

LSST Alert Streams & Solar System Science

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LSST Data Management

LSST Alert Streams & Brokers

Solar System Science with LSST Alert Streams

Updates Interactions with Science Collaborations

LSST Prompt Processing Data Products for Solar System Science Alert Brokers Broker for Solar System Science

> Solar System Science Use Cases Alert Filtering





- LSST Data Management Scientist
 - Taking over from Mario Jurić
 - Started 14 May 2018

- Based at AURA, LSST HQ Site in Tucson, AZ, USA



 Previously worked on the ESA Gaia mission for over 10 years, on the ATLAS experiment and LHC Computing @ CERN















Mandate

" Ensure that the Data Management (DM) initiatives (pipelines and products) provide solutions that meet the overall LSST scientific goals."

Responsibilities

- Work with the science community to understand their needs and how they will be met by the DM System
- Identify and develop new scientific opportunities for the DM System, identify risks and coordinate change
- Lead the Science Validation of the deliverables of the LSST DM System





Every Science Collaboration has a designated liaison in the DM-SST

Science Collaboration	SC liaison	DM liaison	
Solar System	Meg Schwamb, David Trilling	Mario Jurić	
Galaxies	Michael Cooper, Brant Robertson	Robert Lupton	
Stars, Milky Way & Local Volume	John Bochanski, John Gizis, Nitya Jacob Kallivayalil	Colin Slater (DM-SST Deputy)	
Dark Energy	Phil Marshall, Eric Gawiser	Robert Lupton	
AGN	Niel Brandt	Željko Ivezić	
Transient & Variable Stars	Federica Bianco, Rachel Street	Melissa Graham, Eric Bellm	
Strong Lensing	Charles Keeton, Aprajita Verma	Jim Bosch	
Informatics & Statistics	Tom Loredo, Chad Schafer	Leanne Guy	

LSST Science Collaborations



LSST Data Management



Data Release Data Products via Annual Data Releases



11 Data Releases in 10 years Final database catalog: 15 PB

20TB raw data/night (with calibration exposures)



Prompt Data Products via nightly Alert Streams



Average ~ 10 million/night Real-time latency: 60sec



Data access via Data Access Centres & Services





Prompt

Formerly "Level 1" data products

Real Time Difference Image Analysis (DIA)

- A stream of ~10 million time-domain events per night (Alerts), detected, characterized, and transmitted to event distribution networks with 60 seconds of shutter close.
- A catalog of orbits for ~6 million bodies in the Solar System

Data Release

Formerly "Level 2" data products

Reduced single-epoch & deep co-added images, reprocessed DIA products

- A catalog of ~37 billion objects (20bn galaxies, 17bn stars), ~7 trillion observations ("sources"), and ~30 trillion measurements ("forced sources").
- Produced annually and accessible through online databases.

User Generated

User-produced added-value data products

- Deep KBO/NEO, variable star classifications, shear maps, photometric metallicity, etc.
- Enabled by services and computing resources at the LSST Data Access Centers (DACs) and via the LSST Science Platform.

LSST Data Product Categories & DM Data Products & Key Numbers





World Public

World Public data can be shared with everyone; data rights not required

Alerts: Alerts are immediately world public and can be shared with everyone
Data Releases (DPP): World public following a two year proprietary period from the release date.
Education & Public Outreach (EPO): All data products accessed via the EPO platform

Proprietary

Proprietary Data can only be shared with data rights holders

Alerts Database: Archive of all issued alerts

Prompt Products Database (PPDB): Difference Images, Source Catalogs including pre-covery forced photometry

Data Releases (DRP): Annual Data Releases include images & catalogs as well as re-processed prompt products

Science Platform: Computational resources, mini-broker and data portal are accessible only by data rights holders

Enables transient & time domain science requiring rapid follow-up

- Transient events: nova, supernova, GRBs
- Nearby Solar System Objects: NEOs, PHAs

Single-epoch data products (images and catalogs) and alerts

CANDELS (http://www.spacetelescope.org/images/heic1306d/)



- Sources detected on difference images with S/N > 5 (DIASource)
 - New astrophysical objects (asteroid)
 - Flux changes in existing sources (variable star)



Data Products Definition Document & Science Pipelines Design Document



Prompt Data Products



Difference Images Objects DIA Objects **Difference Image** Sinale Analysis Visits SS Objects DIA Forced **DIA Sources DIA Objects** Sources Only in nightly processing





A DIASource is associated with a known SSObject in real-time

- DIASource
 - ra, dec, time of mid-exposure
 - association with DIAObject or SSObject
 - parent/child de-blending flags
 non-exhaustive
- Measurements of the DIASources on the difference exposures includes trailed PSF models
 - PSF convolved with the line segment is fit to individual images

vith a known	Name	Туре	Unit	Description
	diaSourceId	uint64		Unique source identifier
	ccdVisitId	uint64		ID of CCD and visit where this source was measured
	diaObjectId	uint64		ID of the DIAObject this source was as- sociated with, if any.
ure	ssObjectId	uint64		ID of the SS0bject this source has been linked to, if any.
or SSObject		-		
ags	trailFlux	float	nmgy	Calibrated flux for a trailed source mode(^{41,42} . Note this actually measures the flux <i>difference</i> between the template and the visit image.
	trailRadec	double[2]	degrees	Centroid for trailed source model.
urcos on tho	trailLength	float	arcsec	Maximum likelihood fit of trail

trailAngle

trailCov

traill nl

trailNdata

en linked to, if any. librated flux for a trailed source odel^{41,42}. Note this actually meares the flux *difference* between the nplate and the visit image. ntroid for trailed source model. Maximum likelihood fit of trail float arcsec length^{43,44}. float degrees Maximum likelihood fit of the angle between the meridian through the centroid and the trail direction (bearing, direction of motion). float[15] various Covariance matrix of trailed source model parameters. Natural *log* likelihood of the observed float data given the trailed source model. The number of data points (pixels) int used to fit the model.

Table 1: DIASource Table

Data Products Definition Document





Table 3: SSObject Table

Name	Туре	Unit	Description
ssObjectId	uint64		Unique identifier.
oe	double[7]	various	Osculating orbital elements at epoch
			(q , e , i , Ω , ω , M_0 , epoch).
oeCov	double[28]	various	Covariance matrix for oe.
arc	float	days	Arc of observation.
orbFitLnL	float		Natural log of the likelihood of the or-
			bital elements fit.
orbFitChi2	float		χ^2 statistic of the orbital elements fit.
orbFitNdata	int		The number of data points (observa-
			tions) used to fit the orbital elements.
MOID	float[2]	AU	Minimum orbit intersection dis- tances ⁵³
moidLon	double[2]	degrees	MOID longitudes.
н	float[6]	mag	Mean absolute magnitude, per band
			[<u>14</u> , magnitude-phase system].
G_1	float[6]	mag	G_1 slope parameter, per band [14] magnitude-phase system].
G_2	float[6]	mag	G_2 slope parameter, per band [14]
			magnitude-phase system].
hErr	float[6]	mag	Uncertainty of H estimate.
g1Err	float[6]	mag	Uncertainty of G_1 estimate.
g2Err	float[6]	mag	Uncertainty of G_2 estimate.
flags	bit[64]	bit	Various useful flags.

 Moving Object Pipeline Software (MOPS) runs on DIASource catalog within 24h

- SSObject: the catalog of orbits of objects in the Solar System
 - Orbits, physical properties
 non-exhaustive
- Available in the Prompt Products database via LSST Science Platform
- <u>DM-12092</u>: Reviewing the SSObject
 Schema with the SSSC interoperation with the MPC?

Data Products Definition Document





- Nightly processing of LSST images produces a world-public stream of alerts, issued within 60 seconds of the shutter closure
- An alert is triggered solely by the detection of a DIASource with SNR > 5
- One alert per new DIASource detections
- Expect up to ~10 million alerts/night, roughly 1TB
- Will contain all classes of astrophysical events, Supernove, RR Lyrae, etc
- The goal is to quickly transmit information about new detections, enabling downstream classification & follow-up

Challenge: Identify & extract the subset of events of interest in the full alert stream





Alert Packet: a text file containing the data & associated schema for one DIASource Each alert (a VOEvent packet) will at least include the following:

- AlertID: An ID uniquely identifying this alert
- Prompt Products database ID
- Science Data
 - The DIASource record that triggered the alert
 - The entire DIAObject or SSObject record
 - Time series (up to 12 months) of all previous of DIASource detections
 - Matching Object IDs from the latest Data Release, and 12 months of DIASource records
 - Various summary statistics ("features") computed of the time series
- 30x30 pixel, cut-out of the difference image (FITS)
- 30x30 pixel, cut-out of the templagte image (FITS)





Alerts are delivered to community brokers that filter and classify events to enable science



Individual scientists will receive alerts through one or more of these services.

Data Management Science Pipelines Design





Primary end-points of LSST's event streams

- Provided by third parties,
- Trigger additional follow-up observations,
- Crossmatch with extant astronomical catalogs and alert streams
- Filter and classify events according to science goals,
- Provide machine learning classification of events,
- Provide user interfaces
- Alerts transmitted in VOEvent format & standard IVOA protocols,

A finite number of community brokers will be selected by a proposal process to receive the full stream





Simple filtering service for real-time access to a subset of the alert stream

- Access to the filtered stream via US DAC Science Platform
- User-defined filters that act only on single alert packets
- Provide some pre-defined filters, No cross-matching, no exclusive classification
- Support for 100 simultaneous users, 20 alerts/user/visit, some limits on runtime & bandwidth
- Coupled to the LSST Science Platform , access to alerts via LSST Science Platform

Development of mini-broker use cases & architecture ongoing.





What can be done with LSST-side filters on the alert stream?

- Formal requirement that the capability exist
 - Pre-defined filters will be provided but are as of yet undefined.
 - What would you like to see that would:
 - serve a broad community and
 - interest many people?





What will setting up a dedicated SSSC broker entail?

- Open question
- Can always write filters for the mini-broker
 - Performance requirements will not allow for many filters
 - 100 simultaneous connected users 100 filters is not much
- Is a full stream broker required to serve SS science?
 - Probably not?
 - Community broker proposal call does open up the possibility to receive a filtered stream and not the full stream,
 - e.g alerts on known solar system objects or trailed objects

Solar System Science with the LSST Alert Stream



does the alert packet provide enough information to enable common Solar System Science use cases with brokers?

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LSST discovers new moving object with heliocentric distance r>50 AU

- If no corresponding DIAObject/SSObject is found in the Prompt Products
 Database, a new DIAObject is created and the new DIASource associated.
- An event alert is issued for the new DIASource.
- Trailed source parameters in the DIASource record could be used to infer the object is an asteroid.
- Solar System Object Processing is only run during the following 24h to compute orbit and parameters and identification as a SSObject confirmed.
 - Three trackless required to realise an Object is an asteroid
- Better to execute this as a query against the Prompt Products database
 - e.g return all objects with heliocentric distance < X AU.





LSST observed object X in a new filter and its g-r colour is >Z

- Previous 12 months of DIASource records included in the alert packet can easily compute the color
- Is the most recent detection the only in this colour?
- Could easily do in the mini-broker in the LSST Science Platform





LSST observed object X at a time that is equivalent to a phase between 0.2-0.3 with a period of 1.2345678 days. Or at a phase that is ~0.1 from known phases.

- Alert packet includes a year's worth of time series data.
- Periodic time series features computed on DIAObjects:
 - Lomb-Scargle periodogram, 32 parameters for each band, 3 fundamental frequencies, 4 harmonics
 - TVS SC has a task force for reviewing these parameters.
- User-defined filter to compute phase of new DIASource based on extant time series data, filter on those satisfying phase criteria
- Do we need to compute periodic features on SSObjects?





LSST re-observed an object for the first time in this season

- For all new DIASource, the prompt products database is searched for a positional association to a DIAObject or SSObject.
- If the newly detected DIASource is associated with a known SSObject, it will be flagged as such and an alert will be issued.
- The alert packet contains the DIASource and the entire SSObject
 - DIASource: ra/dec, time of mid-exposure (midPointTai), SSObjectId
- A user-defined filter can be written to filter alerts for SSObject satisfying
 Num DIASource > 1 & Y < midPointTai < X





LSST observed an object that is more than 0.2" from its predicted position

- Involves computing an offset, how effectively can we reconstruct from the orbital parameters?
- DIASource contains ra/dec and time of mid-exposure
- SSObject contains orbital parameters
- User-defined filter computes the predicted position on each SSObject alert using previously computed orbital parameters, compares with the position of the newly associated DIASource and filters on differences > 0.2"





Can I get an email with all my alert results?

- There is no requirement to make an e-mail digest available
 ... but a desire to make the mini-broker as available as possible.
- We are in favour of providing good way to get summaries, e.g email digest or a single dashboard-like report interface.
- Currently under investigation



Questions