

Rubin Observatory Community Brokers

real-time astronomical alert processing

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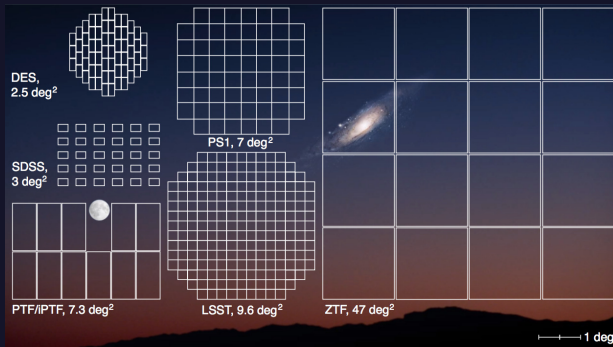


LineA Webinar, November 11 2021

The LSST Survey

Telescope

- 8.4-meter (6.7 m equivalent) at Rubin Observatory
- world's largest CCD camera: 3.2×10^9 pixels
- 6 optical bands *ugrizy* (320 - 1050 nm)

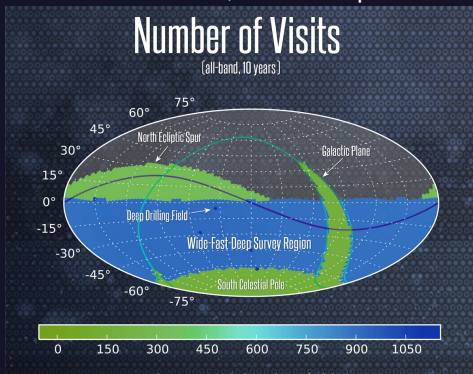


Field of view of various large-survey cameras. Moon and Andromeda Galaxy (Messier 31) shown to scale. (Laher et al. 2018)

The LSST Survey

Survey

- 10-year photometric survey *ugrizy*
- 1000 images/night = 15 TB/night, 10 million transients/night
- first light ComCam: Oct. 2022, start of operations: \sim Oct. 2023

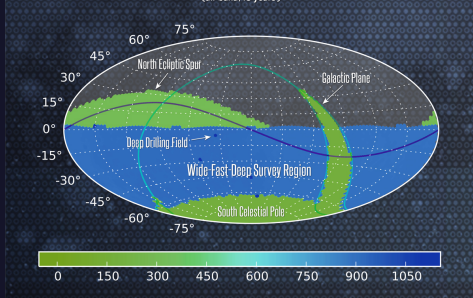


LSST survey strategy, showing regions with varying number of visits for sub-surveys.
(image source: www.lsst.org)

The LSST Survey

Number of Visits

(all-band, 10 years)



Main survey:

Wide-Fast-Deep: $2\times$ per night every three nights over $18,000 \text{ deg}^2$

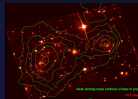
Special programs:

- Deep Drilling Fields
- Galactic Plane
- North Ecliptic Spur
- South Celestial Pole

Science with the LSST Survey

LSST is designed to address four science areas:

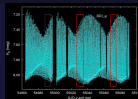
Probing Dark Energy and Dark Matter



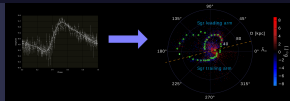
Cataloging the Solar System



Exploring the Variable/ Transient Optical Sky



Mapping the Milky Way



deep, wide, fast & long survey

LSST Data Products

readout

Raw Data

30 s image, 20 TB/night



37 s

Prompt Data Products

difference image analysis (DIA)
alerts: up to 10 million/night



24 h

Prompt Products Database

images, object & source catalog
solar system bodies orbit catalog



yearly

Annual Data Release

via LSST Science Platform
& LSST Data Access Centers



10 years

Final 10 Year Data Release

images: 5.5 million \times 3.2 Gpx
catalog: 15 PB, 37 billion objects



Alert Brokers

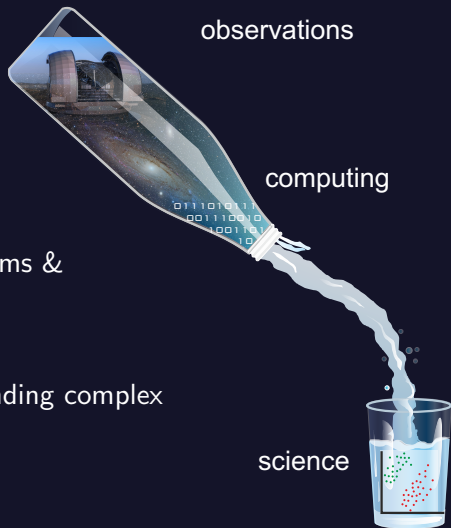


LSST Data Products

astronomy is largely determined by the available computational capacity

⇒ telescopes & instruments as front-ends for data processing systems & follow-up telescopes


⇒ challenge and chance: understanding complex phenomena requires complex data




LSST Data Products

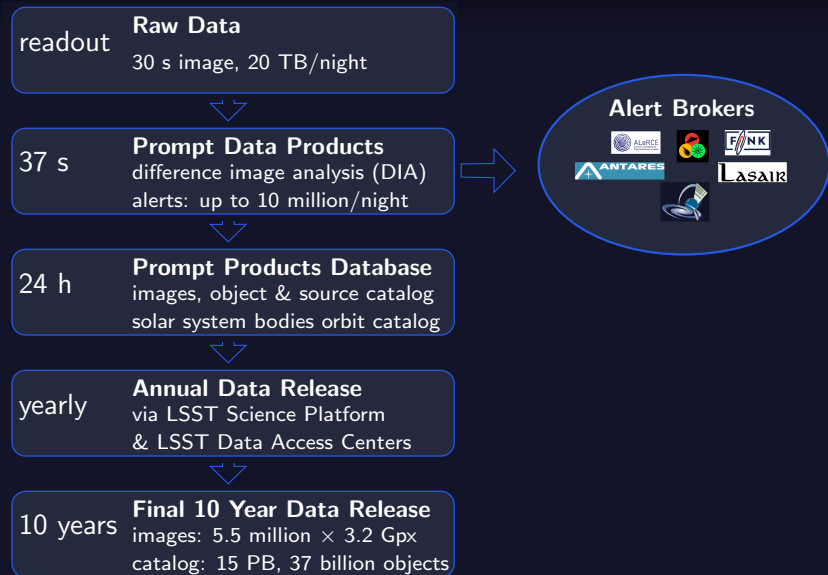
typical use cases from *complex data*:

- “unknown unknowns”
- known rare “1-in-a-million” events
- objects requiring immediate follow-up (e.g.: supernova, merger for multi-messenger astronomy)
- some follow-up requires accurate and up-to-date lightcurve information

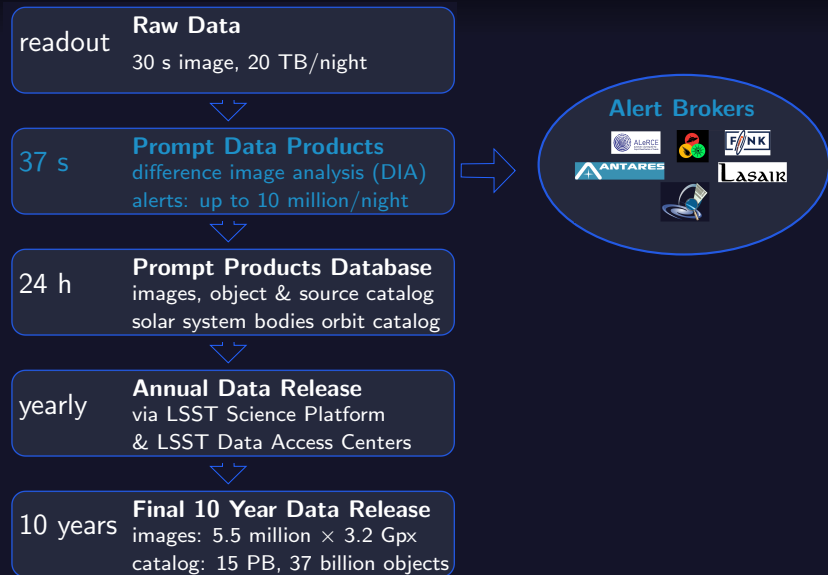
possible with LSST: large footprint  high cadence
allow for detailed light-curve analysis (cadence, baseline) as well as
for statistics from a large data set (footprint)

 software systems to sort and filter alerts at scale to enable
better follow-up

Rubin Observatory Alerts and Community Brokers



Rubin Observatory Alerts and Community Brokers



Rubin Observatory Alerts and Community Brokers

Rubin Observatory's real-time difference image analysis processing for LSST creates a stream of alerts containing data about transient, variable, and moving sources

alerts will be distributed to brokers:

software systems that **ingest**, **process** and **redistribute** astronomical alerts to the broader scientific community

typical functionality:

- cross-match with archival catalogs (object, association)
- photometric classification based on light-curve analysis
- identification and prioritization of objects for follow-up observations
- user-interaction

Selection of Rubin Observatory Community Brokers

anticipated high bandwidth of the Rubin Observatory alert stream



limited number of brokers can receive the stream directly

May 2019: Letters of Intent submitted from 15 teams

June 2019: 1st Community Brokers Workshop

August 2019: full proposals from 9 teams

Full-Stream Alert Brokers

- Alerce
- AMPEL
- ANTARES
- BABAMUL
- Fink
- Lasair
- Pitt-Google

Downstream Alert Brokers

- [Point of Interest](#)
- SNAPS

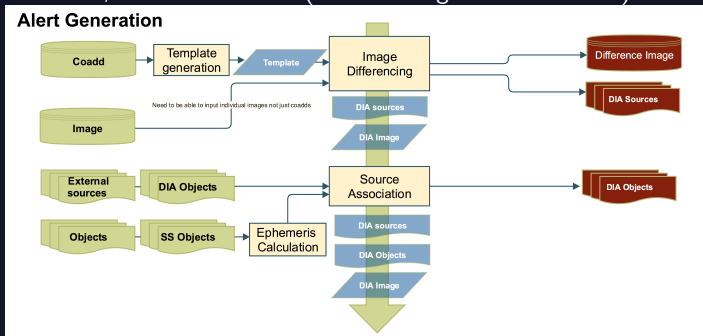
LSST Data Management System (DMS) Alert Production

process new data from DIA telescope with Difference Imaging Analysis (DIA)

$S/N > 5$: *detected*, record written to source catalogs, alert generated



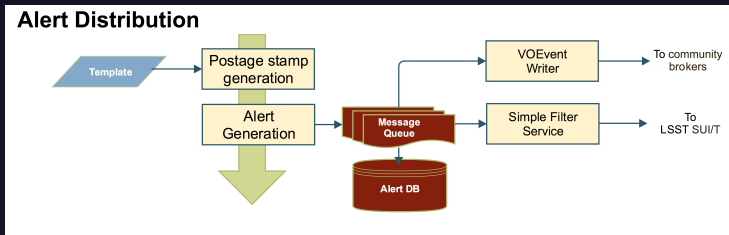
alert: package containing coordinates, photometry, image cutouts, other information (calculated light curve features)



LSST DMS Alert Production Pipeline (image source: ls.st/LDM-151)

LSST Data Management System (DMS) Alert Distribution

The time-averaged data rate of the alert stream is estimated to be ~ 0.2 Gb/s, potentially with bursts of up to 5.4 Gb/s. The estimated size of the alerts database after 10 years is ~ 2.2 PB.



LSST DMS Alert Distribution Pipeline (image source: ls.st/LDM-151)

Alert Production

pre-LSST alert streams

currently broker systems are tested with a **ZTF alert stream** and an archive of ZTF alerts made available by the University of Washington

(Patterson et al. (2019): The Zwicky Transient Facility Alert Distribution System)

	ZTF	LSST
Number of detections	1 trillion	7 trillion
Number of objects	1 billion	37 billion
Nightly alert rate	1 million	10 million
Nightly data rate	1.4 TB	15 TB
Alert latency	< 20 minutes	60 seconds

Alert Production

(anticipated) content of LSST alert streams

- cutout images
- photometry, light-curve history
- machine-learned Real/Bogus score
- set of light-curve features

Point of Interest Broker

Different brokers will have different capabilities and are directed towards different science cases.

Point of Interest broker: A lightweight broker for variable star identification, classification & follow up.

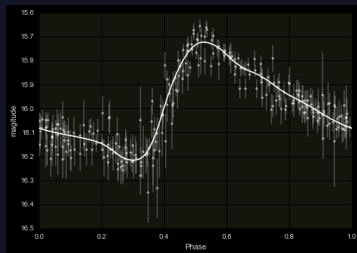


Scientific Goals: Variable Stars

the background: a project to characterize the Milky Way from variable stars

RR Lyrae, Cepheids:

- easy to detect: variable with specific light-curve profile
- distance measurement (period-luminosity relationship)



⇒ detection of structure such as tidal streams, dwarf galaxies

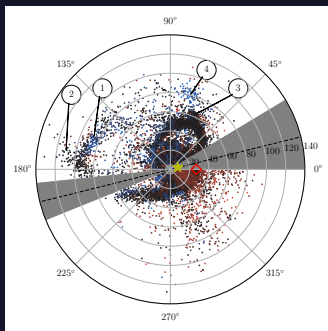
⇒ answering questions regarding the formation history of our Milky Way

Scientific Goals: Variable Stars

many “points” or regions of interest known:

- dwarf galaxies
- globular clusters
- tidal streams & substructure within

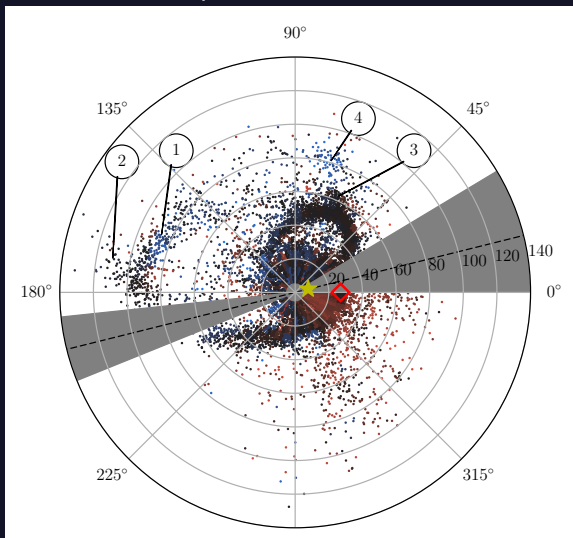
⇒ can be traced by periodic variable stars



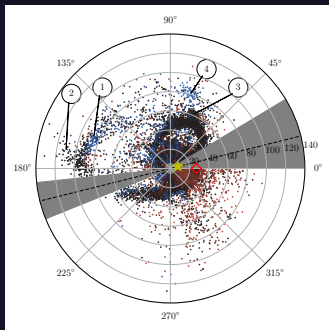
Sgr stream, traced with RRab stars from PS1 3π survey (Hernitschek+2017,2018)

Scientific Goals: Variable Stars

Sagittarius stream with “spurs”:



Scientific Goals: Variable Star Classification



important: to fill in more and more data points
e.g.: we looked for PS1 3π RRab stars to get $\sim 360^\circ$ view on Sgr stream

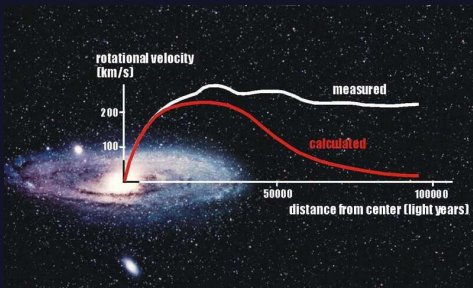
➔ reliable variable star identification & classification

Scientific Goals: Variable Star Follow-Up

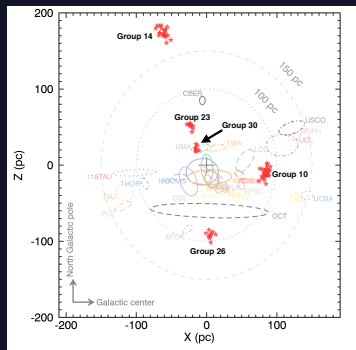
the background: a project to get accurate photometry for timing spectroscopic follow-up

Milky Way dynamics: get 3D velocities

Dark Matter



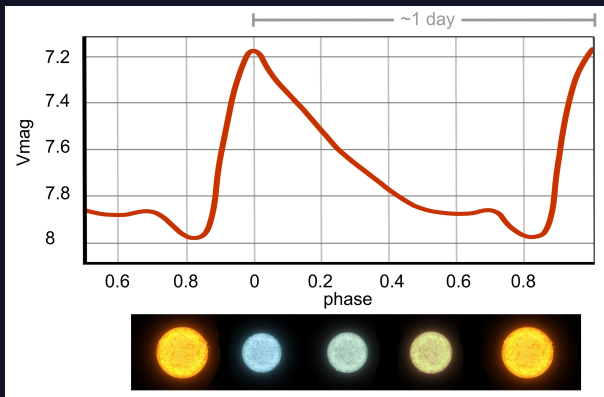
comoving groups and clusters in the Milky Way



Faherty+2018

Scientific Goals: Variable Star Follow-Up

crucial for RR Lyrae (and pulsators in general): **timing**

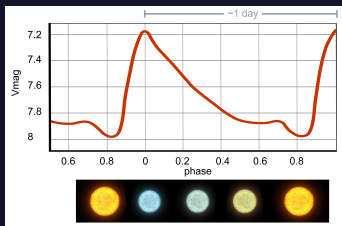


Cause of pulsation: lack of hydrostatic equilibrium beneath surface (outward pressure and inward gravity compression are out of sync)

This causes a **change in brightness**: As the star shrinks, its surface heats up, like a piston compressing air into a small volume. Then, as its surface expands, it cools.

Scientific Goals: Variable Star Follow-Up

crucial for RR Lyrae (and pulsators in general): **timing**



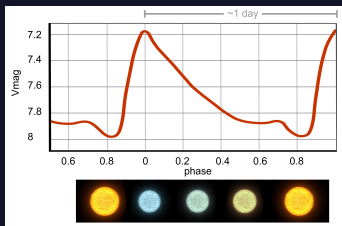
$$v_{\text{obs}} = v_{\text{systemic}} + v_{\text{photospheric}}$$

from pulsation models:

observe at $\phi = 0.37$ where $v_{\text{photospheric}} \sim 0$

Scientific Goals: Variable Star Follow-Up

crucial for RR Lyrae (and pulsators in general): **timing**



$$V_{\text{obs}} = V_{\text{systemic}} + V_{\text{photospheric}}$$

from pulsation models:

observe at $\phi = 0.37$ where $V_{\text{photospheric}} \sim 0$

observing program: collaboration of Caltech & the Observatories of the Carnegie Institution for Science, from spring 2017 on

overall goal: dynamically characterize substructure in the outer Galactic halo using Keck ESI & Magellan MIKE spectra with timing from PS1 3π and ZTF

The Idea

The Idea:

Rubin Observatory's LSST survey (deep, wide, fast & long) is ideal to do

detailed analysis based on high light-curve cadence

statistics over large samples based on survey footprint & duration



An alert broker to **enable users to get updates on variable star observations within interesting regions.**

The Idea

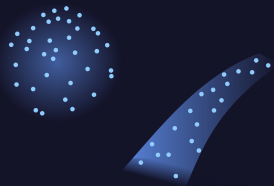
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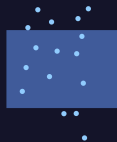
predefined

known stellar streams, dwarf galaxies and globular clusters

(frequently updated)

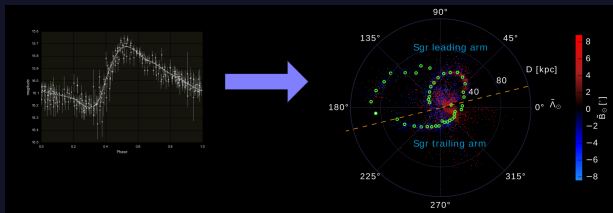


user-created



The Idea

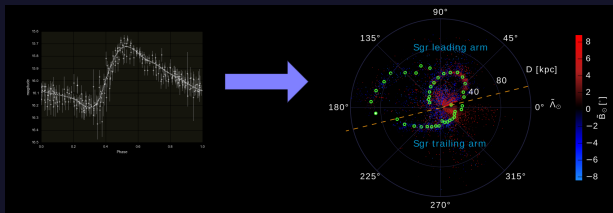
add value to two of the four science pillars as specified for LSST:
Exploring the Transient Optical Sky and *Mapping the Milky Way*



large and deep sets of such variable stars
⇒ understanding the nature of the stellar halo of our Milky Way
⇒ constraining its history

The Idea

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Exploring the Transient Optical Sky and *Mapping the Milky Way*

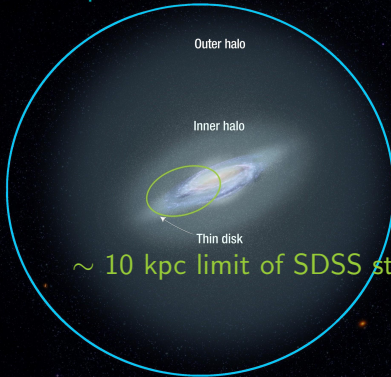


large and deep sets of such variable stars
⇒ understanding the nature of the stellar halo of our Milky Way
⇒ constraining its history

PS1 3π is pushed to its limits - LSST will be at least 2 mag deeper

~400 kpc LSST

~120 kpc PS1 3π



~ 10 kpc limit of SDSS studies for kinematics & [Fe/H]

The Idea



Data Products & Services

a) light curves of RR Lyrae and Cepheids (classification!)
specific regions of interest

b) value-added information: periods, phase offsets

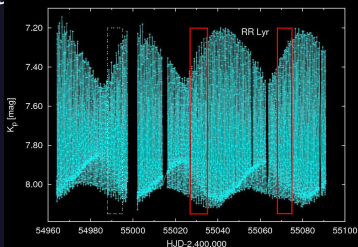
Astronomers working with variable stars are usually interested in **precise light curve information** \Rightarrow fit periods \Rightarrow determine e.g.

- distances
- phases at given time stamps - crucial for spectroscopic follow-up studies as e.g. demonstrated currently by the *Caltech/Carnegie Survey of the Outer Halo of the Milky Way* (Hernitschek et al. 2020b, in prep).

The Idea

Anticipated Output

- light curves of RR Lyrae and Cepheids (classification!) in specific regions of interest
- value-added information: periods, phase offsets
- specific value-added information: e.g. some RR Lyrae show a modulation of the pulsation phase or amplitude (Blazhko effect)



Blazhko effect, Kepler light curve

The Idea

Anticipated Output

- a) light curves of RR Lyrae and Cepheids (classification!) in specific regions of interest
- b) value-added information: periods, phase offsets
- c) specific value-added information: e.g. some RR Lyrae show a modulation of the pulsation phase or amplitude (Blazhko effect)

LSST's high cadence will provide better features:

⇒ amplitude, period, phase offset, possible modulations

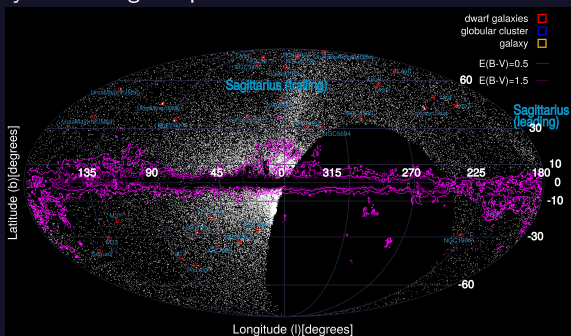
The Idea

Cross-Matches

To provide information on variable stars within defined regions, the alert broker should perform

a) cross-matching with variable catalogs such as the PS1 Sample RR Lyrae catalog (Sesar & Hernitschek 2017)

⇒ as early as LSST gets operational



The Idea

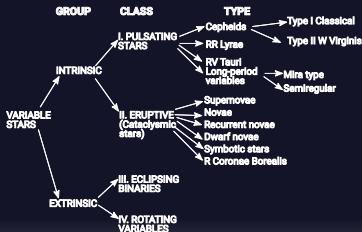
Cross-Matches

To provide information on variable stars within defined regions, the alert broker should perform

a) cross-matching with variable catalogs such as the PS1 Sample RR Lyrae catalog (Sesar & Hernitschek 2017)
 ⇒ as early as LSST gets operational

b) classifying variable light curves
 ⇒ as soon as the light-curve quality is sufficient

also: re-classify stars found by e.g. PS1 ⇒ **catalog-cleaning**



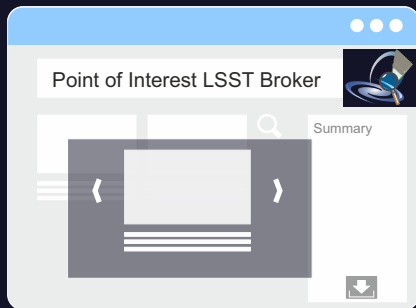
The Idea

User Access

data products should be easily accessible:

website showing individual information for each star
within a region of interest

retrieving data: simple GUI & SQL-like data-query language for
advanced tasks



The Idea

User Access

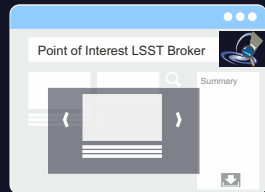
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advanced tasks

table download

- light curves (filtered: number of epochs, specific coordinates...)
- overview tables: observed within a region
- light curve features



The Implementation

Broker Back-End

Functionality:

- ingest & store stream
- light-curve generation (beyond the 30-day light-curve from alert)
- annotate stream: feature calculation
- cross-match: Query the CDSXmatch service: Simbad, ALLWISE, 2MASS, Pan-STARRS...

Implementation:

- Python with weave
- `sqlite3` database



currently processing ZTF alert stream & archive

The Implementation

Broker Front-End

Functionality:

- user interface (web service)
- selecting/filtering alerts
- displaying science images, features, cross-matches
- allowing for download of data

Implementation:

- Python with flask, sqlalchemy

The Implementation

Point Of Interest Alert Broker — Mozilla Firefox

POI POI Point Of Interest Alert Broker Help Contact

See the [help](#) page for descriptions of the table values and available filters.

⏪ First
⏪ Prev
Next ⏩
Last ⏩

date	candid	objectId	jd	filter	ra	dec	magpsf	magap
20210411	1561155860515015014	ZTF21aaudrgj	2459315.6558681	r	135.91692	-5.42688	19.46	19.61
20210411	1561155864015010001	ZTF20aaospam	2459315.6558681	r	135.27020	-0.87847	20.24	20.20
20210411	1561154904315015000	ZTF21aaudrgn	2459315.6549074	r	133.36569	-23.35511	18.23	18.58
20210411	1561155860515015010	ZTF20aafsiob	2459315.6558681	r	135.87372	-5.50182	20.01	20.36
20210411	1561154902315015015	ZTF21aaudrgb	2459315.6549074	r	135.74282	-25.36849	19.13	19.79
20210411	1561155396215015003	ZTF21aaudrkw	2459315.6553935	r	129.01505	-7.63712	19.07	19.53
20210411	1561155861115010015	ZTF18acrxtst	2459315.6558681	r	135.39565	-5.85110	17.27	17.62
20210411	1561154906115010002	ZTF19aapwykm	2459315.6549074	r	130.11814	-20.69240	18.41	19.02
20210411	1561154903115010015	ZTF21aaudrsf	2459315.6549074	r	131.75772	-25.81207	19.61	19.90
20210411	1561155860915015004	ZTF21aaudrna	2459315.6558681	r	134.49126	-4.97011	19.49	20.05

Filter Clear

Rows: 369424

The Implementation

Point Of Interest Broker — Mozilla Firefox

127.0.0.1:5000/?&page=7

80% ☆ Search

20210411	1561155860515015014	ZTF21aaudrgj	2459215.8550601	F	135.91692	-5.42600	19.46	19.01
20210411	1561155864015010001	ZTF20aaad						19.20
20210411	1561154904315015000	ZTF21aaud						19.58
20210411	1561155860515015010	ZTF20aaaf						19.36
20210411	1561154902315015015	ZTF21aaud						19.79
20210411	1561155396215015003	ZTF21aaud						19.53
20210411	1561155861115019015	ZTF18acrj						19.02
20210411	1561154906115010002	ZTF19aaap						19.90
20210411	1561154903115019015	ZTF21aaud						19.05
20210411	1561155860915015004	ZTF21aaud						19.65
20210411	1561154906015015012	ZTF21aaud						19.78
20210411	1561155865115015001	ZTF21aaud						19.76
20210411	1561154904315019000	ZTF20aaud						19.38
20210411	1561155393715015000	ZTF18acrj						19.68
20210411	1561154903015015002	ZTF21aaud						19.25
20210411	1561154906015015017	ZTF20aaad						19.92
20210411	1561154904315015006	ZTF21aaud						19.13
20210411	1561155860515019027	ZTF18acrj						19.61
20210411	1561155864415015001	ZTF21aaud						19.05
20210411	1561154904315019016	ZTF21aaud						19.62
20210411	1561154904315019006	ZTF21aaud						19.20
20210411	1561155864715015009	ZTF18acrj						19.20
20210411	1561154900615019000	ZTF20aaaf						19.05
20210411	1561154903115015006	ZTF21aaud						19.62
20210411	1561155860015015012	ZTF21aaud						19.06
20210411	1561154902015010007	ZTF21aaud						19.04

ZTF20aaafsiob

Lightcure Overview **Features** Classification

Candid: 1561155860515015010 Date: 20210411

dc Magnitude

time (MJD)

Science Template Difference

PIXEL

The Implementation

The screenshot shows a web browser window titled "Point Of Interest Broker — Mozilla Firefox". The address bar displays "127.0.0.1:5000/?&page=7". The main content area contains a table with columns for time, object ID, and other identifiers. A modal window titled "ZTF20aafsiob" is open, showing details for a specific object. The modal has three tabs: "Lightcurve Overview", "Features", and "Classification". The "Features" tab is active, displaying the following information:

```

Features:
date: 20210411
candid: 1561155860515015000
objectId: ZTF20aafsiob
A_s_f_g: null
gamma_sf_g: null
A_s_f_r: null
gamma_sf_r: null
sigmaDRW_g: null
tauDRW_g: null
sigmaDRW_r: null
tauDRW_r: null
gr: null
ri: null
A_r: 0.06765836927311142
A_g: 0.10117076659216906
P: null
H1: null
R21: null
R31: null
phiI21: null
phiI31: null
gamma1: null
gamma2: null
K: null
  
```

The background table shows a list of objects with columns for time (e.g., 20210411), object ID (e.g., 1561155860515015014), and other identifiers (e.g., ZTF21aaudrg).

The Implementation

Point Of Interest Broker — Mozilla Firefox

127.0.0.1:5000/?&page=7

ZTF20aafsiob

Lightcurve Overview Features Classification

Classification:

date: 20210411
candid: 1561155860515015000
objectId: ZTF20aafsiob
Simbad_name: Unknown
Simbad_objecttype: null
PS1_RRL_P: null
PS1_RRL_hello_dist: null
AllWISE_name: J090329.68-053006.2
AllWISE_W1mag: 13.416
AllWISE_W2mag: 12.538
AllWISE_W3mag: 10.036
AllWISE_W4mag: 7.702
twoMASS_name: 09032969-0530060
twoMASS_angDist: 0.480376
twoMASS_lmag: 16.053
twoMASS_hmag: 15.343
twoMASS_kmag: 14.643
twoMASS_Qf: ABB
twoMASS_Rf: 222
twoMASS_Af: 0
ASASSN_name: Unknown
ASASSN_OtherNames: null
ASASSN_amplitude: null
ASASSN_period: null
ASASSN_filters: null

Future Implementation

Point of Interest is now a downstream broker of ANTARES



<https://antares.noirlab.edu/>

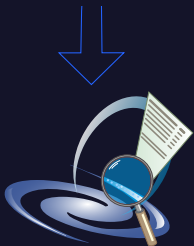


Future Implementation

Point of Interest is now a downstream broker of ANTARES



<https://antares.noirlab.edu/>



- alerts
- light-curves
- annotated: cross-match, features
- classification

- more specific classification: amplitude-period-phase modulation (Blazhko effect)
- watch for modulation
- specific "Points of Interest": from publications, user-created
- specific calculations for follow-up: phase/time from model