

LSST Solar System Processing Review and Updates

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for the LSST Solar System Processing Team



LSST SSSC SCIENCE SPRINT

Seattle, WA, July 10th, 2018



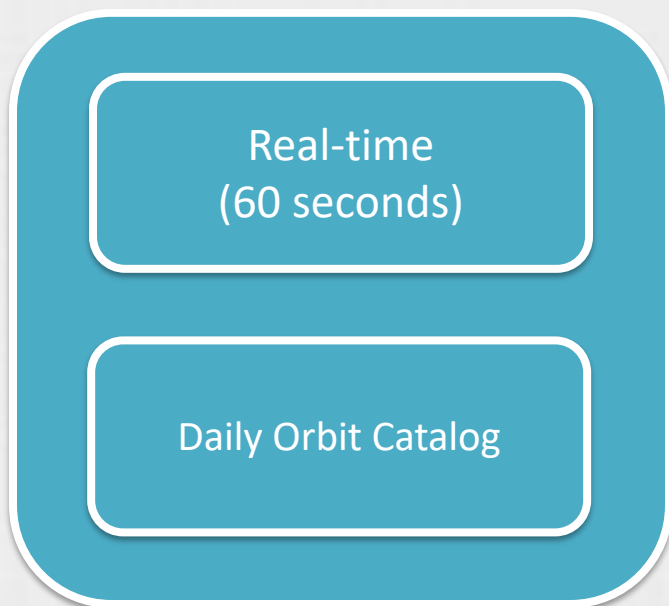
Overview



- Data products overview
- Changes being considered to prompt processing flow
- Team updates
- Science use cases

LSST will provide three types of products to enable Solar System science:

Prompt Products



Data Release Products



Data Products Definition Document: <http://ls.st/LDM-163>

1. Prompt Products: Real-Time



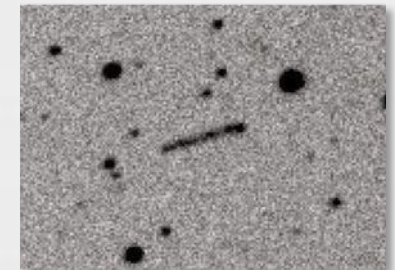
- DIASources are associated with known moving objects in real-time (in time to send the alerts)...

ssObjectId	uint64	ID of the SSObject this source has been linked to, if any.
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- ... and trailed sources are identified as such.

trailFlux	float	nmgy	Calibrated flux for a trailed source model ^{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.
trailLength	float	arcsec	Maximum likelihood fit of trail length ^{43,44} .
trailAngle	float	degrees	Maximum likelihood fit of the angle between the meridian through the centroid and the trail direction (bearing, direction of motion).
trailCov	float[15]	various	Covariance matrix of trailed source model parameters.
trailLnL	float		Natural <i>log</i> likelihood of the observed data given the trailed source model.
trailChi2	float		χ^2 statistic of the model fit.

Enable rapid identification and follow-up of fast moving asteroids (NEOs)



2014 MF6 (PHA), 60sec exposure, MPC Q62 (Guido, Howes & Nicolini)

DIASource Table
<http://ls.st/lse-163>

2. Prompt Products: Daily Orbit Catalog



- These are aimed to provide a catalog of objects to enable their identification in subsequent LSST imaging (and further follow up).
- **Product:** Catalog of orbits and physical properties of objects discovered by LSST (DPDD, Table 3)
 - Orbits
 - Physical properties (H, G)
- Some desiderata:
 - This catalog should be as complete as possible
 - The software should evolve as rapidly as needed to keep it complete
 - This should be cross-matched to external catalogs

Table 3: `SSObject` Table

Name	Type	Unit	Description
ssObjectId	uint64		Unique identifier.
oe	double[7]	various	Osculating orbital elements at epoch ($q, e, i, \Omega, \omega, M_0$, epoch).
oeCov	double[28]	various	Covariance matrix for oe.
arc	float	days	Arc of observation.
orbFitLnL	float		Natural log of the likelihood of the orbital elements fit.
orbFitChi2	float		χ^2 statistic of the orbital elements fit.
orbFitNdata	int		The number of data points (observations) used to fit the orbital elements.

Continued on next page

Name	Type	Unit	Description
MOID	float[2]	AU	Minimum orbit intersection distances ⁵³
moidLon	double[2]	degrees	MOID longitudes.
H	float[6]	mag	Mean absolute magnitude, per band [14, 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.

3. Data Release Catalog



- The goal is to provide a catalog of moving objects that enables estimates of completeness and population studies.
- The contents is the same as for catalogs generated in daily processing, but:
 1. This catalog is generated with a single version of MOPS
 2. This catalog takes advantage of improved astrometry and photometry available in data release processing.
 3. (This catalog includes LSST-only information)



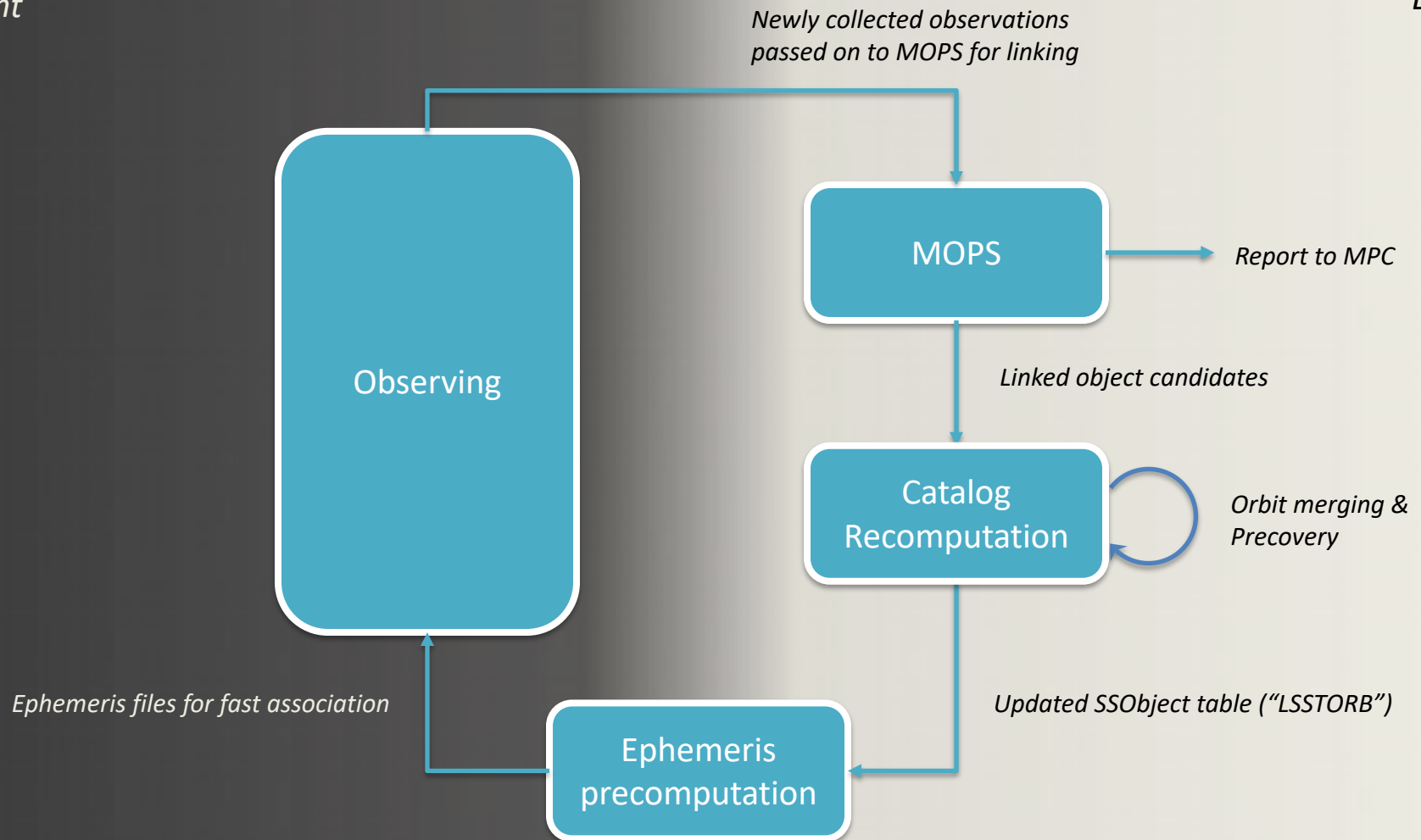
Changes to Prompt Processing Flow

Prompt Solar System Processing Flow (Current)



Night

Day



For DR: Reprocess



- Associating the observed sources with objects from the MPC catalog followed a relatively complex scheme.
 - Consequence: each object would have an LSST ID and/or a MPC designation, causing bookkeeping headaches.
- We don't have firm plans to cross-reference the LSST catalog to the MPC catalog.
 - Consequence: Everyone in the community would have to write code to establish that “LSST123456” is really (2309) Spock (and such codes are somewhat non-trivial)
- Tracklets that are never linked are not reported to the MPC.
 - Objects where LSST's tracklet could be linked to a tracklet from another survey are lost.

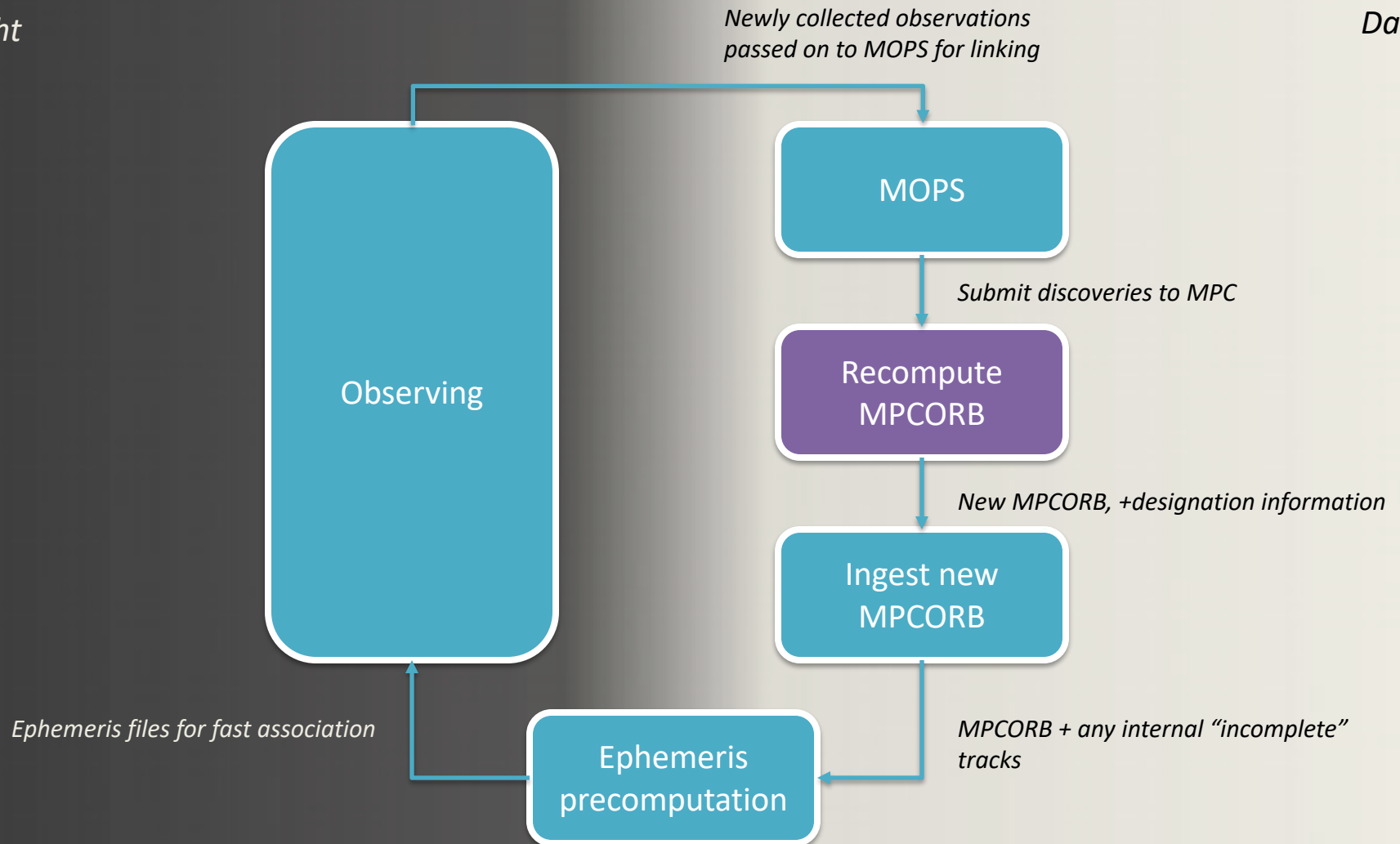
Caused us to look over the past ~year whether we can do better

Prompt Solar System Processing: Changes



Night

Day



Daily Solar System Products Changes



Old

SSObject Table
("LSSTORB")

DIASource Table
+ computed quantities
("LSSTOBS")

New

MPCORB Catalog

LSSTPHYS
(absolute magnitudes, addt'l
useful quantities)

DIASource Table
+ computed quantities
("LSSTOBS")

This Brings Significant Improvements



- The orbit catalog used for association is now maximally complete at all times.
- Solves the cross-match problem: cross-matching two orbit catalogs is not entirely trivial (there will always be corner cases). Now there is only one catalog.
 - Reduces community confusion: no “LSST catalog” vs “MPC catalog”
- No need to do anything special to take advantage of LSST data if all one cares about are orbits – it’s all in MPCORB. Makes the LSST data more accessible/useful.
- Places the LSST into a more general (and partially existing) framework of how surveys work with the MPC
- Opens the possibility to submit *all* tracklets to the MPC, including trails
- Enables cross-survey linking at MPC: LSST’s first tracklet may complete a track that some other survey has started nights before; detectable with MPC’s existing tools. Shortens time to discovery of new objects.

We also evolve together with the MPC...



- ... and drive some of that evolution.
- New orbit format that includes covariances
 - This is necessary to compute reasonable error ellipses for association
- Updates to ADES data exchange format
 - Support probabilistic tracklet associations
 - Updates to the catalog format
- Improvements to MPC services
 - Improved (downloadable) MPCChecker, with standardized pre-computed position formats

Bottom line: we benefit from the work of the MPC and the broader community, and vice-versa.



The Team

Going Forward: The LSST DM Solar System Team



~40% FTE



100% FTE



25% FTE



The LSST Solar System Products & Software Team

Joachim Moeyens (UW; Graduate Student)

Siegfried Eggl (UW; incoming, Research Associate)

Mario Juric (UW; Solar System Product Owner)

Lynne Jones (UW; LSST Performance Scientist)

Eric Bellm (UW; Prompt Processing Lead)

+ many, many, others from the overall LSST DM effort!



- Document the details of MPC plans, discuss with the collaboration, and propose formal baseline changes.
 - Plan and milestones update
- Develop a research note working through a few specific use cases (down to actual SQL queries)
- Continue developing MOPS
- Deploy and test on ZTF
 - Real-time (alert) component (streaks)
 - Running MOPS on ZTF public survey (the cadence is designed to mimic LSST's).



Getting your feet wet: the Zwicky Transient Facility

<http://ztf.caltech.edu>

Three months into ops, ZTF had **submitted ~600,000 measurements** to the MPC (~320 new objects).

The new discoveries include **seven NEOs**, one of which (2018 CL) is a PHA.

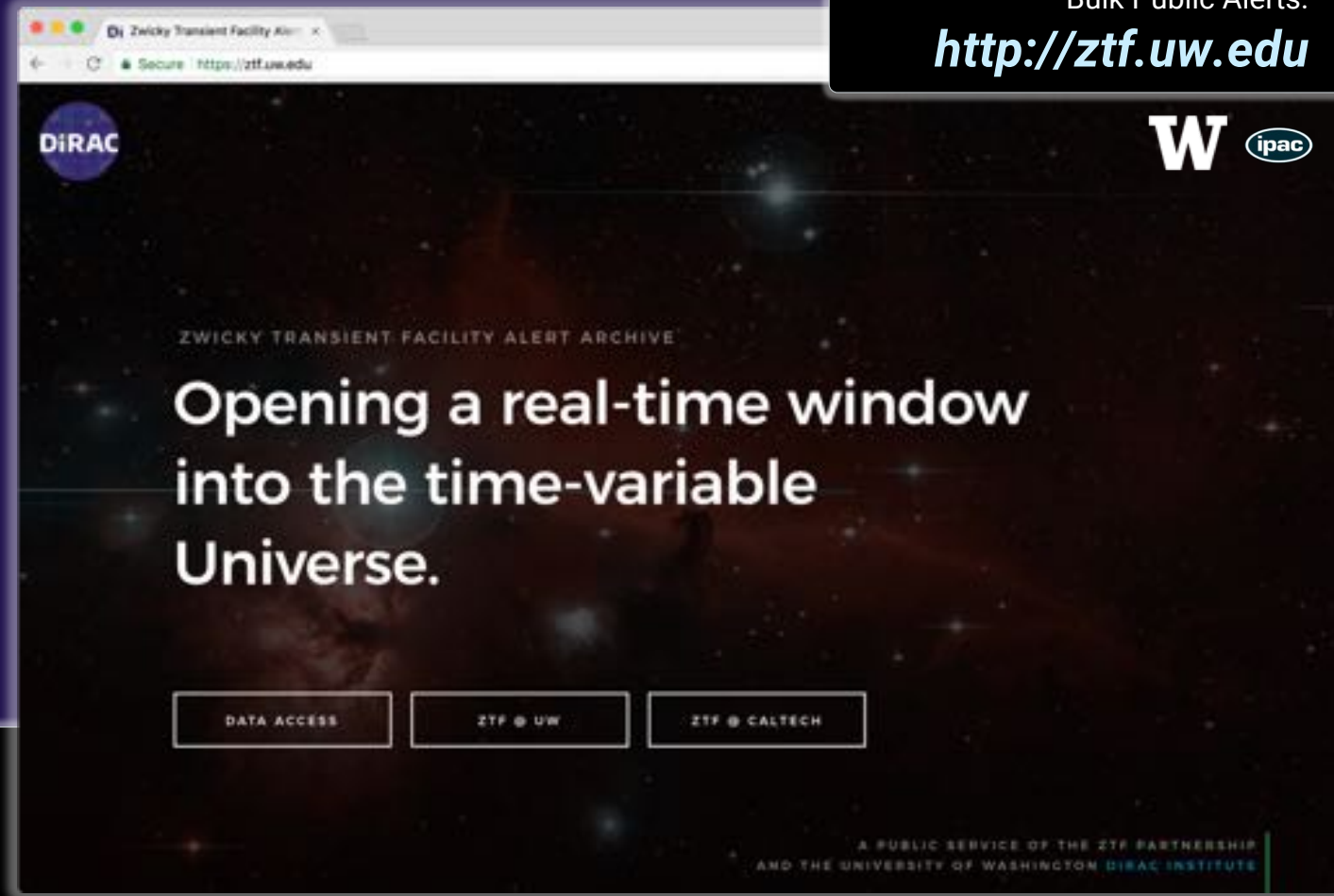
Five of these seven new NEOs were detected by the **ZTF streak-detection pipeline** (Waszczak et al. 2017).

ZTF alerts from the public survey (~40%) are now available in bulk!

Streaming coming later this summer (via ANTARES and others).

Bulk Public Alerts:

<http://ztf.uw.edu>



Caltech





Working Through Some Science Use Cases



- *“LSST just discovered a new moving object with heliocentric distance $r > 50$ AU”*
 - SQL query the daily orbit database for newly discovered objects with detections at $r > 50$ AU
- *“LSST observed object X in a new filter and its $g-r$ color is $> Z$ ”*
 - Real-time: compute the $\langle g \rangle - \langle r \rangle$ colors from previous observations present in the alert (12 months of data), compare to desired threshold
 - Batch: compute $\langle g \rangle - \langle r \rangle$ colors with a SQL query, compare to threshold
 - Note: estimated absolute magnitudes will be included in the alert; these may be better estimators of color



- *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.*
 - Note: We're not presently planning to estimate periods of solar system objects. This is likely an omission, however, since periods will be estimated for static sources and the math is the same.
 - If we estimate periods:
 - This is a SQL query against the daily catalog
 - If we don't:
 - The collaboration could maintain a database of periods that could be queried



- *LSST re-observed an object for the first time in this season*
 - SQL query against the daily catalog
- *LSST observed an object that is more than 0.2'' from its predicted position*
 - Real-time: Filter on measured position being off by more than 0.2'' from predicted position
 - Batch: SQL query for all objects with detections that are more than 0.2'' from their predicted positions



- Starting in September, the Solar System team will be fully staffed.
- Looking to change the processing/reporting flow to be more similar to present-day asteroid search surveys.
 - Goal for this sprint: discuss orbit catalog changes, subm. format changes
- Will define the initial, concrete, schema in the next ~6 months.
 - Goal for this sprint: push that forward significantly.
- Working on MOPS.



Questions !