

# LSST: Revealing the universe

William O'Mullane

Data management  
Large Synoptic Survey Telescope  
Tucson, AZ USA

5<sup>th</sup> March 2019  
NOAO  
Tucson

# The origin of the Milky Way



(De Bruijn)

Tintoretto (1575, National Gallery, London)





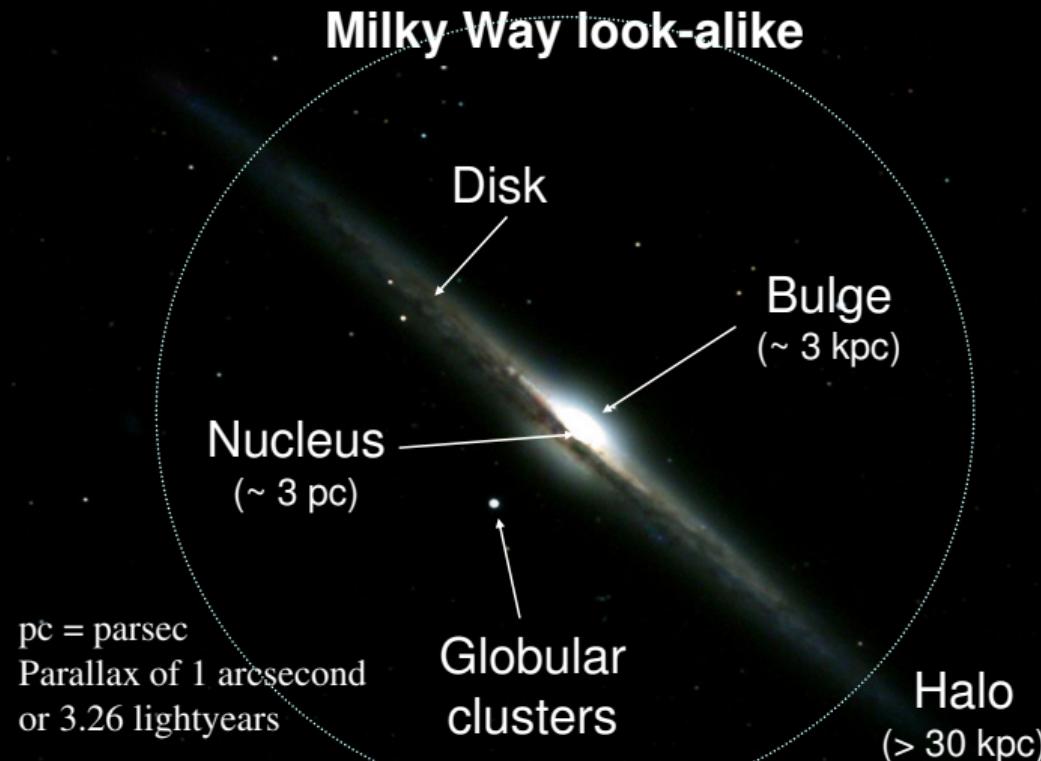
Milky way analogue

‘Our sun’ →

Our view is severely obstructed by the dust in the disk and relatively little is known about the origin, history, and structure of our own Galaxy

We are unraveling the formation, composition, and evolution of the Galaxy

Jos de Bruijne



Stellar motions can be predicted into the future and calculated for times in the past when all 6 phase-space coordinates (3 positions, 3 velocities) are known for each star

Stellar motions can be predicted into the future and calculated for times in the past when all 6 phase-space coordinates (3 positions, 3 velocities) are known for each star

The evolutionary history of the Galaxy is recorded mainly in the halo, where incoming galaxies got stripped by our Galaxy and incorporated



Stellar motions can be predicted into the future and calculated for times in the past when all 6 phase-space coordinates (3 positions, 3 velocities) are known for each star

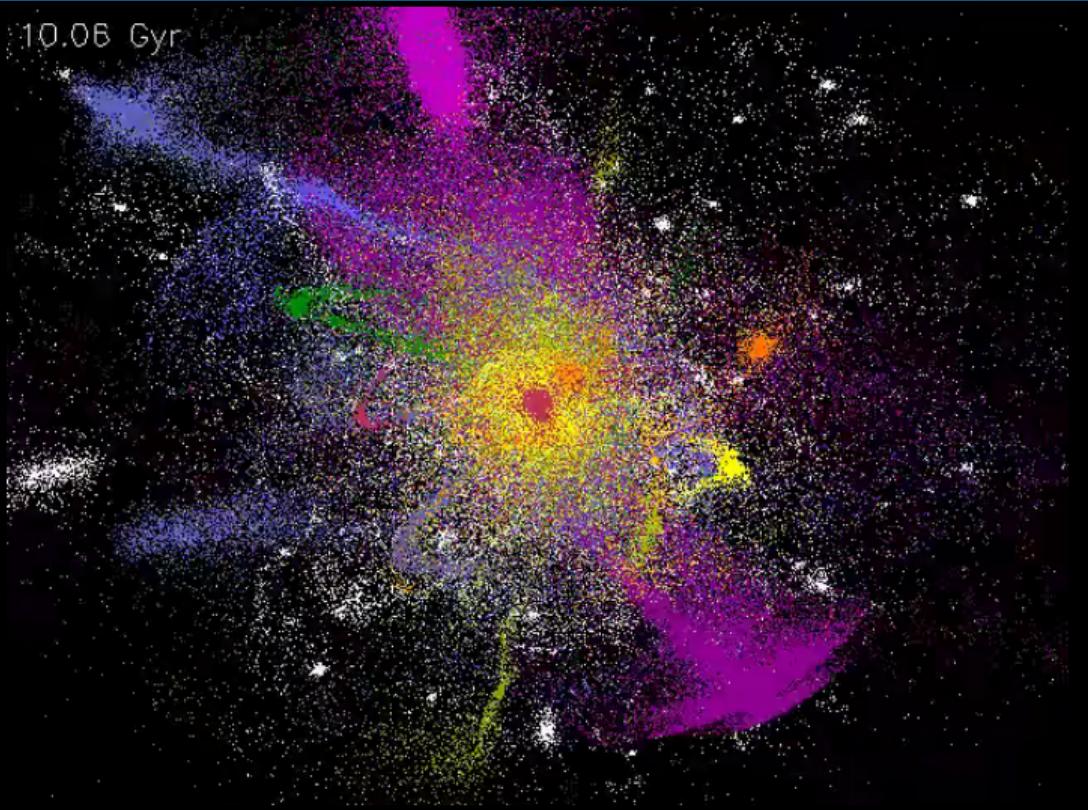
The evolutionary history of the Galaxy is recorded mainly in the halo, where incoming galaxies got stripped by our Galaxy and incorporated



In such processes, stars got spread over the whole sky but their energy and (angular) momenta were conserved. Thus, it is possible to work out, even now, which stars belong to which merger and to reconstruct the accretion history of the halo (de Bruijne)

## Origin of the Milky Way - take 2

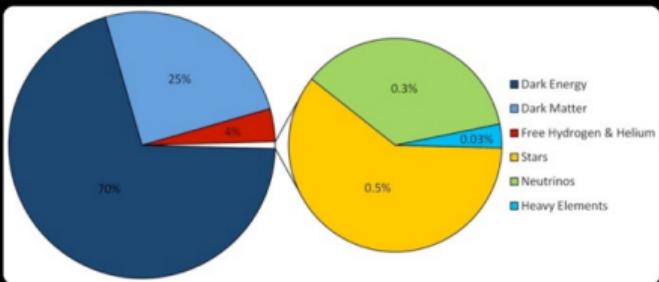
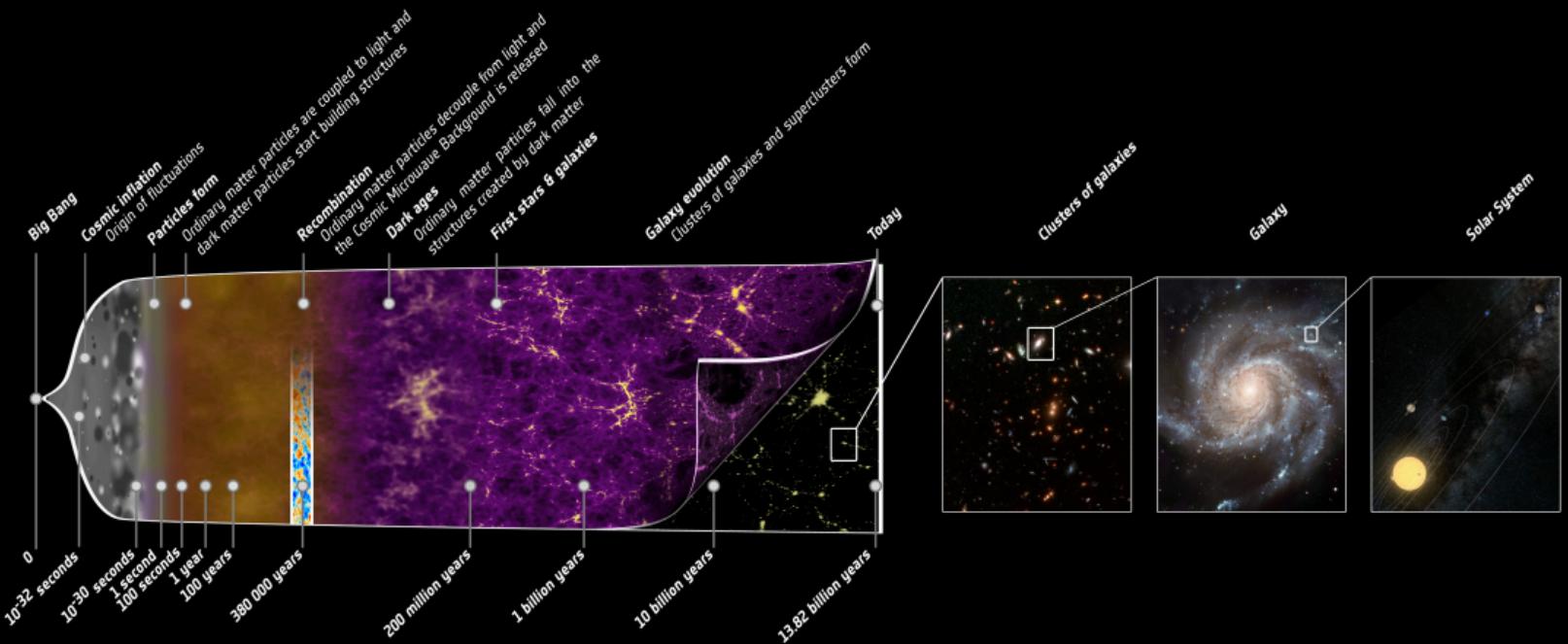
10.08 Gyr



Streams paper using Gaia DR2 Koppelman et al. (2018)



Image credit: R. Jay GaBany



The modern cosmological models can explain all observations, but need to postulate dark matter and dark energy (though gravity model could be wrong, too)

LSST scans the sky repeatedly and compares the images with templates allowing us to:

- discover new, distant transient events
- study variable objects in universe
- capture rare and exotic objects
- gain new insight into known transients:
  - new remnants of dead massive stars, including neutron star and black hole binaries;
  - variability at the heart of distant galaxies - feeding habits of the rapacious supermassive black holes at their centers;
  - catch the faint cosmological explosions of dying, merging stars, illuminating where the universe's heavy metals are forged.



The Crab Nebula, result of a supernova noted in 1054 A.D.

By NASA, ESA, J. Hester and A. Loll (Arizona State)

Large Synoptic Survey Telescope



Tunguska  
(1908)

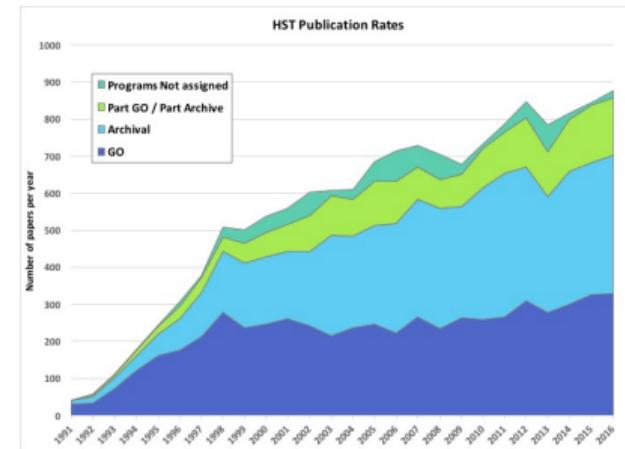
Shoemaker-Levy 9  
(1994)

LSST is the only survey capable of delivering completeness specified in the 2005 USA Congressional NEO mandate to NASA (to find 90% NEOs larger than 140m)



The Barringer Crater, Arizona: a 40m object 50,000 yr. ago

## The Era Of Surveys



[https://archive.stsci.edu/hst/bibliography/  
pubstat.html](https://archive.stsci.edu/hst/bibliography/pubstat.html)

...indicates archival research  
probably play an important role in  
the scientific success of  
XMM-Newton Ness et al. (2014)

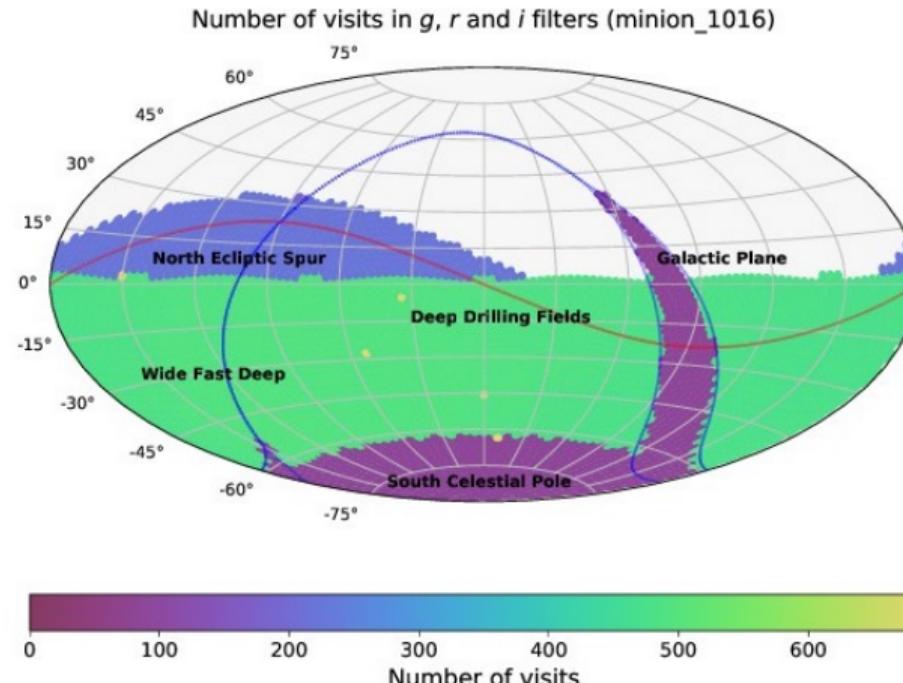
## LSST:uniform sky survey

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!

see also <http://www.lsst.org> and Ivezić et al.

(2008)-arXiv:0805.2366



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

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

File Edit View Run Kernel Hub Tabs Settings Help

Files Running Commands Cell Tools Tabs

```
psf_size.ipynb x optical_model.jl x
+ × Code LSST_Stack (Python 3) ○
```

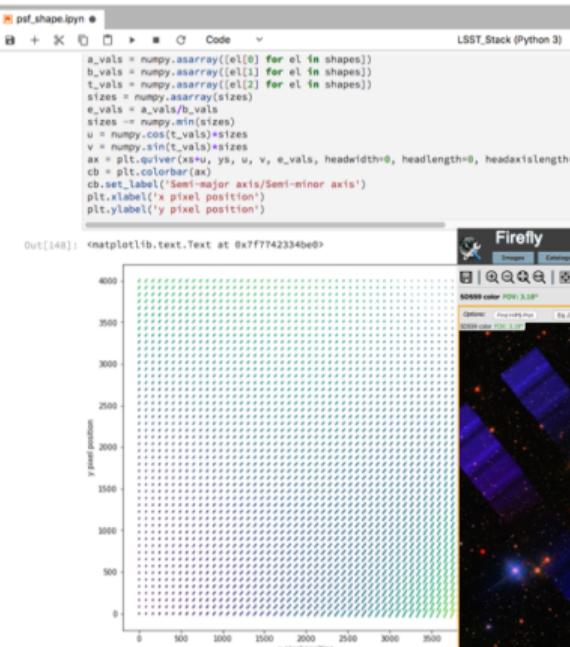
```
psf_shape.ipynb ●
+ × Code LSST_Stack (Python 3) ○
```

In [17]:

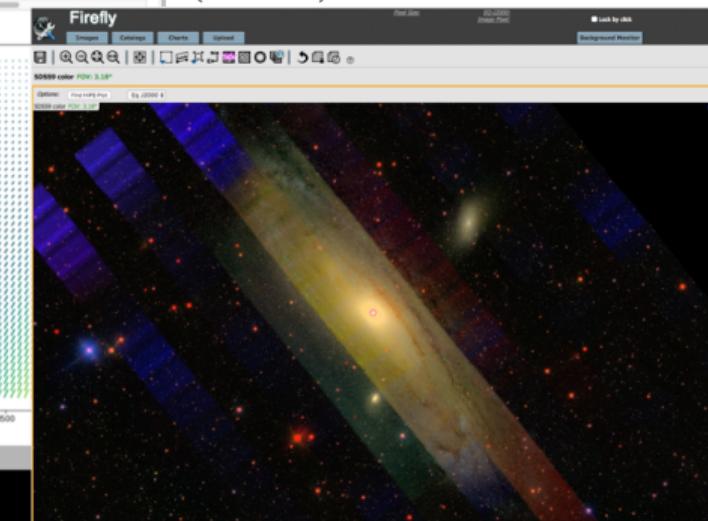
```
sizes = numpy.asarray(sizes)
hist = plt.hist(sizes.pixel_to_arcsec, bins=100)
plt.xlabel("PSF size in arcseconds")
```

Out[17]: <matplotlib.text.Text at 0x7fa77b70d4a8>

In [ ]:



Portal/Browser  
Notebooks  
Web API  
(Batch)



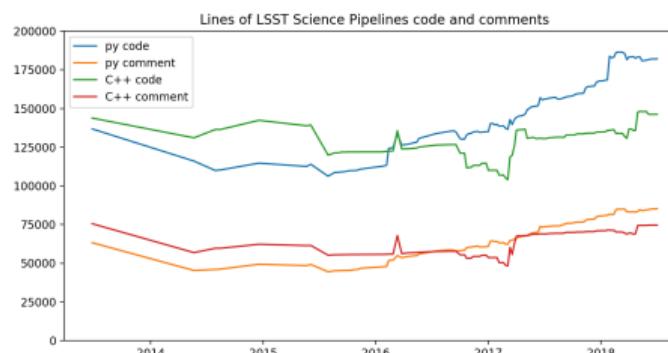
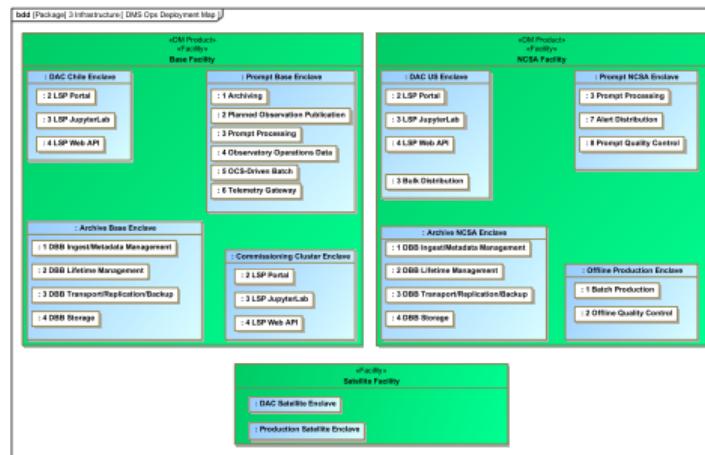
```
temp1.ipynb x tutorial-firefly.jl x Untitled1.ipynb x simonkrughoff x
> 3021 2.423106169952765e+02 1.769904465957362e+02 -6.832216831024466e+02 1.708446376791623e+02 -9.262084e-02 5.620393e-02 1.057140e-01
> 3022 2.063186169563763e+02 1.769904464399857e+02 3.9821884957483918e+02 1.76843931481943113e+02 -9.2667738e-02 -5.649182e-02 1.084437e-01
> 3023 2.0731861694292492e+02 1.7699972681243644e+02 2.9721574948340555e+02 1.7684326377235684e+02 -9.4867746e-02 -5.676916e-02 1.105556e-01
> 3024 3.0431861692947358e+02 1.768995387257871e+02 3.0421258105769260e+02 1.7684208821011345e+02 -9.8803587e-02 -5.745651e-02 1.136292e-01
[simonkrughoff@jld-lab-simonkrughoff-wc281813 ~]
```



DM Mission :  
Stand up operable,  
maintainable, quality  
services to deliver  
high-quality LSST data  
products for science, all on  
time and within reasonable  
cost.

LSST DM development is distributed across the Americas.  
Plus we have partners like IN2P3  
See Management Plan LDM-294.

# Build and Deploy with a view to Ops



DM must build everything to get LSST data products—as described in LSE-163—to end users.

- Large data sets (20 TB/night)
- Complex analysis with small systematics
- Science alerts issued within one minute

~  $\frac{3}{4}$  million lines of code/comments  
(C++/Python/Java/JavaScript/Kotlin)

See SPIE paper by Jenness et al. (2018)

Architecture and Components LDM-148.

Concept of Operations LDM-230.

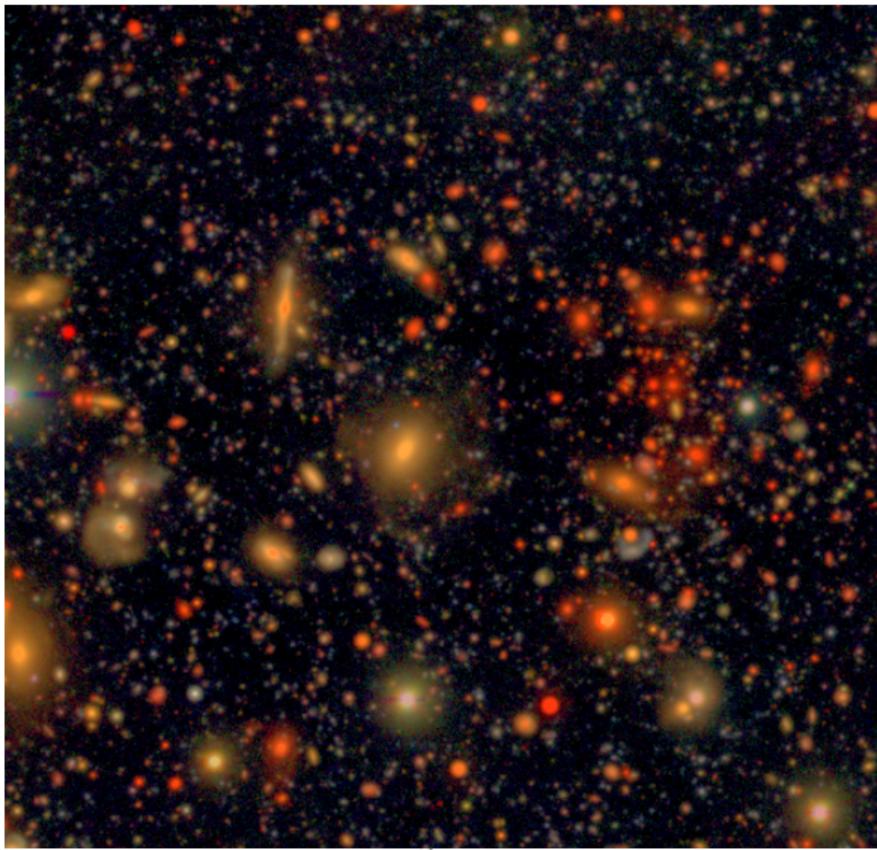
Upper diagram courtesy K-T Lim, LDM-148.

Lower diagram by Tim Jenness; covers only the Science Pipelines codebase.



Nice colors Lupton et al. (2004)  
 $\approx 3.5'$

Image Robert Lupton



HSC image (COSMOS) from g,r(1.5 hrs) ,i(3 hrs) PSF matched co-add ( $\approx 27.5$ )

Processed with LSST Stack  
<https://pipelines.lsst.io/>

YES the Pipelines are already in use with other facilities like Hyper Suprime-Cam.

Still working on performance, algorithmic enhancements, orchestration, etc.

Design LDM-151; Test Specs LDM-533;  
LDM-534; Test Reports DMTR-52;  
DMTR-53

Image HSC collaboration, Robert Lupton

The LSST Data Products are organized into three main categories.



## Prompt Data Products

### Real Time Difference Image Analysis (DIA)

- A stream of ~10 million time-domain events/night (Alerts), transmitted to event distribution networks within 60s of 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 LSST Science Platform and Data Access Centers.



## User Generated Data Products

User-produced derived, added-value data products

- Deep KBO/NEO, variable star classifications, shear maps, statistical population studies, etc
- Enabled by services & computing resources at the LSST DACs and via the LSST Science Platform (LSP).
- 10% of LSST computing resources will be allocated for User Generated data product storage & processing.

LSST Data Product Categories & DM Data Products & LSST Key Numbers

## Alerts: identify time varying objects

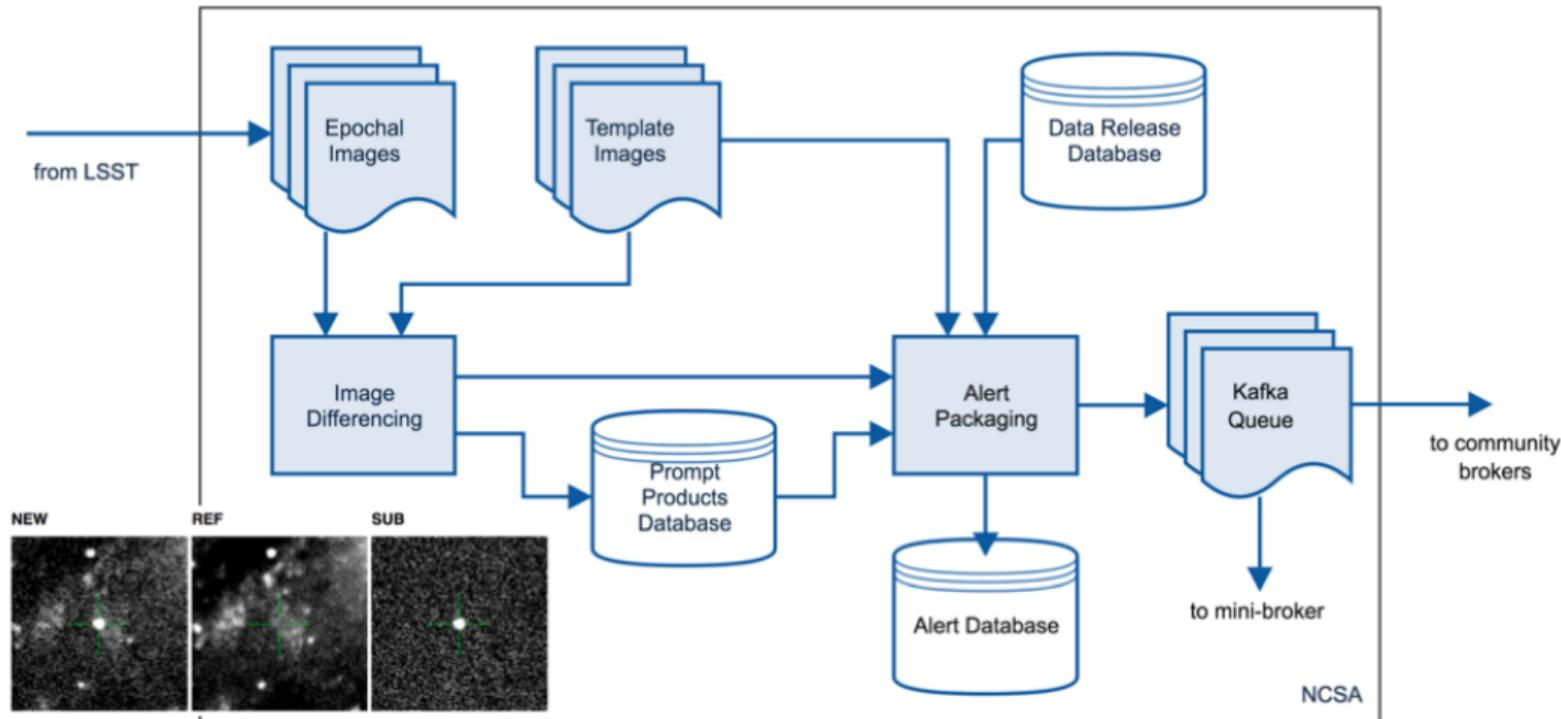


Figure from Eric Bellm

- LSST Mini Broker - Users can create filters that return
  - a subset of LSST alerts based only on data in the alert packet
  - can use lightcurve, variability parameters, colors, etc.,
  - no crossmatch to external catalogs
  - Runs in the LSST Data Access Center(-> users must have data rights)
- Community Alert Brokers - further enabling science on alerts e.g.:
  - Provide public access to alerts
  - Classification and Crossmatch to other catalogs or data streams
  - Provide filtering, visualization, and search
  - Coordinate scientific activity and/or followup observations
  - Aggregate alert annotations (community classifications, etc.)
- Call has gone out for community brokers
- **Mini Broker capacity/Number of community brokers limited by bandwidth**

see also LDM-612



<http://www.lsst.org>

Southern Sky

<http://community.lsst.org>

Acronym	Description
API	Application Programming Interface
AU	deprecated acronym for astronomical unit; use au instead
AURA	Association of Universities for Research in Astronomy
C	Specific programming language (also called ANSI-C)
DM	Data Management
ESA	European Space Agency
HSC	Hyper Suprime-Cam
IR	Infra Red
LDM	LSST Data Management (Document Handle)
LSE	LSST Systems Engineering (Document Handle)
LSST	Large Synoptic Survey Telescope
NASA	National Aeronautics and Space Administration
NCSA	National Center for Supercomputing Applications
NEO	Near-Earth Object
NOAO	National Optical Astronomy Observatories (USA)
PB	PetaByte
PSF	Point Spread Function
SDSS	Sloan Digital Sky Survey
TB	TeraByte
XMM	X-ray Multi-mirror Mission (ESA; officially known as XMM-Newton)
arcmin	arcminute, minute of arc (unit of angle)
arcsec	arcsecond, second of arc (unit of angle)

# References

- [LDM-612], Bellm, E., co authors, 2018, Plans and Policies for LSST Alert Distribution, LDM-612, URL <https://ls.st/LDM-612>
- [DMTR-53], Bellm, E., Swinbank, J., 2018, LDM-503-03 (Alert Generation) Test Report, DMTR-53, URL <https://ls.st/DMTR-53>
- [LDM-533], Bellm, E.C., 2017, Level 1 System Software Test Specification, LDM-533, URL <https://ls.st/LDM-533>
- [DMTR-51], Bosch, J., Chiang, H.F., Gower, M., et al., 2017, LDM-503-02 (HSC Reprocessing) Test Report, DMTR-51, URL <https://ls.st/DMTR-51>
- [LDM-542], Dubois-Felsmann, G., Lim, K.T., Wu, X., et al., 2017, LSST Science Platform Design, LDM-542, URL <https://ls.st/LDM-542>
- [DMTR-52], Dubois-Felsmann, G.P., 2018, LDM-503-01 (WISE Data Loaded in PDAC) Test Report, DMTR-52, URL <https://ls.st/DMTR-52>
- Ivezic, Z., et al., 2008, ArXiv e-prints (arXiv:0805.2366), ADS Link
- Jenness, T., Economou, F., Findeisen, K., et al., 2018, In: Software and Cyberinfrastructure for Astronomy V, vol. 10707 of Proc. SPIE, 1070709, doi:10.1117/12.2312157, ADS Link
- [LSE-319], Jurić, M., Ciardi, D., Dubois-Felsmann, G., 2017, LSST Science Platform Vision Document, LSE-319, URL <https://ls.st/LSE-319>
- [LSE-163], Jurić, M., et al., 2017, LSST Data Products Definition Document, LSE-163, URL <https://ls.st/LSE-163>
- Koppelman, H., Helmi, A., Veljanoski, J., 2018, The Astrophysical Journal, 860, L11, URL <https://doi.org/10.3847%2F2041-8213%2Faac882>, doi:10.3847/2041-8213/aac882
- [LDM-148], Lim, K.T., Bosch, J., Dubois-Felsmann, G., et al., 2018, Data Management System Design, LDM-148, URL <https://ls.st/LDM-148>
- Lupton, R., Blanton, M.R., Fekete, G., et al., 2004, PASP, 116, 133 (arXiv:astro-ph/0312483), doi:10.1086/382245, ADS Link
- Ness, J.U., Parmar, A.N., Valencic, L.A., et al., 2014, Astronomische Nachrichten, 335, 210 (arXiv:1311.5751), doi:10.1002/asna.201312001, ADS Link
- [LDM-294], O'Mullane, W., Swinbank, J., Jurić, M., DMLT, 2018, Data Management Organization and Management, LDM-294, URL <https://ls.st/LDM-294>
- [LDM-230], Petrvick, D., Butler, M., Gelman, M., 2018, Concept of Operations for the LSST Data Facility Services, LDM-230, URL <https://ls.st/LDM-230>
- [LDM-534], Swinbank, J.D., 2017, Level 2 System Software Test Specification, LDM-534, URL <https://ls.st/LDM-534>
- [LDM-151], Swinbank, J.D., et al., 2017, Data Management Science Pipelines Design, LDM-151, URL <https://ls.st/LDM-151>