The Large Synoptic Survey Telescope: 
Data Management Pipelines and Products

Webinar for the Inter-institutional Laboratory for e-Astronomy in Brazil (LIneA)
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The Large Synoptic Survey Telescope

LSST Data Management: Pipelines and Products Overview

LSST Special Programs

LSST Data Management: Resources and Participation

An Overview

Data Management System Science
DM Data Products & Pipelines
LSST Science Platform

Open Opportunities
Observational Boundaries
Call For Proposals

LSST DM Communications
LSST Community Forum
LSST Science Collaborations
Future LSST-Related Meetings
The Large Synoptic Survey Telescope

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LSST Overview: Science Drivers

“From Science Drivers to Reference Design”
Ivezic et al. (2008), arXiv:0805.2366

- Cosmology:
  - weak lensing
  - baryon acoustic oscillations
  - type Ia SN dark energy

- Milky Way:
  - spatial maps of stellar characteristics
  - reach well into the halo

- Transient & Variable Phenomena
  - fill in variability phase-space
  - physical mechanisms

- Solar System Small Objects
  - object inventory, dynamics
  - potentially hazardous asteroids
  - (U.S. Congressional mandate for NASA to find 90% of near earth objects with diameter >140m)

See also: https://www.lsst.org/scientists/scibook
These science goals drive the LSST design: they can all be met with a deep, wide-area, multi-band survey of the full southern sky with an 8m-equivalent telescope doing 30 second exposures all night every night for 10 years.

These science goals also drive the design of the pipelines and products: prompt difference imaging and alerts, yearly releases of deep co-adds and catalogs, fully calibrated data products available through a dedicated user interface.
LSST Overview: Survey Design

**Hardware**

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<table>
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<tbody>
<tr>
<td>primary mirror</td>
<td>8.4 m</td>
</tr>
<tr>
<td>field of view</td>
<td>9.6 deg²</td>
</tr>
<tr>
<td>pixel size</td>
<td>10 µm, 0.2”</td>
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<tr>
<td>number of pixels</td>
<td>~3.2 Gpix</td>
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<td>filters</td>
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**Main Survey (Wide-Fast-Deep)**

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<tr>
<td>single-visit exposure</td>
<td>30s (2x15s)</td>
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<tr>
<td>single-visit depth</td>
<td>23.9, 25.0, 24.7, 24.0, 23.3, 22.1</td>
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<tr>
<td>single-visit saturated</td>
<td>14.7, 15.7, 15.8, 15.8, 15.3, 13.9</td>
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<tr>
<td>survey visits/field</td>
<td>56, 80, 184, 184, 160, 160 (824)</td>
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<tr>
<td>survey full depth</td>
<td>26.1, 27.4, 27.5, 26.8, 26.1, 24.9</td>
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<tr>
<td>survey full area</td>
<td>18000°²</td>
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<tr>
<td>first light</td>
<td>2020</td>
</tr>
<tr>
<td>survey start</td>
<td>2022</td>
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e.g., Ivezic et al. (2008), arXiv:0805.2366
LSST Overview: Survey Design

Wed Apr 18

dome completion planned for mid-2018

https://www.lsst.org/news/see-whats-happening-cerro-pachon
Commissioning Camera
- single-raft “ComCam”
- expect on summit late-2019

Science Camera
- two companies are supplying CCDs
- the first CCDs are delivered, in testing
- camera integration and testing starts 2018
- expect on summit early-2021
The issue: Universal Cadence leads to a visit every ~3 days in *any* filter, every ~15 days in a single filter, and some science goals require more frequent sampling.

Figure 2.9: The median inter-night gap for r band visits is shown in Aitoff projection for all proposals and all filters for candidate Baseline Cadence minion_1016. On average, fields in the main survey get revisited in the r band about every two weeks.
A *living* document for the community to communicate to the LSST Project the impact of observing strategy on science, now and through Operations.
LSST Overview: Survey Design

Nightly alerts on ~10 million time-domain events, and final catalogs of ~32 trillion observations of ~40 billion objects over 10 years.

more sources, higher redshift

improved resolution, better deblending

more low surface brightness features

“From Science Drivers to Reference Design”: Ivezic et al. (2008), arXiv:0805.2366
**LSST Data Management**

**Data Release Data Products**
via Annual Data Releases

- 11 data releases in 10 years
- Final database catalog: 15 PB

**Prompt Data Products**
via Alert Streams

- Average $\sim 10^6$ per night
- Real-time latency: 60 sec

**LSST Science Platform**

- Data access via Data Access Centers & Services

- Portal, Notebooks, Web APIs
- LSST Users, Internet

**Alerts database and mini-broker.**

*slide by Leanne Guy*
Mandate: the scientific validation of the planned DM deliverables to ensure that the DM pipelines and products are designed to meet the overall LSST scientific goals.

1. Work with the science community to understand their needs and how they will be met by DM.
2. Identify scientific opportunities and risks related to the DM subsystem and initiate change.
3. Evaluate the scientific impact of proposed changes to DM deliverables driven by e.g., schedule.

Cheat Sheet

**Validation:** do the specifications capture the customer’s needs.

**Verification:** does the product meet the specifications.
Everything regarding DM data products is from these documents.

See also Ivezic et al. (2008), arXiv:0805.2366
Real-time difference image analysis (DIA). A stream of ~$10^6$ time-domain events per night (Alerts), detected, characterized, and distributed within 60 seconds. A catalog of orbits for ~6 million bodies in the Solar System.

Processed single-epoch and deep co-added images, and reprocessed DIA products. A database of ~$7 \times 10^{12}$ detections (~$30 \times 10^{12}$ measurements) for ~$37 \times 10^9$ objects (~$20 \times 10^9$ galaxies and $17 \times 10^9$ stars), produced annually and accessible online.

User-produced added-value data products, e.g., deep KBO/NEO catalogs, variable star classifications, shear maps, etc. Enabled by services and computing resources at the Data Access Centers and via the LSST Science Platform.
World Public data can be shared with anyone, with or without data rights.

**Alerts**: The full stream will be delivered to a limited set of community brokers who can share the Alerts with anyone.

**Data Releases after 2 years**: Could be accessed through collaboration with data rights holders, or by paying the “cost of shipping and handling”.

**Education and Public Outreach**: Limited data subsets for citizen science.

Proprietary data cannot be shared, and requires data rights.

**Alerts Database**: An archive of all issued Alerts.

**Prompt Images and Catalogs**: Difference images and source catalogs that are created and made available in real time (60s to 24h latency).

**Annual Data Releases**: Image stacks and source catalogs.

**LSST Science Platform**: Data portal, analysis toolkit, help-desk service, computational resources for user processing, an Alerts filtering service.
Definitions of Terms

Standard Visit — an LSST observation (i.e., 2x15 second images)
Processed Single Visit Image — reduced, combined standard visit
Template Image — a transient-free co-add of 6-12 months depth
Coadded Image — a stack of images (i.e., median-combined)

DIA — Difference Image Analysis
DIASource — single detection on a single DIA image
DIAObjects — association of DIASources, by coordinate
Alert — packet of information about a $|\text{SNR}| > 5$ DIASource

DRP — Data Release Pipeline
Source — single detection in any image (single visit or coadd)
Object — association of Sources, by coordinate

ForcedSource — aperture photometry in a single visit image at the location of an Object or DIAObject, regardless of its SNR
What happens within ~60 seconds of shutter close?
- single visit image is processed and differenced with template
- source detections with $|S/N| > 5$ become a DIASource
- DIASource characterization (PSF, flux, shape, etc.)
- DIASource association with existing DIAObject or SSObject or the creation of a new DIAObject
- DIAObjects detected in past ~12 months get forced photometry
- DIAObject characterization parameters updated (e.g., variability)
- an Alert is issued to the Stream (one per DIASource)
- DIA catalogs are updated in the US Data Access Center

Which tasks are completed within ~24 hours?
- forced photometry in past 30 days of images for all new DIAObjects
- processed images become available in the US Data Access Center
- Moving Object Pipeline Software (MOPS) runs on DIASource catalog
DIA Catalog Contents (non-exhaustive)

What kinds of measurements are provided?

DIASource
- coordinates, and association with DIAObject or SSObject
- time of mid-exposure at location on CCD
- flux in the difference and visit images (PSF, aperture)
- shape parameters (trails, dipoles, FWHM, extendedness)
- parent/child deblending flags

DIAObject
- time-averaged coordinates; parallax & proper motion
- fluxes by filter, time-averaged and single-visit
- periodic and non-periodic variability features
- association with Data Release object catalog (CoAdds)

See also the Database Schema Browser:
https://lsst-web.ncsa.illinois.edu/schema/index.php?sVer=baseline

LSST Data Products Definitions Document (DPDD): ls.st/dpdd
DIA Alert Contents (non-exhaustive)

**What is an Alert packet?**
- formatted text file containing schema and data
- full record of the triggering DIA\textit{Source}
- entire associated DIA\textit{Object} or SS\textit{Object} records
- last 12 months of DIA\textit{Source} records
- matching Object IDs from latest Data Release Object
- image stamps
  - \textit{at least 6”x6”}; difference and template; flux, variance, and mask; includes meta-data such as WCS, zero-point, PSF
- 1 per DIA\textit{Source}; VO\textit{Event} packet format (or similar)

**What is an Alert Broker?**
The primary end-points of LSST’s event streams, and how users will classify and filter events into subsets for their science goals. LSST will provide a basic, limited capacity alert filtering service for astronomers via the Science Platform, the “mini-broker”.
Moving Objects Processing Software (MOPS)

**MOPS**
- runs in the day with the DIASource catalog
- source association to link detections, find moving objects
- uses orbital fits to reject mislinkages
- interfaces with the Minor Planets Center for orbit refinement

**SSObject Catalog Contents**
- orbital parameters and uncertainties
- mean absolute magnitude per filter
- $G_1$ and $G_2$ slope parameters

See also “LSST Solar System Science: MOPS Status, the Science, and Your Questions”, by Mario Juric. [https://www.slideshare.net/MarioJuric/lsst-solar-system-science-mops-status-the-science-and-your-questions](https://www.slideshare.net/MarioJuric/lsst-solar-system-science-mops-status-the-science-and-your-questions)
There are actually two versions of the products of difference imaging analysis:

**Prompt (“living” data products)**
- updated in real time with every readout
- contains last ~12 months of data
- variability parameters based on past 12 months
- associations with the “Yearly” DIA catalog products

**Data Release**
- full LSST data set reprocessed with latest codes
- variability parameters based on full survey to date
- forced photometry for all objects in all epochs
- same types of products as the “Living” versions

To meet different science needs:
- e.g., real-time follow-up
- e.g., rates, population studies
Data Release Pipeline (DRP) Images

What kinds of images are produced annually?

- raw data and calibration frames
- processed single-visit images
- stacked images (CoAdds):
  — short-period (e.g., yearly)* and full survey
  — best seeing and deepest (unless equivalent)
  — for each filter $ugrizy$, and a multi-color*
- transient-free template images

*not persisted, but used for measurements in the catalogs; can be recreated by users
What kinds of measurements are provided?

Source (and ForcedSource)
- coordinates, fluxes in single-visit images
- deblending (parent/child identifiers)
- model fits (bulge/disk, exponential, petrosian, kron)
- surface brightness, extendedness parameters
- color (seeing-independent)

Object
- association of Sources (plus ForcedSources)
- similar characterization parameters as Source
- photometric redshift
- periodic and nonperiodic variability characterization
- proper motions and parallaxes
LSST will not write unique algorithms for re-processing main survey data for alternative science goals,

— but —

LSST will make the Software Stack source code available to the community for user-generated pipelines

— and —

LSST will commit ~10% of its computing resources toward enabling user-driven analysis and data product creation in the US DAC.
What is the LSST Science Platform?
A toolkit, a workspace, and a portal to the data.
- no need to download the data products
- tools for browsing, visualization, analysis
- use of pre-installed code libraries
- computational resources for query/processing

View demos at [http://ls.st/bgt](http://ls.st/bgt)

“Bring the analysis to the data.”
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LSST Special Programs

**What is a Special Program?**
Anything not in the “wide-fast-deep” main survey: different areas, survey strategies, non-standard visit images, etc.

**Why do Special Programs exist?**
Special Programs provide additional or improved science results with the ~10% of observable time not taken up by the WFD main survey.

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North Ecliptic Spur (solar system)

South Celestial Pole (LMC, SMC)

Galactic Plane (stars and planets)

DDF examples

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Ivezić et al. (2008), Figure 18.
Nominal DDF Observing Strategy:
Ivezić et al. (2008) describes a nominal DDF data set as, e.g.: \(~50 \times 15s\) exposures in \textit{griz}, every two nights for four months.

- single image limit \(r<24.5\)
- nightly stack limit \(r<26.5\)
- full stack limit \(r<28.0\)

Assuming a conservative 60% completion rate (weather) yields \(~7.5\) hours of DDF data, stacked with the \(~1.5\) hours of WFD data.

Four approved extragalactic deep fields:
- ELAIS-S1
- XMM-LSS
- Extended CDF-S
- COSMOS

https://www.lsst.org/scientists/survey-design/ddf
First four extragalactic deep fields chosen.

First round of white paper proposals for LSST Special Programs.

planning continues through Science Collaborations, Observing Strategy White Paper

October 2018
Deadline for white paper proposals

June 2018
Call for white paper proposals

DMTN-065

Project Science Team defines criteria; Science Advisory Council reviews proposals and makes recommendations.

Latest set of Special Programs incorporated into the Operations Simulator.

planning continues


DMTN-065: “Data Management and Special Programs”, assesses DM’s plans for processing the diversity of raw data that may be generated by the community’s Special Programs proposals.
What is set and what is open to community* proposals?

Set
- the positions of the four pre-existing deep drilling fields

Open
- additional deep drilling fields
- refined observing strategies** for existing deep drilling fields
- optimized survey areas for the NES, South Pole, and Galactic Plane
- refined observing strategies** for the NES, South Pole, and Galactic Plane
- additional mini-surveys areas and observing strategies
- refined observing strategies for the wide-fast-deep main survey

Estimated timeline (TBC):
- call in ~June 2018
- due in ~Oct-Nov 2018

*Not limited to science collaboration members.
**OpSim runs for proposed DDF/MS expected by late 2019.
What is the format and expected content of these white papers?
To be formalized when the call is announced in June — but in addition to science goals and observing strategy, data processing needs should be discussed.

How will these white papers be evaluated and decisions be made?
Proposals would be reviewed by the Science Advisory Council based on criteria set by the Project Science Team, and recommendations would be made to the LSST Director. Individual proposals may be combined in new observing strategy simulations, which would be released to the community for analysis.

How do these white paper proposals fit in with the `living’ Observing Strategy White Paper?
The next round of DDF/MS white papers will be a separate communication channel from the existing OSWP, but could be incorporated later (e.g., in 2019 with the new OpSim runs that include Special Programs).
Data Management and Special Programs

LSST-DM will:

- **not** write unique algorithms for processing SP data
- allocate 10% of its computational resources for processing SP data
- incorporate SP data into the prompt and data release products when scientifically beneficial
- reconfigure pipelines to generate separate imaging and catalog products for SP data, whenever possible
- make the Software Stack source code available to the community
- allocate an additional ~10% of the LSST computing resources for user-driven analysis and data product creation in the US DAC
Option to contact DM and the LSST user community regarding LSST Special Programs through this Community forum.

Deep Drilling Fields and Data Management

On behalf of the LSST Data Management team, we would like to open up this forum to discuss the processing of proposed "Deep Drilling" and/or "Mini-Survey" programs. This conversation between the science community and the LSST DM team was inspired by the breakout session on "Deep Drilling Fields and Other LSST Mini-Surveys" at the LSST Project and Community Workshop in 2016. The relevant DM-DDF issues are outlined in Gregory Dubois-Felsmann's talk from that session (available at https://zenodo.org/record/61402#.V8mcXJN96Rs, or from the breakout session website https://project.lsst.org/meetings/lsst2016/agenda/deep-drilling-fields-and-other-lsst-mini-surveys), including these questions that we encourage the community to keep in mind while designing their DDF and Mini-Survey proposals:

1. What additional processing beyond that currently planned by the DM team (alerting relative to an annually created template) would greatly enhance the DDF science goals?
2. Are there DDF or Mini-Surveys specific aspects of the Level 3 system that would add significant value if provided? "Level 3" is the LSST-provided capability that enables non-DM, user-driven, processing of LSST data at the LSST Archive center (or remotely).
3. Are there aspects of the Science User Interface & Tools (SUIT) that need to be developed in order to enhance the usefulness of DDF data products?
4. To what degree should the DDF or Mini-Survey imaging could/should be incorporated into the main survey's deep stacks and associated data products (as opposed to being processed as separate data products)?

The following resources may also be of use to the community:
The Large Synoptic Survey Telescope

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Surrogate Mirror Installation

November 9, 2017 - At CAID Industries in Tucson, the Surrogate Mirror has now been mounted to the Primary/Tertiary Mirror (M1M3) Cell. This is a significant
Options for participation in LSST.

Participate in LSST

Now that LSST has received its federal construction start, the Project Office is focused on building the facility and the role of engaging the community to Enable Science from LSST during operations has been taken on by the LSST Corporation.

There are many ways for you to participate in LSST now:

- LSST Communications Code of Conduct (PDF)
- Be informed by subscribing to our Project Digest
- Or join the Scientists Mailing List
- The community.lsst.org forum is available for technical discussion and community-based software support
- Read the community white paper on the LSST Observing Strategy in arxiv and contribute to the living document in GitHub.
- Become an Institutional Member of LSSTC
- Become an International Contributor to support Operations
- Join a Science Collaboration
- Interact with the LSST Science Advisory Committee
- Visit the LSST Data Management Website for information on downloading the Open Source Software stack and access data sets; begin by reading the User’s Guide
- Visit the LSST Simulation Website for information on the LSST Image and Operations Simulations efforts.
- Join the Team - LSST is Hiring
- There are also opportunities for Doing Business with LSST
LSST Data Management Communications

Key LSST information for scientists.

LSST Information for Scientists

September 12, 2017 - The LSST observing strategy has a baseline design but is not yet set in stone: a community of the LSST science collaborations is working on evaluating simulations of the LSST cadence optimizing it in a science-driven way. You can read the most up to date version of the living white paper these investigations on GitHub, and join the conversation in that repository’s issues. You can also release of this white paper on the arxiv or here doi.org/10.5281/zenodo.842713.

August 10, 2017 - Since Spring 2017, LSST’s Project Science Team (PST, https://www.lsst.org/about/PST) has a series of discussions with Science Collaboration chairs (https://www.lsstcorporation.org/science-collaborations) on topics have been chosen based on requests from Science Collaborations. The aim of these discussions effectively disseminate up-to-date Project information to the science community, via the Science Collaboration also by sharing the Powerpoint presentations (and, when available, recordings) to the worldwide comm
The LSST Science Pipelines

The LSST Science Pipelines enable optical and near-infrared astronomy in the big data era. We are building the Science Pipelines for the Large Synoptic Survey Telescope (LSST), but our command line task and Python API can be extended for any optical or near-infrared dataset.

The latest release is 14.0: learn what's new.

Installation

Recommended installation path:

- Installing with newinstall.sh
- Setting up installed LSST Science Pipelines
- Top-level packages to install

Alternative distributions and installation methods:

- Running with Docker
- Installing from source with lsstsw
- CernVM FS (contributed by CC-IN2P3)
New Data Management Initiative: “Data Q&A” Forum
For your science questions regarding data products and pipelines.
New Data Management Initiative: “Data Q&A” Forum
For your science questions regarding data products and pipelines.

more information

https://community.lsst.org/
New Data Management Initiative: “Data Q&A” Forum
For your science questions regarding data products and pipelines.

https://community.lsst.org/
There are currently 8 collaborations:

- Dark Energy
- Transients & Variable Stars
- Galaxies
- Stars, Milky Way & Local Volume
- Solar System
- Active Galactic Nuclei
- Strong Lensing
- Informatics & Statistics

SC Coordinator: Federica Bianco

Science Collaboration membership is limited to data rights holders.

Data Management Subsystem Science Team members are assigned as liaisons to each Science Collaboration.

https://www.lsstcorporation.org/science-collaborations
Meetings
- working group monthly videocons
- collaboration meetings, hackathons

Community Forums
- discussions regarding scientific preparation

Observing Strategy White Paper
- science collaborations analyzing survey simulations

Science Roadmaps

Data Challenges (tool development)

Assessment of Follow-up Capabilities

LSSTC Data Science Fellowship Program
- preparing students (hosting opportunities exist)
Project Science Team seminars to the Science Collaborations

Monthly up-to-date live stream talks on a variety of topics by request from the Science Collaborations; slides/recordings at https://www.lsst.org/scientists.

- What to Expect of the LSST Archives: The LSST Science Platform
- LSST Plans for Cadence Optimization
- Status of the LSST Image Simulations
- Data Management’s Plans for Crowded Stellar Fields
- Simulated Observatory Control System (SOCS) and Scheduler Progress
- Education and Public Outreach
- LSST Commissioning Overview

https://www.lsst.org/scientists
Future Meetings

LSST@Europe
June 11-15 2018, Lyon France
[europe2018.lsst.fr](https://europe2018.lsst.fr) — Late registration closes May 11 2018

LSST Project and Community Workshop
August 13-17 2018, Tucson AZ USA
Obrigada a todos!

Please feel free to contact me at mlg3k@uw.edu with any data products/pipelines science questions, or to use the “Data Q&A” Community Forum.
extra slides
Commissioning Plans

Early Science Verification
- starts mid-2020 with **ComCam**
- resumes early-2021 with the **LSST Camera**

Wide-Area Alert Survey
- template generation: ~3 weeks
- alert production: ~3 weeks

10 Year Depth Survey
- In fields overlapping external imaging and spectroscopy. ~6 weeks

Science Verification starts in mid-2021 with two operational readiness mini-surveys:

**Wide-Area Alert Production** to cover e.g., a 1600 deg$^2$ stripe with a range of source densities, produce real-time alerts.

**10-Year Depth Survey**: to cover e.g., a 300 deg$^2$ field with 825 visits, reaching LSST full-depth equivalent.

Final science verification will be followed by an 8 week shut down for the Operations Readiness Review, early-2022.
Additional Mini-Survey Concepts:
- Mini-Moons (temporary earth-orbiting asteroids)
- Meter-Sized Impactors (small earth-crossing asteroids)
- Twilight Survey (short exposures for bright objects)
- Gravitational Wave Counterparts (extragalactic)

See also Chapter 10 of the Observing Strategy White Paper:


Neil Brandt’s LSST AHM 2016 talk:

https://www.lsst.org/scientists/survey-design/ddf

2011 DDF Whitepapers: https://project.lsst.org/content/whitepapers32012
Filter Changes
The maximum time for filter change is 120 seconds (30 seconds for the telescope to reorient the camera to its nominal zero angle position on the rotator, and 90 seconds to the camera subsystem for executing the change; OSS-REQ-0293, ls.st/lse-30).

The minimum time between filter changes has no restrictions from e.g., thermal tolerances. However, based on overheads and efficiency, it is recommended to keep the filter change rate lower than once every 10 minutes.

The maximum total number of filter changes is 100,000 over 15 years, an average of 18 changes per night.

The maximum number of filter swaps in/out of the carousel is 3000 in 15 years, or once every two nights.

Last three points are from Steve Ritz and Zeljko Ivezic, to be incorporated into public-facing documents soon.
Exposure Times

The minimum exposure time is 1 second, with a stretch goal of 0.1 seconds (OSS-REQ-0291, ls.st/lse-30).

1) The minimum exposure time needed to create an image with a PSF that is well-formed enough for difference imaging is a separate question we will consider in later slides.

2) Assuming a 1 second exposure can be reduced and calibrated, its detected point sources will span $13 < r < 21$ magnitudes, whereas a 15 second exposure saturates at $r \sim 15.8$ mag.

The maximum exposure time is not restricted. However, a 2x150 second image would saturate at $r \sim 18.3$, perhaps leaving too few stars overlapping with e.g., templates or WFD images, for astrometric and photometric calibrations; additionally, the impact on CR rejection routines is untested for long exposures.
Transients and Variable Stars Science Collaboration
Chairs: Federica Bianco and Rachel Street

Private wiki for SC members to collaborate.

see also TVS’s public page at https://tvs.science.lsst.org/
LSST Science Collaborations

Transients and Variable Stars Science Collaboration
Recent activity on the Community forum

https://community.lsst.org/tags/c/sci/tvs