Vera C. Rubin Observatory: A Big Data Machine for the 21st Century

Rubin Observatory

Wednesday 25 November 2020

William O'Mullane

Rubin Observatory

Data Management Project Manager

Vera C. Rubin Observatory - LSST

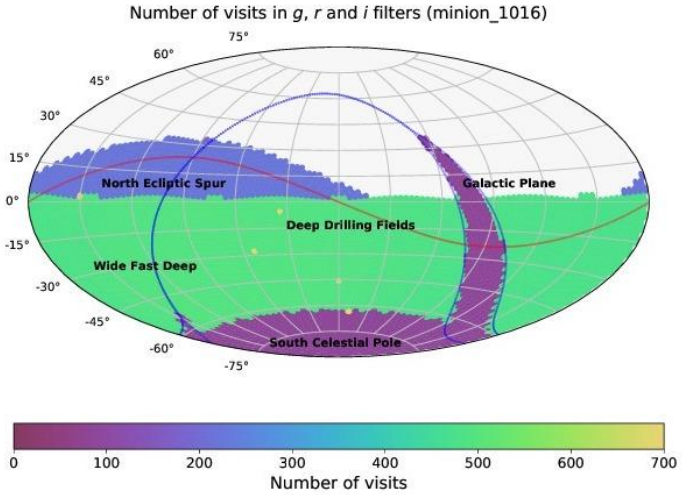
Rubin Observatory

Rubin - Cerro Pachón Chile (ops 2023)

Legacy Survey of Space and Time (LSST)

An optical/near-IR survey of half the sky in ugrizy bands to r 27.5 (36 nJy) based on 825 visits over a 10-year period: deep wide fast.

- 90% of time spent on uniform survey: every 3-4 nights, the whole observable sky scanned twice per night
- 100 PB of data: about a billion 16 Mpix images, enabling measurements for 40 billion objects!



10-year simulation of LSST survey: number of visits in u,g,r band (Aitoff projection of eq. coordinates)

Ivezic et al. (2008)-arXiv:0805.2366

Big FOV 3.5 degrees (9.6 square degrees)

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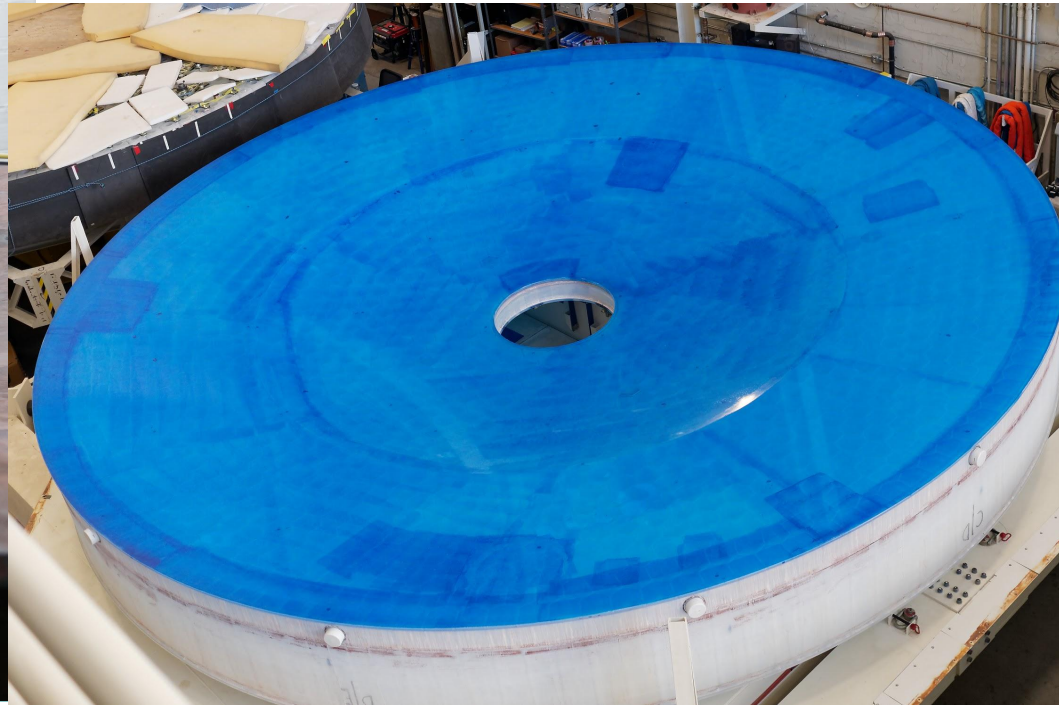
Surrogate for testing

M1+M3 8.4M 16,284 kg Glass



You need a big camera to cover that much sky

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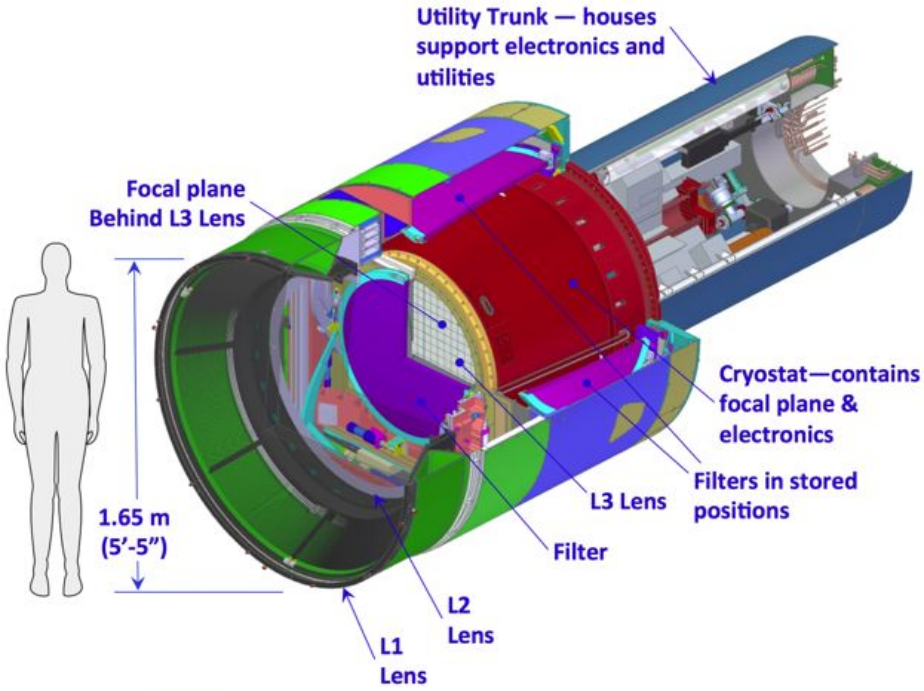
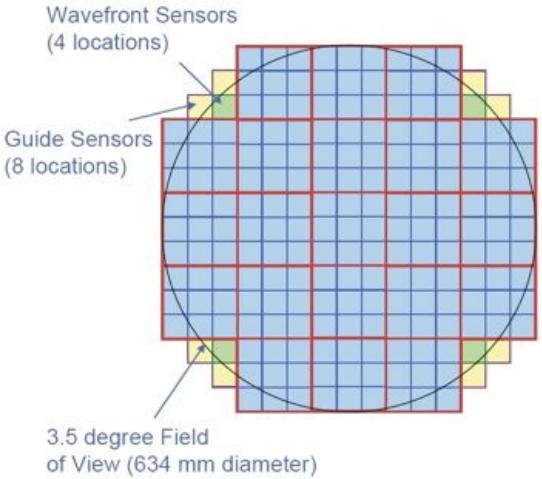


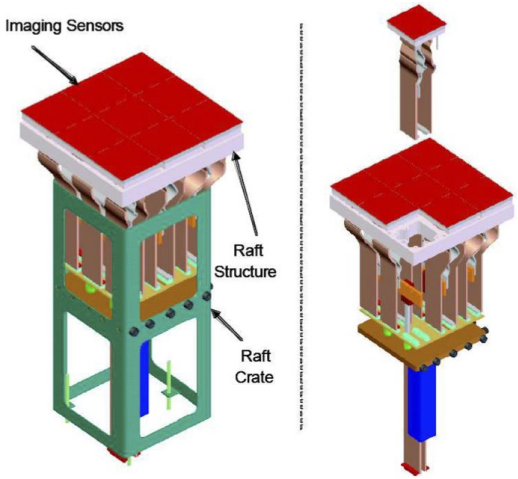
The largest astronomical camera:

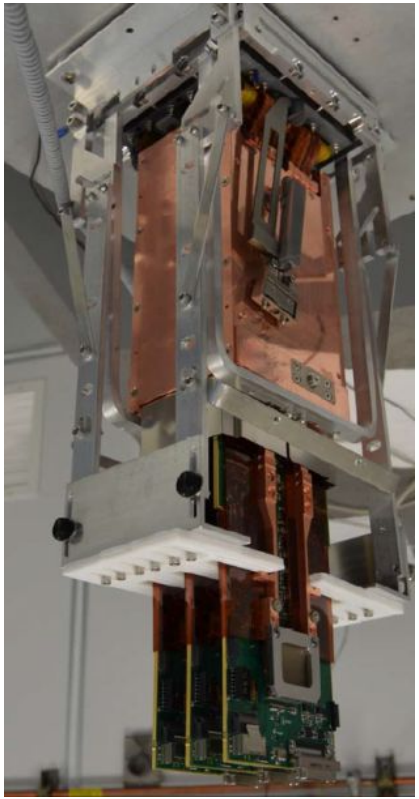
- 3,060 kg
- 3.2 Gpix
- 8.2 GB per exposure

Consider to display every pixel you would need 378 4K monitors

Camera is a DOE contribution built at SLAC







Modular design: 3200 Megapix = 189 x16 Megapix CCD
9 CCDs share electronics: raft (=camera 144 Megapix)

First of 21 rafts (2017) →

All camera parts fabricated and much assembled

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~20TB Every night - a few images every minute

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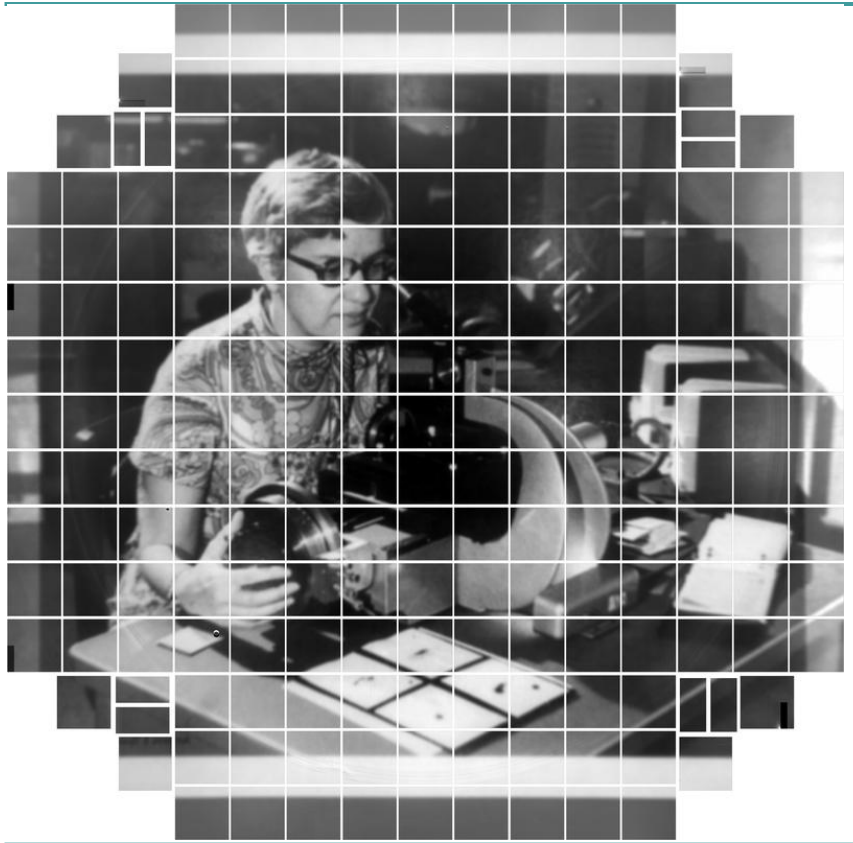


189 4kx4k CCD - 15 second exposures.

Sent to USA in ~5 seconds - dedicated redundant 100Gb/s links.

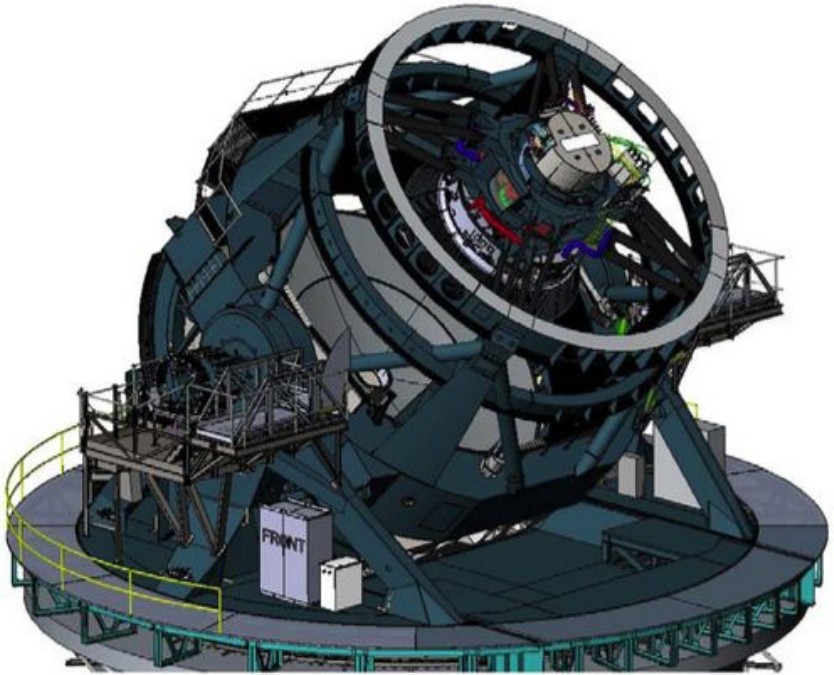
Dedicated alert processing node per CCD.

Images ingested and cataloged in Butler. Users should not touch file just ask butler - you get a Python Object. Data Models Really Impor

Pinhole camera 3.2Gpixel image of Vera C. Rubin

itions Available Here

Need a fast telescope mount assembly



Fabricado en España

Rubin Observatory as imagined and **yesterday!**

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Photo: Eduardo Serrano

El Penon, Cerro Pachon, Chile Altitude: 2647m

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More recent photos 2020 Nov 12 from Eduardo Serrano - work has really recommenced!

Auxiliary Telescope Integration - Pre Lockdown ..

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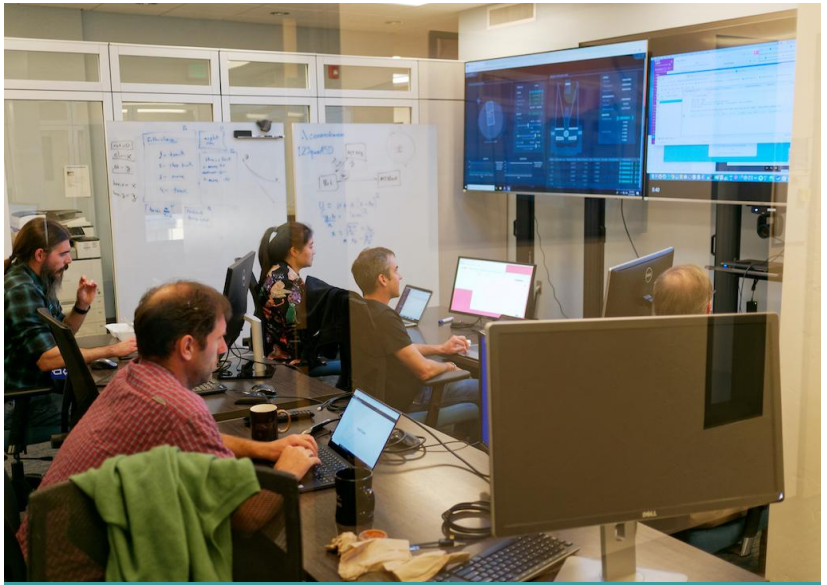
AuxTel operations: Cerro Pachón Control Room
(photo Victor Krabbendam)



Simultaneously in the Tucson Control Room
(photo William O'Mullane)

- Feb 17 2020
- First full week of data produced by the Auxiliary Telescope spectrograph transferred to NCSA.

LSST Schedule – 4.75 Months Contingency (Pre-COVID)

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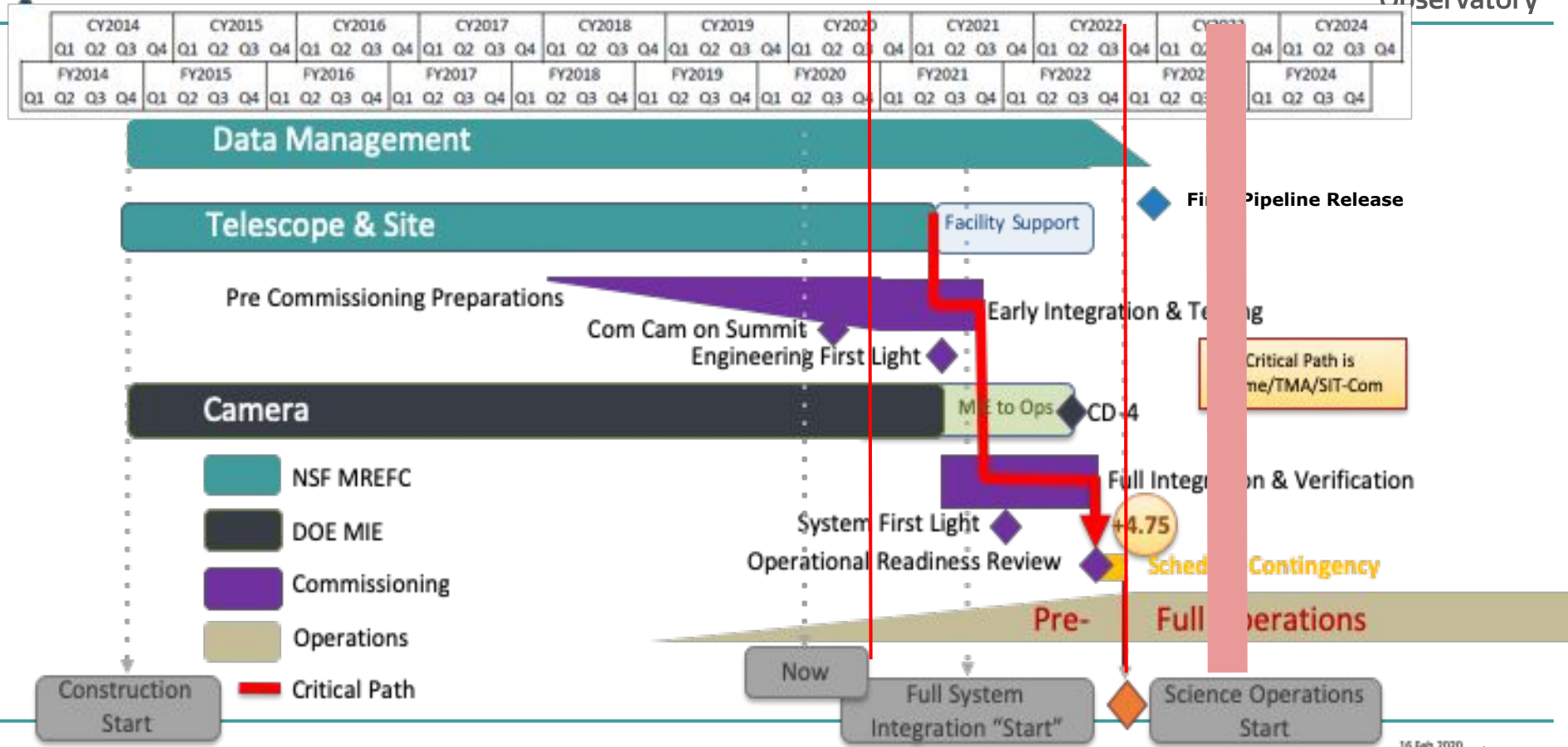

Dome Fabrication Advanced during COVID Shutdown

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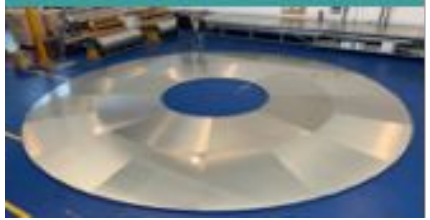
- Interior Dome Structures contracted in Chile, fabrication now complete
- Overhead Bridge Crane completed
- Light baffle fab started, ~20% done
- 22 Louvers fabricated
- Light-wind screen quotations rec'd
- Technical Change Orders resolved

Overhead Bridge Crane Factory Load Testing

Interior Dome Structures Fabricated in Chile

Calibration Screen Panels Complete



Louvers in Fabrication in Italy

DM System Vision

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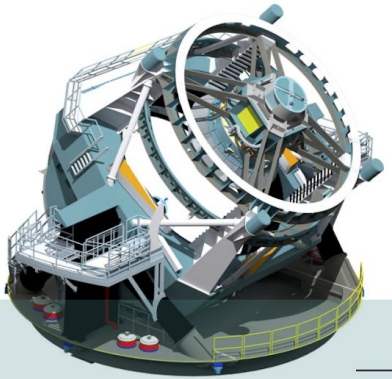
Raw Data: 20TB/night

Sequential 30s images covering the entire visible sky every few days



Prompt Data Products

Alerts: up to 10 million per night

60s via nightly alert streams

Results of Difference Image Analysis (DIA): transient and variable sources

Solar System Objects: ~ 6 million

24h via Prompt Products Database

Data Release Data Products

Final 10yr Data Release:

- Images: 5.5 million x 3.2 Gpx
- Catalog: 15PB, 37 billion objects

via Data Releases

Community Brokers

LSST Alert Filtering Service

LSST DACs (Chile & NCSA)

Independent DACs (iDACs)

LSST Science Platform

Provides access to LSST Data Products and services for all science users and project staff

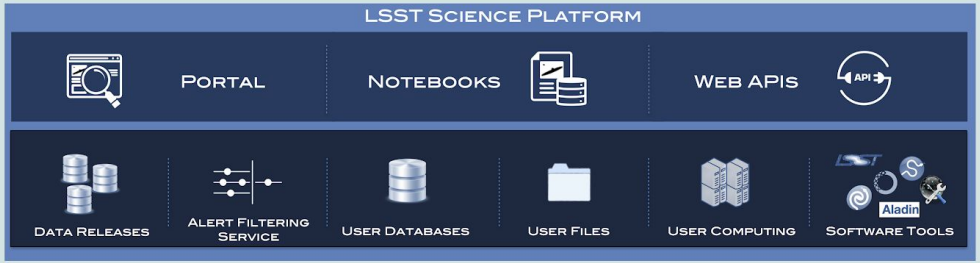
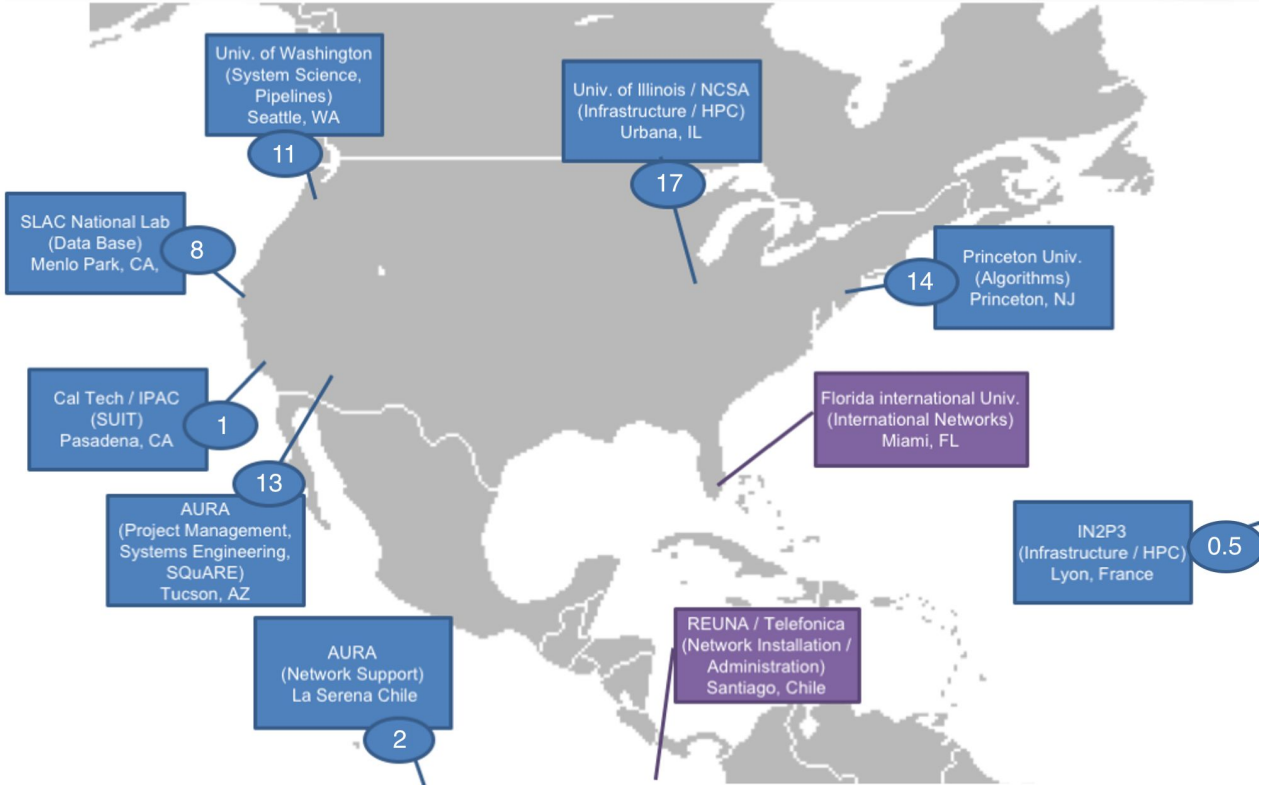


Diagram credit: Leanne Guy

Mission Statement



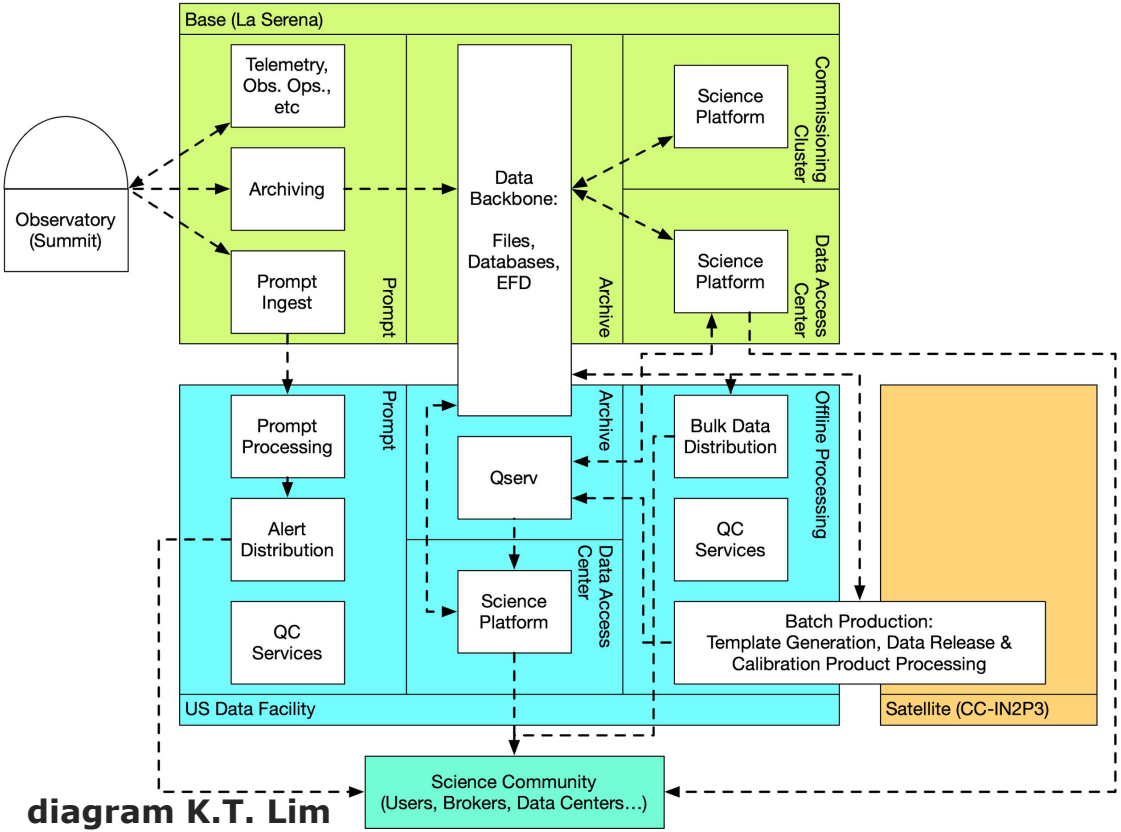
DM's mission is to stand up operable, maintainable, quality services to deliver high-quality LSST data products for science, all on time and within reasonable cost.

Development is distributed across the Americas, and we work closely with partners like IN2P3 in France.

Over 100 individuals ≈75 FTE

DM Management Plan, LDM-294.

Rubin DM build and deploy



DM must build everything to get Rubin products to users.

- large data sets (20TB/night)
- complex analysis
- aiming for small systematics
- Science Alerts in under 2 minutes .. (aiming for 1 minute)

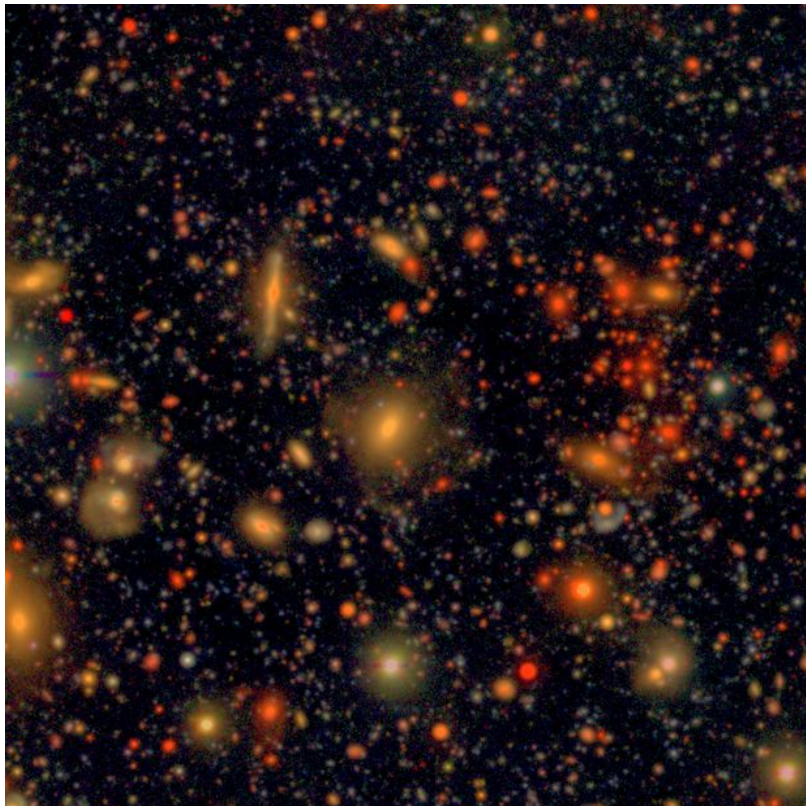
All code on github: https://github.com/lsst

A Massive **Open Source** software development

Rubin Observatory

Images from Frossie Economou

Wide, Fast, Deep… Difficult?

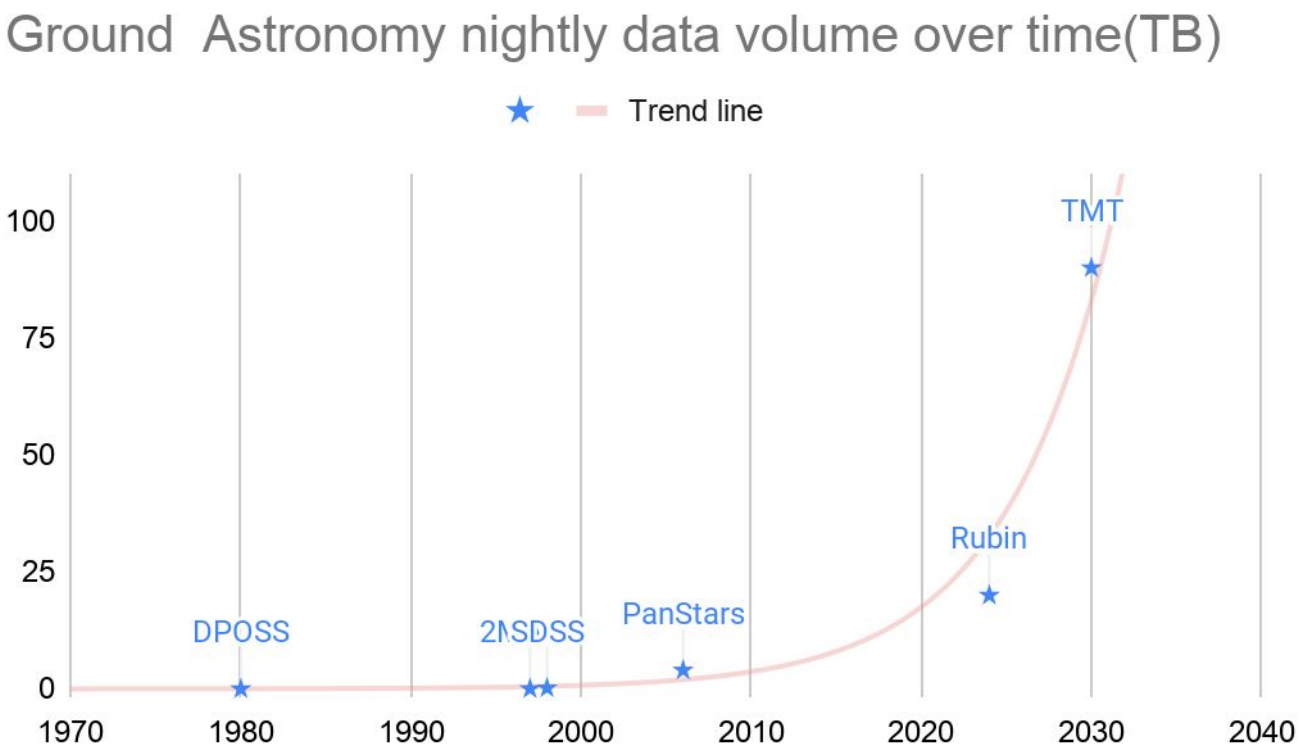


The COSMOS field seen by Hyper Suprime-Cam, courtesy of the HSC Collaboration, R. Lupton, and N. Lust.

- Rubin's LSST is not the first wide-field imaging survey…
- …but the combination of depth, area, and throughput make it uniquely challenging e.g.
  - Everything is blended.
  - Many measurements are systematics limited.
- Testing on precursors like HSC!

Data volume is trending exponential

Rubin Observatory



Alex Szalay was already talking about Astro data doubling every year and the Data Tsunami in 2000

Then there is Radio...

Reminder from Marc's talk yesterday

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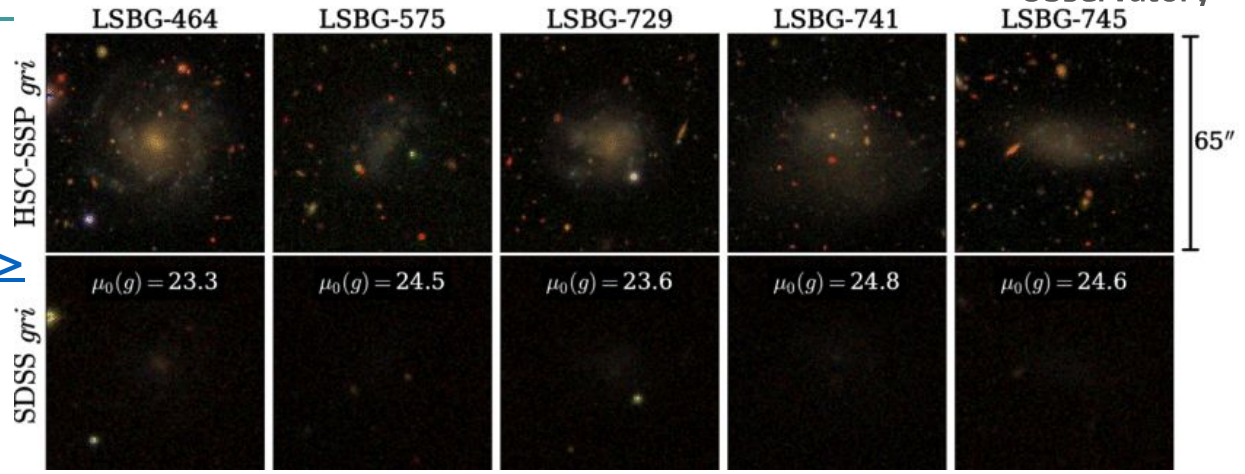
Different cameras require different training sets ..

HSC PDR1 ~26

Greco18->

Entirely new low surface brightness galaxies

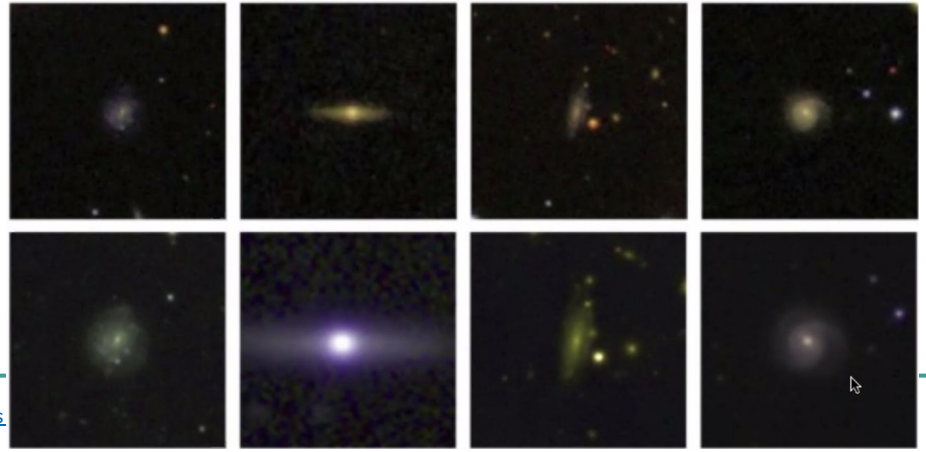
ML arms race ?



We keep up with data volume - detectors and computers are silicon based

SDSS ~22

DES ~24



Pipelines & Science Algorithms - 2020

Rubin Observatory

- Satellites — the challenge of the moment.
  - See e.g. Tyson et al. (2020).
- Developed tools for masking streaks (as might be caused by satellites or other fast-moving objects).
- This functionality will be in release (21.0.0) of the Science Pipelines.

- Pipelines Release 20. Includes:
  - Gen2→Gen3 repo conversion
  - Collimated beam projector support
  - Alert Packet Generation
    - Suitable for distribution to community brokers as described in DMTN-093 & DMTN-149.
  - Release 21 is imminent

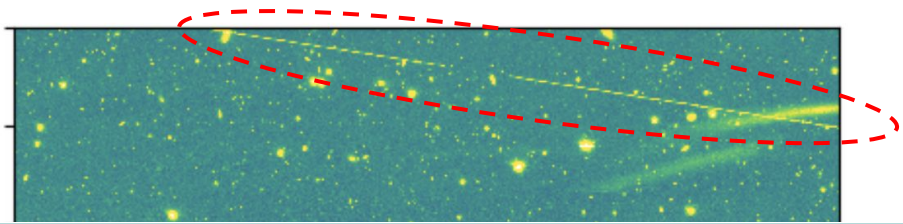
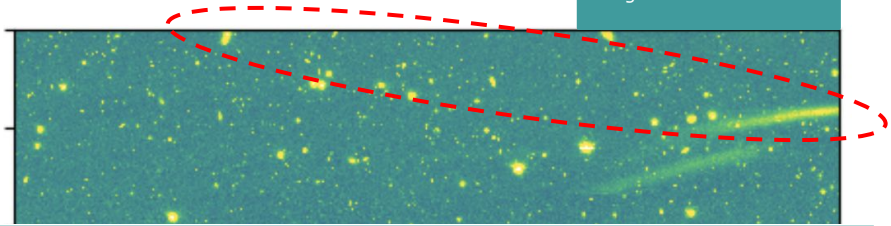


Figure: Clare Saunders



Astronomy is changing …some of my telescopes

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There was/is a lot of individual observations and poor stats.

Survey Telescopes change all that - possibly similar for your project

The Era Of Surveys

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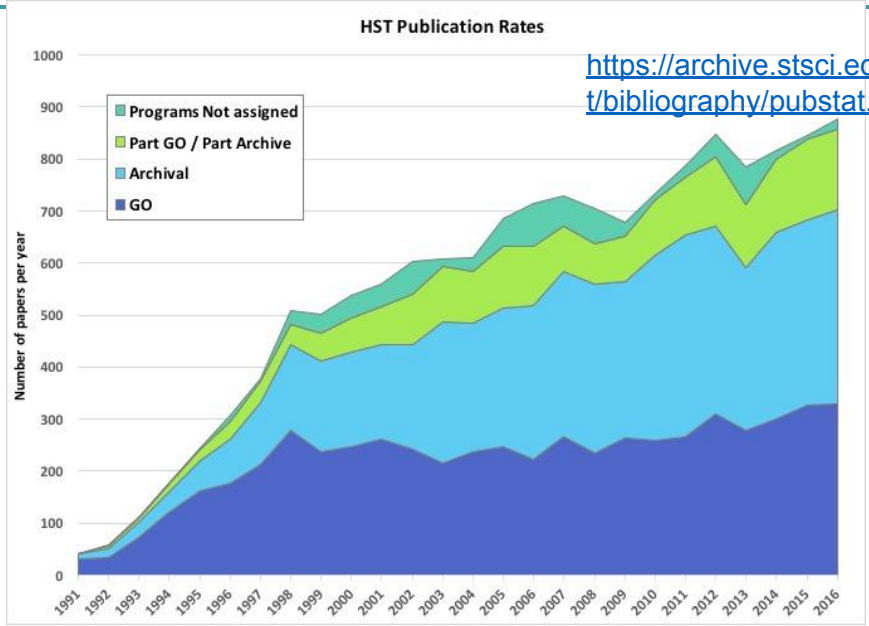
My ultimate telescope ?



https://archive.stsci.edu/hst/bibliography/pubstat.html

XMM-Newton also indicates importance of the archive

https://ui.adsabs.harvard.edu/abs/2014AN....335..210N/abstract

Data Product Categories

Rubin Observatory

Prompt Data Products

Real Time Difference Image Analysis (DIA)

- Stream of ~10 million time-domain events per night (Alerts), transmitted to event distribution networks within 60s of camera readout.
- Images, Object and Source catalogs derived from DIA, and an orbit catalog for ~6 million Solar System bodies within 24h.
- Enables discovery and rapid follow-up of time domain events.

Data Release Data Products

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

- Catalogs of ~37 billion objects (20 billion galaxies, 17 billion stars), ~7 trillion sources and ~30 trillion forced source measurements.
- 11 Data Releases, produced ~annually over 10 years of operation.
- Accessible via the Rubin Science Platform (RSP) & Rubin Data Access Centers (DACs).

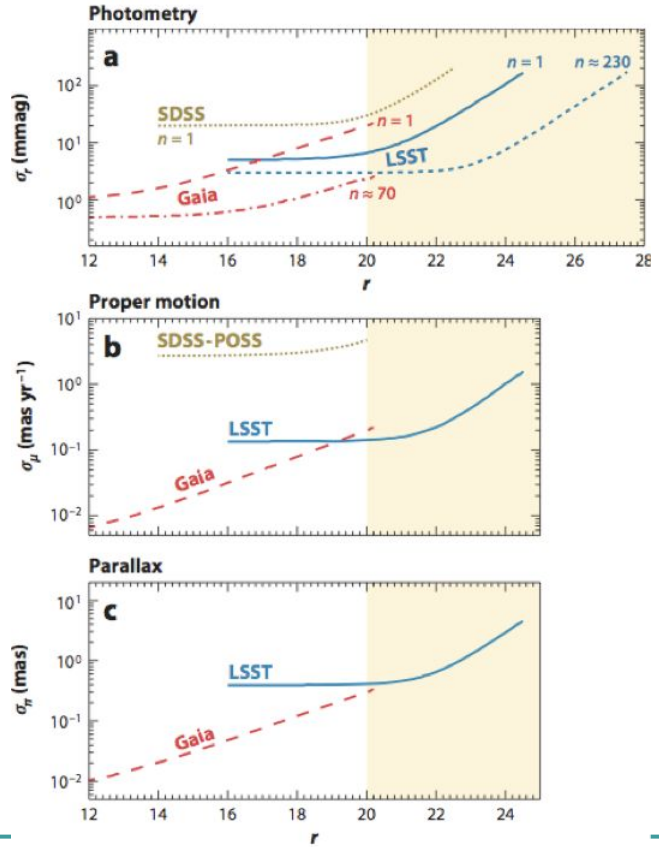
User Generated Data Products

User-produced derived, added-value data products

- Deep KBO/NEO, variable star classifications, shear maps, etc …
- Enabled by services & computing resources at Rubin DACs and via the Rubin Science Platform (RSP).
- 10% of computing resources at the US Data Facility (USDF) will be allocated for User Generated data product storage & processing.

Credit: Leanne Guy & Mario Juric

Gaia and Rubin LSST



- Gaia: excellent astrometry (and photometry), but only to r > 20
- LSST: photometry to r < 27.5 and time resolved measurements to r < 24.5
- Complementary: photometric, proper motion and trigonometric parallax errors are similar around r=20

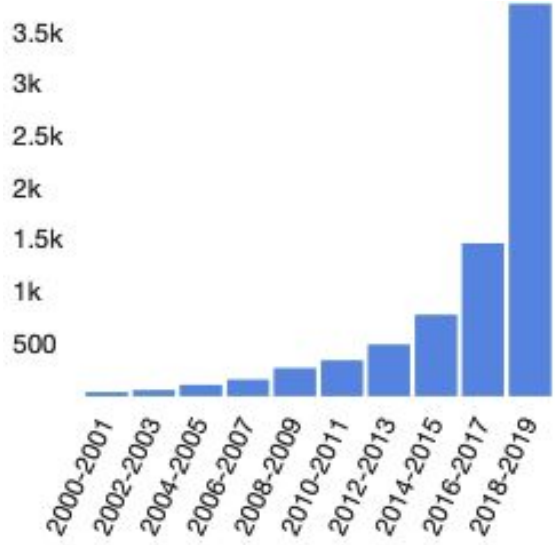
Potentially anything you do with Gaia you can do with Rubin catalogs + Rubin has images

A dream for ML enthusiasts

Rubin Observatory

Rubin will provide lots of well curated and consistently processed data:

- 20B galaxies
- 17B resolved stars
- 6M orbits of solar system bodies



ADS: Papers per year mentioning Machine learning

And about 10 million alerts per night

Yes Marc showed a similar plot yesterday !

Data Access

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Data rights holders will have access to the catalogs and images via the Science platform.

- We are currently considering having parquet files along side Qserv
  - We think we need "unpredictable" access which Qserv may or may not handle
  - Many cloud tools work best with cloud formats like parquet
- A subset of data will be public via Education and Public outreach
  - Including for citizen science projects
- Alert stream will be public

Science Platform to bring the code to the data

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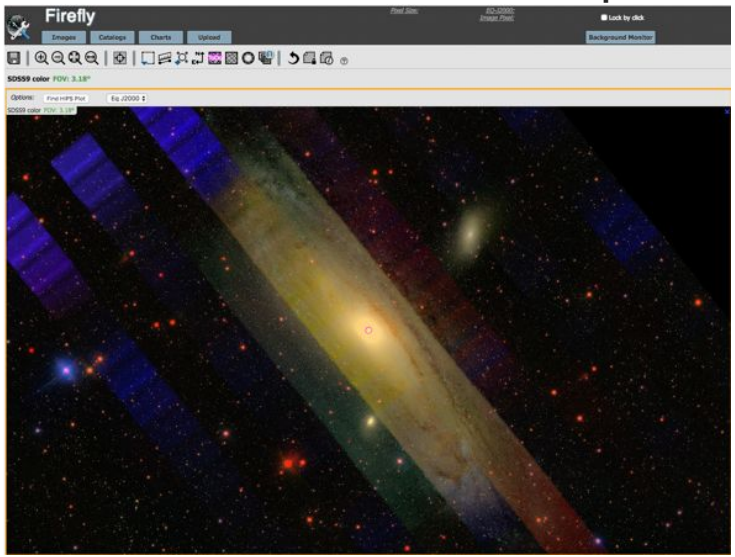
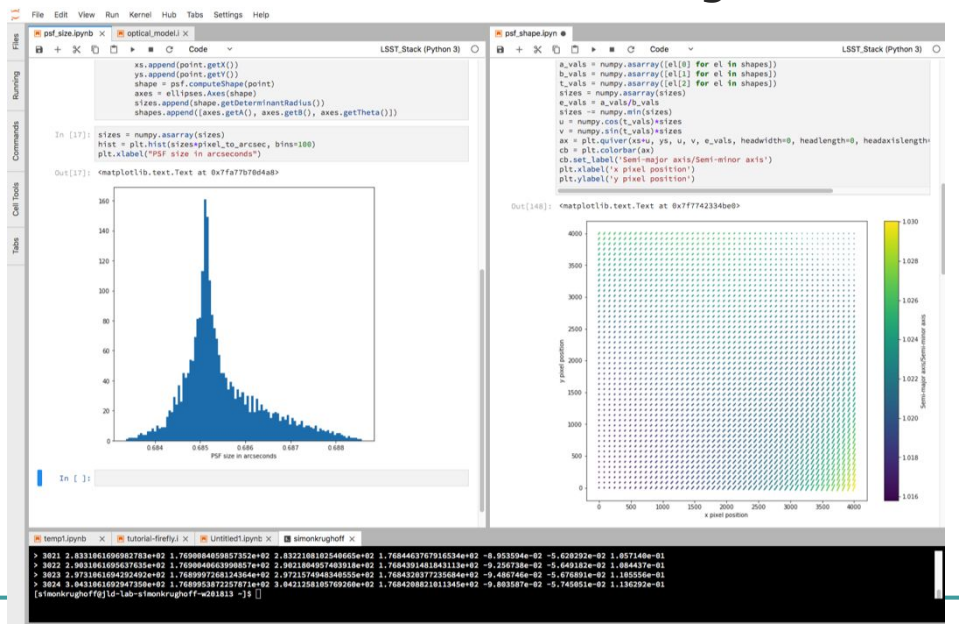
Science Platform: Portal, JupyterLab and Web APIs (IVOA)

Vision: LSE-319 — Design: LDM-542 — Test: DMTR-51

Some astronomers now expect this environment - it is no longer novel.





Images Xiuqin Wu ^ and Simon Krughoff->

Retrieving (manipulated) Image Files via SODA

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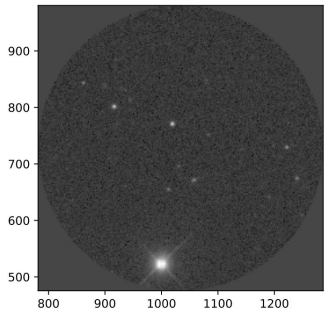
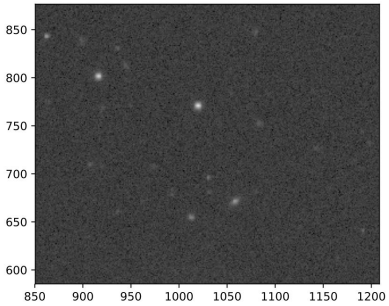
Creating virtual data products for retrieval

```
size = 100/3600.  # 100 arcsec radius
q1 = pyvo.dal.adhoc.SodaQuery(sodeServiceURL,
   ID='DC_W13_Stripe82.calexp.r',
   POS='CIRCLE 37.644598 0.104625 %f'%size
)
```

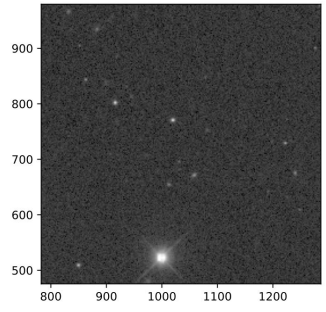
Circular Cutout



Polygon Cutout



Lat/Lon Cutout



SDSS Stripe82, r-band data

Construct a query for a cutout and retrieve an object

Execute the query and stream the results to the user's workspace

Notebook Credit : Kenny Lo

https://github.com/lsst-sqre/notebook-demo/blob/master/LSST%20SODA%20Tutorial.ipynb

But I want all images with ….

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Much astronomy uses catalogs (that is all you get from Gaia) extracted from images. These tend to be highly structured, tabular, somewhat predictable access.

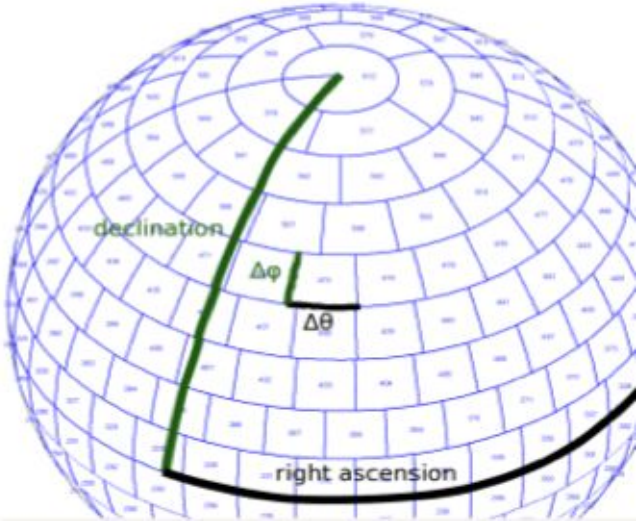
- Rubin Data, by DR11(2035):
  - 60T rows (mostly ForcedSource) 10PB (mostly Source +ForcedSource + Object extra)
- Most significant tables (rows x cols, storage):
  - Object: 47B x 330, 100TB
  - Objectextra: 1.5T x 7,600, 1.2PB
  - Source: 9T x 50, 5PB
  - ForcedSource: 50T x 6, 2PB

- Data for small area - <10 sec
- Scan billions of objects - ≈ 1 hour
- Deeper analysis (Object_*) - ≈ 8 hours
- Analysis of objects close to other objects - ≈ 1 hour, even if full-sky
- Analysis that requires special grouping - ≈ 1 hour, even if full sky
- Source, ForcedSource scans - ≈ 12 hours
- Cross match & anti-cross match with external catalogs - ≈ 1 hour

Qserv (slides from Fritz Muller)

Rubin Observatory

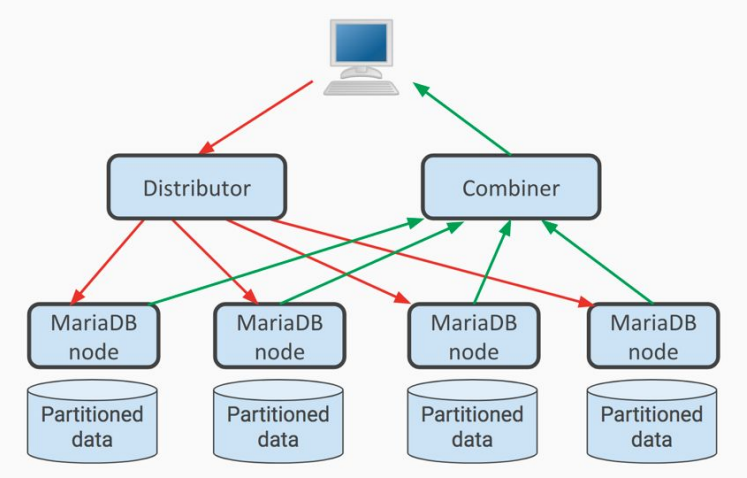
- Shared-nothing MPP RDBMS (SQL, throughput, horizontal scaling)
- Spherical partitioning with overlap (near-neighbor self-joins)
- Shared scans (concurrent query load) Replicated data (resiliency)
- Fixed-purpose, dedicated hardware (cost, predictability)



Tessellation not O'Mullane et al. (2001)

Design optimized for use case + hardware efficiency LDM-135
Built on project at SLAC, leverage existing tech within Stanford (MariaDB, MySQL Proxy, XRootD, Google protobuf, Flask)
100% open source https://github.com/LSST/Qserv

Shared Nothing Massively Parallel Processing



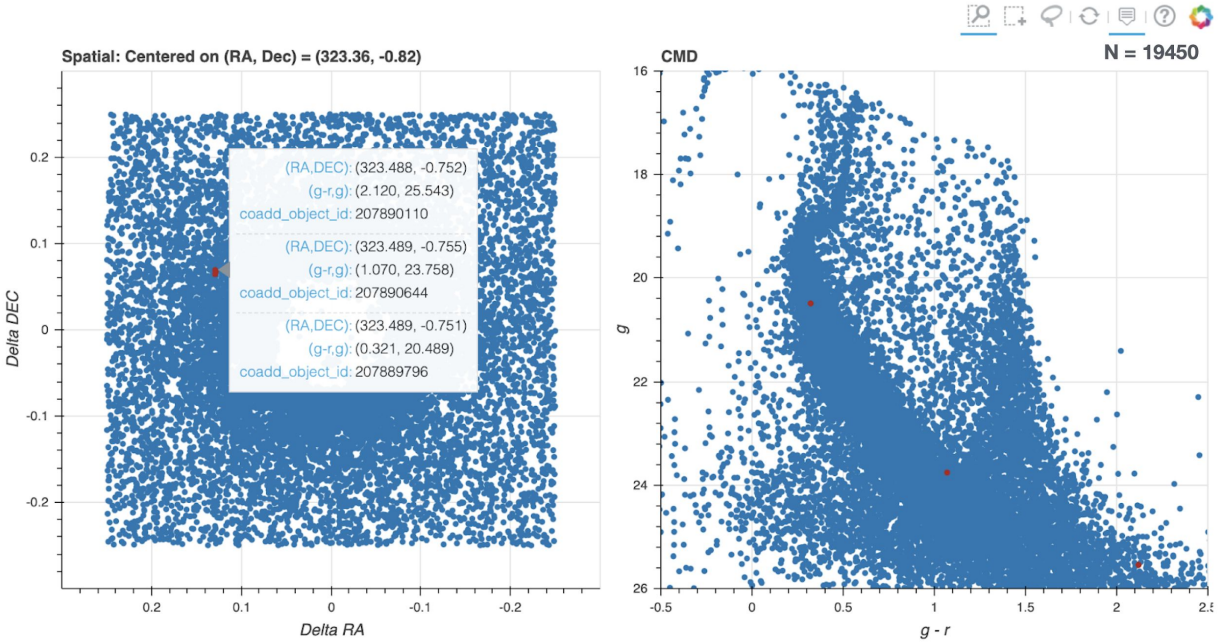
- Ultimate target platform 300 nodes in 2 international data-centers
- Development cluster @CC-IN2P3:
  - 400 cores, 800 GB memory, 500 TB storage
  - DESC DC2 dataset on 2 x 25 nodes
- Dev Cluster @NCSA:
  - 500 cores, 4 TB memory, 700 TB storage
  - 150 TB science datasets
    - HSC reprocessing + GAIA DR2 + SDSS Stripe 82 + WISE
  - on 30 nodes

Recent scale tests:
DMTR-71
Perf comparison BigQuery:
Document-31100

Interactive Visualization in Notebooks

Rubin Observatory

Brushing and linking with Bokeh in Notebooks



Dark Energy Survey DR1, Data from the M2 globular cluster database

Appendix C of the DES DR1 paper from the DES Data Release page

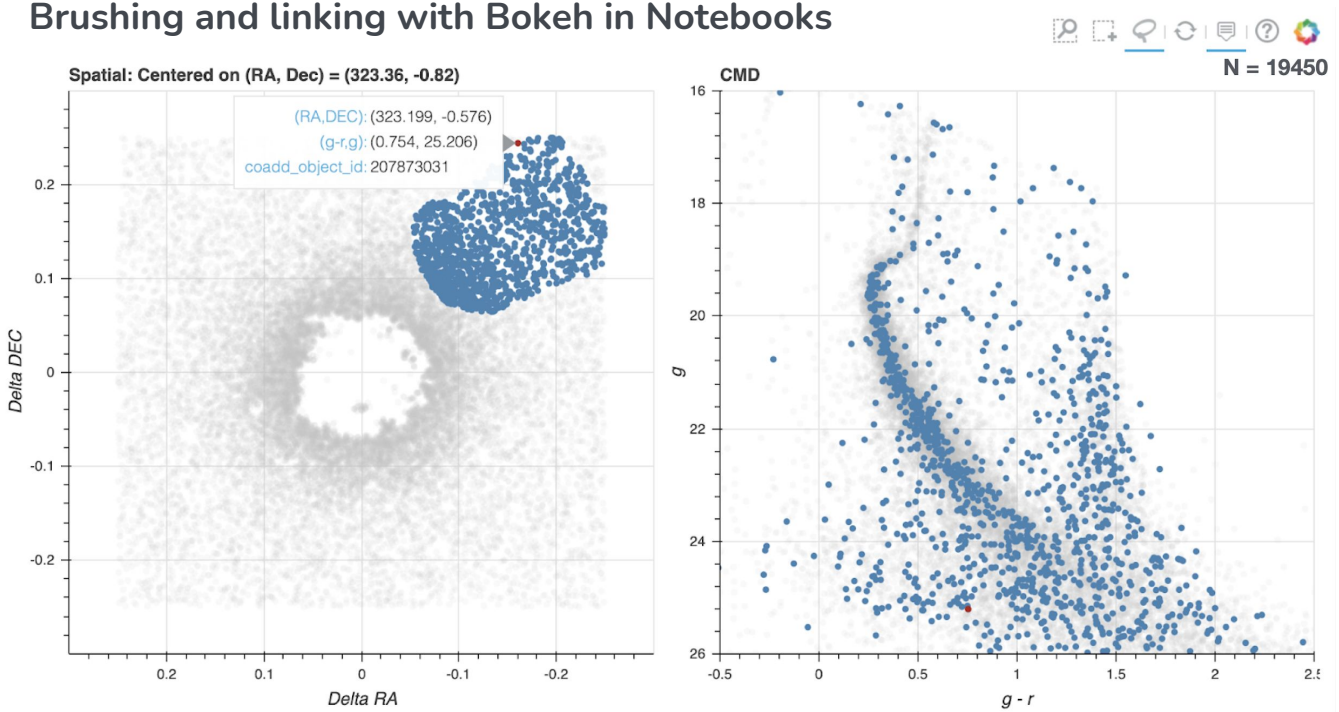
Notebook Credit : Keith Bechtol

https://github.com/LSSTScienceCollaborations/StackClub/blob/master/Visualization/bokeh_holoviews_datashader.ipynb

Interactive Visualization in Notebooks

Rubin Observatory

Brushing and linking with Bokeh in Notebooks



The **“lasso” tool** has been used to select a 2D region in the left-hand RA/Dec plot.

The same points are blue in the color-magnitude diagram on the right.

Notebook Credit : Keith Bechtol

https://github.com/LSSTScienceCollaborations/StackClub/blob/master/Visualization/bokeh_holoviews_datashader.ipynb

Visualizing Large Datasets in the RSP

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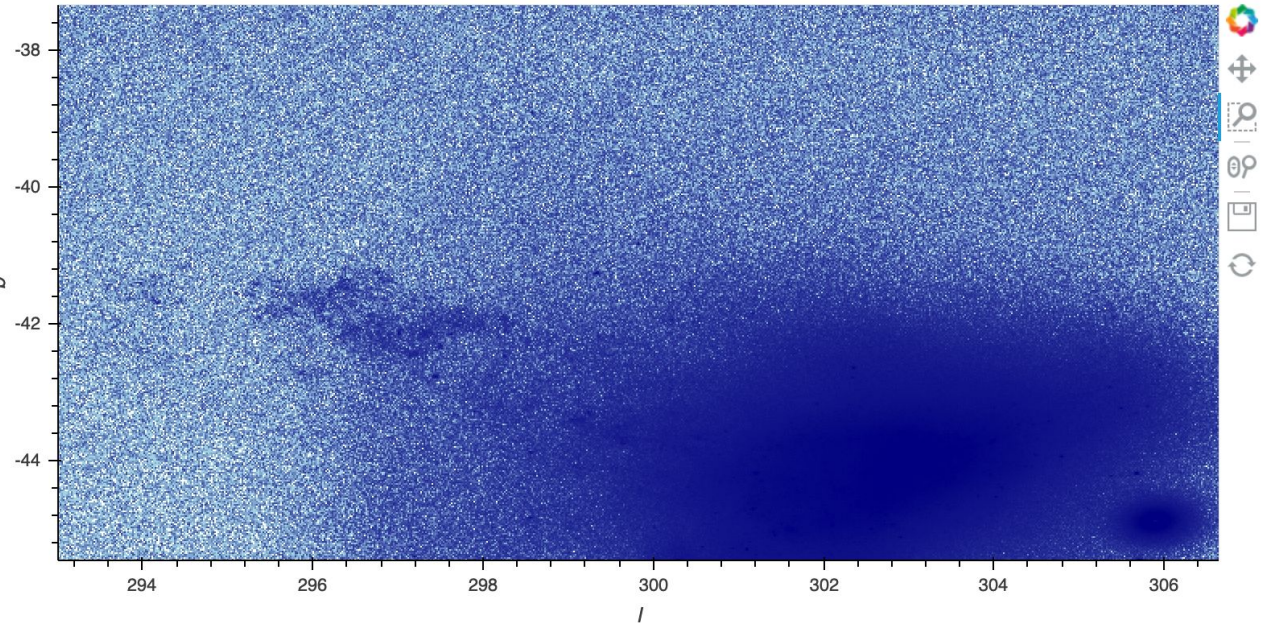
Gaia DR2 data with Parquet, Dask, HoloViews and Datashader - allows panning zooming



Gaia DR2 Density Map

1.7 billion objects in the Gaia source catalog

Data in parquet files

Dask: 15 workers, 4 cores, 12GB RAM,

~20 sec to aggregate & bin

Notebook Credit : Simon Krughoff

https://github.com/lsst-sqre/notebook-demo/blob/master/experiments/DASK-notebooks/rv_gaia.ipynb

Transients - Alert Stream

Rubin Observatory

About 10 million transients a night .. Zwicky x10 (See LDM-612, DMTN-102)

- We must support 10K alerts per visit on average (peak 40K).
  - That is a requirement not a statement on physical properties of the sky.
- Each packet has variable-sized cutouts
  - Trailed NEAs can be 0.5 degree in 30 second exposures…
  - Discussion for square cutouts centered on source (for ML)

Thanks to Eric Bellm for the info on alert slides

A lot of alerts ...

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Some estimates per visit on average:

- ~7200 variable star alerts
- ~200 Supernovae events (SNe)
- ~70 Active Galactic Nuclei (AGN)
- ~3000 moving objects (Solar system objects)

Sample Alerts - July 2020

Rubin Observatory

Rubin Data Management -initial release of sample alerts and tools.

- sample-alert-info, a living README pointing to data and software
- ~5000 g-band CCD-visits from the DECam-HITS survey (Förster+16) processed by the DM pipelines and serialized as Avro files on disk
- The corresponding Prompt Products Database (PPDB) as SQLite
- alert_packet, pip-installable python package for end users containing alert schemas and utility code for reading alerts
- alert-stream-simulator, Docker-based tool for broker teams to test a Kafka stream and perform basic load and ingestion tests

Rubin will send the full-volume alert stream to community brokers (at least 5) selected through the proposal process.

Alert sample details ..

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- Generated from real precursor data processed by today's pipelines (w_2020_29)
  - plenty of artifacts (~4:1 bogus:real)
  - cadence, volume, depth, and filter set are not representative of LSST alerts
- Many DPDD fields are currently missing (see sample-alert-info):
  - no trailed source fitting
  - no extendedness or spuriousness scores
  - no timeseries features
  - no association to known Solar System Objects

We plan to iteratively update the sample as the pipelines improve.

Feedback and questions are welcome via the Community Data Q&A Topic.

You can use all locally...

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To use Rubin Pipeline see https://pipelines.lsst.io/ (**newinstall.sh**)

One easy way is with docker(https://hub.docker.com/r/lsstsqre/centos/tags/):

```
    >docker run -ti lsstsqre/centos:7-stack-lsst_distrib-v20_0_0
In the container:
    >source /opt/lsst/software/stack/loadLSST.bash
    >setup lsst_distrib
```

The JupyterLab images (for Science Platform) are also available:
https://hub.docker.com/r/lsstsqre/sciplat-lab/tags/

Using the notebook locally is a little more involved see :
https://community.lsst.org/t/running-dm-jupyter-notebooks-locally/3323

The End

Blast 20 Cerro Pachón April 2011

Rubin Observatory Sept 2019

http://www.lsst.org

http://community.lsst.org