations Team (2020) describes the Rubin Data Rights policies. In brief, alert packets are world-public and can be freely shared with anyone. Similarly, the contents of the PPDB are freely sharable, although direct access to the PPDB is restricted to Data Rights holders. All other data products are proprietary.

## 4. PIPELINE

The Alert Production Pipelines are a specialized configuration of the LSST Science Pipelines. ? provides a general overview of their design and capabilities. In this section we describe the detailed implementation used for Alert Production.

consider a (simplified?) pipeline graph

emphasize not a static/permanent release; evolving over time

#### 4.1. Template Generation

#### 4.2. Preload

#### 4.3. Single Frame Processing

ISR, PSF and Background fitting, photometric and astrometric calibration. Likely major commonalities with DRP; perhaps point to DP2 paper and describe any differences

#### 4.4. Image Differencing

including background subtraction

#### 4.5. Source Detection and Measurement

Including discussion of point source, dipole, and trail detection on difference images.

#### 4.6. Initial Filtering

glint detection

<sup>3</sup> <https://avro.apache.org/>

<sup>4</sup> [https://github.com/lsst/alert\\_packet/](https://github.com/lsst/alert_packet/)

satellite filtering

FilterDiaSourceCatalogTask in `lsst.ap.association`

#### 4.7. Reliability scoring

Image-differencing searches for transients typically contend with high rates of false positives. Among the raw detections, artifacts may dominate real astrophysical sources by an order of magnitude. These may be due to imperfectly-corrected instrument signatures, astrometric mismatches between the template and the science image, cosmic rays, or algorithmic failures in the differencing. Modern surveys employ machine-learned classifiers to winnow these candidates (e.g., Bailey et al. 2007; Bloom et al. 2012; Brink et al. 2013; Wright et al. 2015; Goldstein et al. 2015; Duev et al. 2019). These have steadily improved in performance and sophistication as the classifiers transitioned from Random Forest models trained on manually-constructed feature sets to deep neural networks trained directly on image pixels. Some approaches have combined both detection and scoring without using the difference image (Sedaghat & Mahabal 2018; Acero-Cuellar et al. 2023).

Acero-Cuellar et al. (2026) describes the training and performance of the reliability classifier versions deployed in Alert Production. Here we summarize the currently-deployed model

Eric: version

. Further improvements are planned as more data is taken.

overview of the algorithm, training, and performance of the ML spuriousness score; detailed discussion likely deferred to separate paper

#### 4.8. Catalog Transformation

TransformDiaSourceCatalogTask in `lsst.ap.association`

Eric: schema tables?

#### 4.9. Source Association

Due to AP’s real-time nature, it is not possible to perform *post-facto* source association as in the annual data releases. Instead, spatial association is performed on-the-fly by the `DiaPipelineTask` within the `lsst.ap.association` package. A dedicated Alert Production Database (APDB; §5.2) holds the current state of the system.

During the preload step (§4.2), `DIAObjects` and `SSObjects` overlapping the expected field of view of the image are stored in the local prompt processing worker butler repository. The new `DIASources` are first spatially associated with the existing `DIAObjects` by finding the closest match within a maximum distance of one

arcsecond. Pairs with the closest spatial separations are joined first to minimize misassociations. When a match is found, the `DIASource` is added to the `DIAObject`’s list of measurements. Unassociated `DIASources` are then spatially associated with the predicted positions of the `SSObjects` at the time of the exposure. For `DIASources` with no matching `DIAObject` or `SSObject`, a new `DIAObject` is created and the `DIASource` is added to it.

#### 4.10. Alert Generation

Each `DIASource` not filtered for quality purposes (§4.6) produces an alert (§3.1).

Eric: sizing estimates here or in initial performance section? if not, collapse into next section

#### 4.11. Alert Distribution

We use the Kafka distributed streaming platform<sup>5</sup> to transmit alerts to brokers. Kafka provides a fault-tolerant, low-overhead mechanism to transmit large volumes of data to multiple consumers and is widely used both in industry and in astronomy.

Eric: cite patterson, GCN, Hopskotch, other Rubin usage...

The Alert Distribution Kafka system is deployed at the USDF using Kubernetes.

Bri: details of the deployment

Bri: schema management

Because of the large size of the alert packets and the short latency requirement, bandwidth out of the US Data Facility (USDF) at SLAC limits the number of direct recipients of the full alert stream. Seven community alert brokers receive the full alert stream directly from the USDF (§7.1).

#### 4.12. Forced Photometry

#### 4.13. Source Injection

#### 4.14. Metrics

### 5. DATA PROCESSING

#### 5.1. Prompt Processing Framework

(Findeisen et al. 2026)

#### 5.2. Alert Production Database

#### 5.3. Metrics and Monitoring

#### 5.4. Morning Batch Processing

Eric: deduplication

<sup>5</sup> <https://kafka.apache.org/>

Ian: catchup, single frame detection, visit-level consolidation, metrics

## 6. INITIAL PERFORMANCE

### 6.1. *Template Properties*

### 6.2. *Alert Rate*

### 6.3. *Alert Purity*

Raw and after ML scoring

### 6.4. *Alert Completeness*

### 6.5. *Alert Latency*

### 6.6. *Photometric Precision*

### 6.7. *Astrometric Precision*

### 6.8. *Association Accuracy*

### 6.9. *Association of Known Solar System Objects*

Jake: completeness, astrometric accuracy

### 6.10. *Direct Source Catalogs*

### 6.11. *Crowded Field Performance*

## 7. DATA ACCESS SERVICES

### 7.1. *Community Alert Brokers*

Near real-time access to alert packets is available through services provided by community alert brokers. Due to limited bandwidth from the USDF, seven brokers were selected through a proposal process (Bellm et al. 2020) to receive the alert stream directly from the alert distribution system at the USDF (§4.11):

- ALerCE: Automatic Learning for the Rapid Classification of Events (Förster et al. 2021)
- AMPEL: Alert Management, Photometry, and Evaluation of Light Curves (Nordin et al. 2019)
- ANTARES: Arizona-NOIRLab Temporal Analysis and Response to Events System (Matheson et al. 2021)
- Babamul (Jegou du Laz et al. 2025)
- Fink (Möller et al. 2021)
- Lasair (Smith et al. 2019)
- Pitt-Google

As alert packets are world-public and freely sharable (§3.4), additional brokers and other services may operate “downstream” by connecting to full or filtered streams provided by the upstream brokers. As of this writing, downstream brokers include

- Point of Interest Broker

- SNAPS: Solar System Notification Alert Processing System

Eric: check broker sites if there are newer citations

### 7.2. *Alert Filtering Service*

The original requirements on the Rubin Data Management system (DMS) specify 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 users of this service “shall be able to use a predefined set of simple filters” (Dubois-Felsmann & Jenness 2019). These requirements were written before the current brokers existed, and they are already providing beyond this basic required functionality. Instead of creating a redundant alert filtering service, Rubin staff are instead supporting the community to use alerts by creating and maintaining a set of “community filters”, to be installed in the NOIRLab’s ANTARES broker (chosen because of the NOIRLab connection). As described in Graham et al. (2025), these community filters will cover a range of basic science use-cases and be generated based on community input. The first community filters are expected to be installed and validated by the fall of 2026.

### 7.3. *Rubin Science Platform*

Gregory: todo

#### 7.3.1. *Alert Archive*

#### 7.3.2. *Image Services*

#### 7.3.3. *Butler Data Products*

#### 7.3.4. *Prompt Products Database*

### 7.4. *IDACs*

confirm IDAC section

## 8. SUPPORT FOR COMMUNITY SCIENCE

The overall model for supporting the community to do science with Rubin data products, services, and tools was described for Data Preview 1 in Vera C. Rubin Observatory Team (2026). For the release of Prompt products, we developed documentation at <https://prompt-products.lsst.io/> and tutorials based on Prompt-processed data for the Notebook, Portal, and API aspects of the Rubin Science Platform. A series of virtual alerts and broker tutorials were held January to

407 April 2026 as part of the Rubin Science Assemblies, and  
408 recordings are available<sup>6</sup>.

409 The Rubin Community Forum<sup>7</sup> is the primary venue  
410 for user support and issue resolution (as a modern,  
411 open-source helpdesk). All are encouraged to post their  
412 Rubin-related questions there, and Rubin staff monitor  
413 the Support category. Several of the broker teams  
414 (ALeRCE, Fink, and Lasair, at the time of publication)  
415 are using sub-categories in the Forum to Support their  
416 own users, and Rubin staff support them in this effort.

## 417 9. CONCLUSION

418 Eric: summarize

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431 Members.

432 *Facility:* Rubin:Simonyi (LSSTCam), Ru-  
433 bin:USDAC

434 Eric: review and update citations to use current  
435 DOIs

436 *Software:* Rubin Data Butler (Jenness et al. 2022),  
437 LSST Science Pipelines (?), LSST Feature Based Sched-  
438 uler v3.0 (Yoachim et al. 2024; ?) Astropy (Astropy Col-  
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<sup>6</sup> [https://rubinobservatory.org/for-scientists/events-deadlines/  
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<sup>7</sup> <https://community.lsst.org/>

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