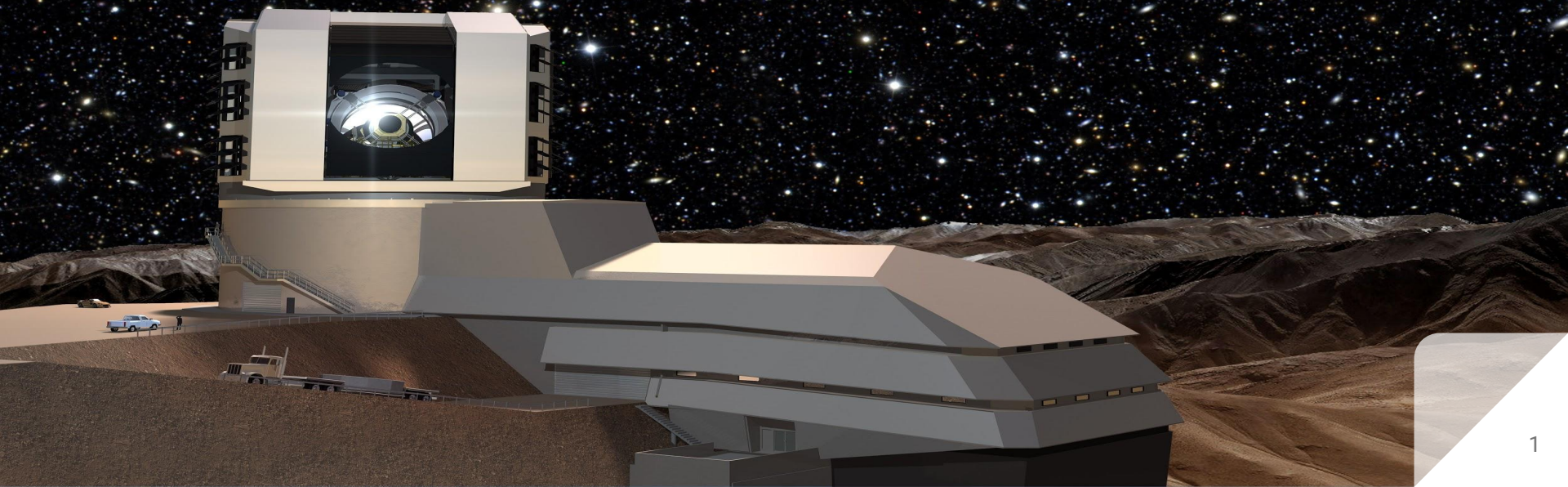


# Cosmic Peta-Scale Data Analysis at IN2P3

**Fabrice Jammes**

Scalable Data Systems Expert

LSST-France Technical Coordinator for Databases



# LSST in short

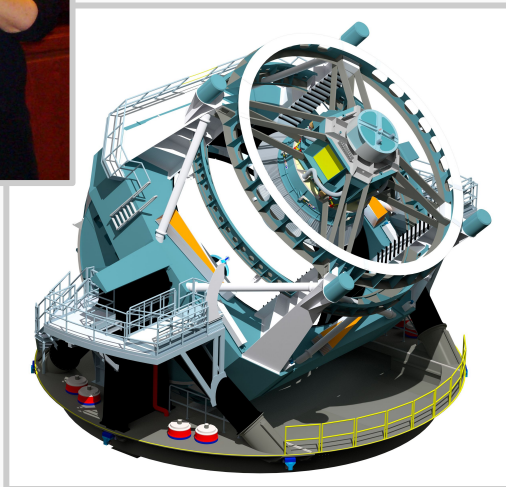
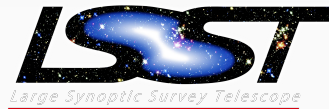
## Large Synoptic Survey Telescope

Large aperture, wide-field, ground-based survey telescope

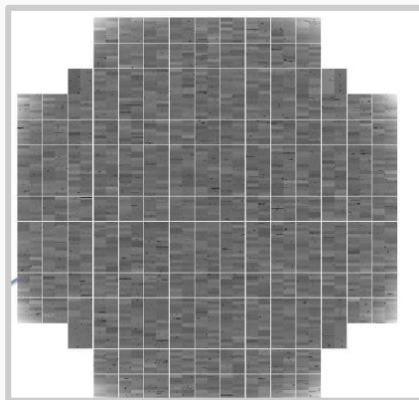
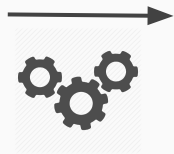
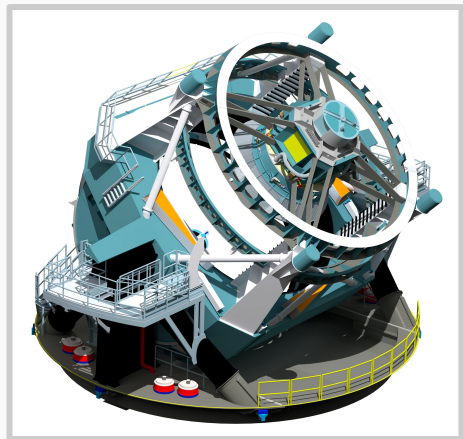
**The largest imager ever built for astronomy**

## Characteristics

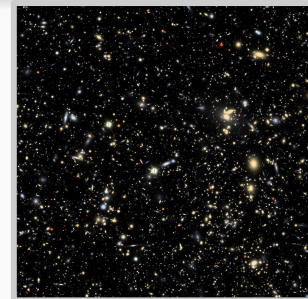
- ★ All visible sky in 6 bands
- ★ ~20000□
- ★ 15 seconds exposures, 1 visit/3 days
- ★ During 10 years!
- ★ **60 PB of raw data**



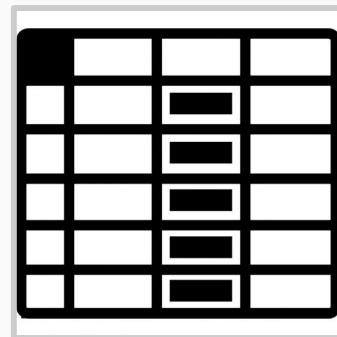
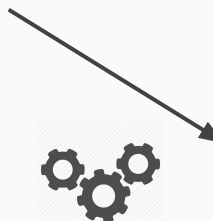
# 80+ PB of astronomical catalog



Raw data



Processed image



**Catalog** (stars, galaxies, objects, sources, transients, exposures, etc.)

LSST will build a catalog of 20 billion galaxies and 17 billion stars and their associated physical properties

# Who we are

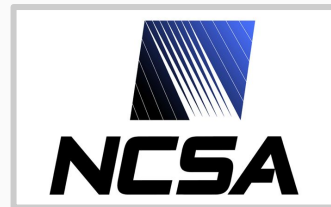
## Database and Data access team

- ★ 10 engineers at SLAC + 1 LPC-IN2P3 (~10 FTE)
  - *Software development*



## Operations teams

- ★ 5 engineers at CC-IN2P3
  - *Large Scale development platform*
  - *System administration, Monitoring*
- ★ 5 engineers at NCSA
  - *Prototype Data Access Center*



## Research and development

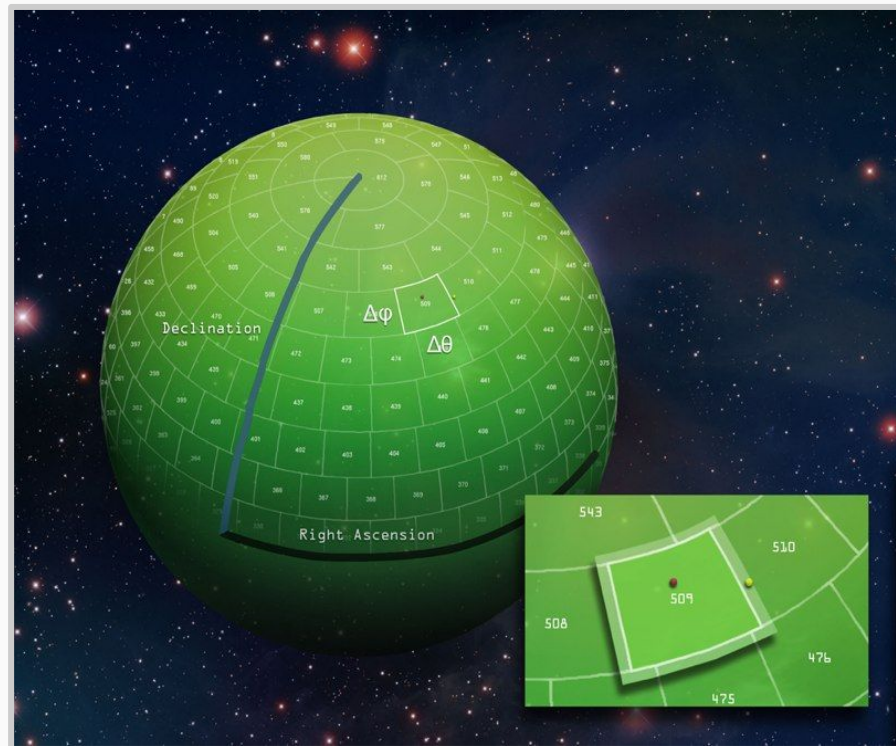
- ★ 5 engineers at LPC-IN2P3/LIMOS (1.5 FTE)
  - *Data-loading*
  - *Cloud-computing, containers, CEPH*
  - *Large Scale Continuous integration*




# What we do

## Data Access and Database

- ★ Data and metadata
- ★ Images and databases
- ★ Persisting and querying
- ★ For pipelines and users
- ★ Real time Alert Production and annual Data Release Production
- ★ For Archive Center and all Data Access Centers
- ★ For USA, France and international partners
- ★ Persisted and virtual data
- ★ **Estimating, designing, prototyping, building, and productizing**



# Database schema



**LSST Database Schema Browser** *alpha*

Schema versions available for browsing: [baseline](#) | [DC3a](#) | [PT1\\_1](#) | [PT1\\_2](#) | [1mSim](#) | [S12\\_sdss](#) | [S12\\_lsstsim](#) (underlined showed)

User defined functions documentation: [version 0.1](#), [version 0.2](#), [version 0.3](#) (default on lsst10)

Table List	Details for table <i>Object</i>																																																																																																																		
AAA_Version_3_2_4 ApertureBins CcdVisit CcdVisitMetadata DiaForcedSource DiaObject DiaObject_To_Object_Match DiaSource ForcedSource LeapSeconds Object Object_APMean Object_Extra Object_NonPeriodic Object_Periodic prv_Amp prv_Ccd prv_cnf_Amp prv_cnf_Ccd prv_cnf_Filter prv_cnf_Fpa prv_cnf_InputDataSet prv_cnf_Node prv_cnf_Raft prv_cnf_Run prv_cnf_Task prv_cnf_Task2TaskExecution prv_cnf_Task2TaskGraph prv_cnf_TaskExecution prv_cnf_TaskGraph prv_cnf_TaskGraph2Run prv_Filter prv_Fpa prv_InputDataSet prv_Node prv_ProcHistory prv_Raft prv_Run prv_Snapshot prv_Task prv_Task2TaskExecution	<p>The Object table contains descriptions of the multi-epoch static astronomical objects, in particular their astrophysical properties as derived from analysis of the Sources that are associated with them. Note that fast moving objects are kept in the MovingObject tables. Note that less-frequently used columns are stored in a separate table called Object_Extra.</p> <table border="1"><thead><tr><th>name</th><th>type</th><th>not null</th><th>unit</th><th>ucd</th><th>description</th></tr></thead><tbody><tr><td>objectId</td><td>BIGINT</td><td>y</td><td></td><td>meta.id;src</td><td>Unique id.</td></tr><tr><td>parentObjectId</td><td>BIGINT</td><td></td><td></td><td></td><td>Id of the parent object this object has been deblended from, if any.</td></tr><tr><td>procHistoryId</td><td>BIGINT</td><td>y</td><td></td><td></td><td>Pointer to ProcessingHistory table.</td></tr><tr><td>psRa</td><td>DOUBLE</td><td></td><td>deg</td><td>pos.eq.ra</td><td>RA-coordinate of the center of the object for the Point Source model at time 'psEpoch'.</td></tr><tr><td>psRaSigma</td><td>FLOAT</td><td></td><td>deg</td><td>stat.error;pos.eq.ra</td><td>Uncertainty of psRa.</td></tr><tr><td>psDecl</td><td>DOUBLE</td><td></td><td>deg</td><td>pos.eq.dec</td><td>Decl-coordinate of the center of the object for the Point Source model at time 'psEpoch'.</td></tr><tr><td>psDeclSigma</td><td>FLOAT</td><td></td><td>deg</td><td>stat.error;pos.eq.dec</td><td>Uncertainty of psDecl.</td></tr><tr><td>psMuRa</td><td>FLOAT</td><td></td><td>mas/yr</td><td>pos.pm</td><td>Proper motion (ra) for the Point Source model.</td></tr><tr><td>psMuRaSigma</td><td>FLOAT</td><td></td><td>mas/yr</td><td>stat.error;pos.pm</td><td>Uncertainty of psMuRa.</td></tr><tr><td>psMuDecl</td><td>FLOAT</td><td></td><td>mas/yr</td><td>pos.pm</td><td>Proper motion (dec) for the Point Source model.</td></tr><tr><td>psMuDeclSigma</td><td>FLOAT</td><td></td><td>mas/yr</td><td>stat.error;pos.pm</td><td>Uncertainty of psMuDecl.</td></tr><tr><td>psParallax</td><td>FLOAT</td><td></td><td>mas</td><td>pos.parallax</td><td>Stellar parallax. for the Point Source model.</td></tr><tr><td>psParallaxSigma</td><td>FLOAT</td><td></td><td>mas</td><td>stat.error;pos.parallax</td><td>Uncertainty of psParallax.</td></tr><tr><td>uPsFlux</td><td>FLOAT</td><td></td><td>nmgy</td><td>phot.count</td><td>Calibrated flux for Point Source model for u filter.</td></tr><tr><td>uPsFluxSigma</td><td>FLOAT</td><td></td><td>nmgy</td><td>stat.error;phot.count</td><td>Uncertainty of uPsFlux.</td></tr><tr><td>gPsFlux</td><td>FLOAT</td><td></td><td>nmgy</td><td>phot.count</td><td>Calibrated flux for Point Source model for g filter.</td></tr><tr><td>gPsFluxSigma</td><td>FLOAT</td><td></td><td>nmgy</td><td>stat.error;phot.count</td><td>Uncertainty of gPsFlux.</td></tr><tr><td>rPsFlux</td><td>FLOAT</td><td></td><td>nmgy</td><td>phot.count</td><td>Calibrated flux for Point Source model for r filter.</td></tr></tbody></table>	name	type	not null	unit	ucd	description	objectId	BIGINT	y		meta.id;src	Unique id.	parentObjectId	BIGINT				Id of the parent object this object has been deblended from, if any.	procHistoryId	BIGINT	y			Pointer to ProcessingHistory table.	psRa	DOUBLE		deg	pos.eq.ra	RA-coordinate of the center of the object for the Point Source model at time 'psEpoch'.	psRaSigma	FLOAT		deg	stat.error;pos.eq.ra	Uncertainty of psRa.	psDecl	DOUBLE		deg	pos.eq.dec	Decl-coordinate of the center of the object for the Point Source model at time 'psEpoch'.	psDeclSigma	FLOAT		deg	stat.error;pos.eq.dec	Uncertainty of psDecl.	psMuRa	FLOAT		mas/yr	pos.pm	Proper motion (ra) for the Point Source model.	psMuRaSigma	FLOAT		mas/yr	stat.error;pos.pm	Uncertainty of psMuRa.	psMuDecl	FLOAT		mas/yr	pos.pm	Proper motion (dec) for the Point Source model.	psMuDeclSigma	FLOAT		mas/yr	stat.error;pos.pm	Uncertainty of psMuDecl.	psParallax	FLOAT		mas	pos.parallax	Stellar parallax. for the Point Source model.	psParallaxSigma	FLOAT		mas	stat.error;pos.parallax	Uncertainty of psParallax.	uPsFlux	FLOAT		nmgy	phot.count	Calibrated flux for Point Source model for u filter.	uPsFluxSigma	FLOAT		nmgy	stat.error;phot.count	Uncertainty of uPsFlux.	gPsFlux	FLOAT		nmgy	phot.count	Calibrated flux for Point Source model for g filter.	gPsFluxSigma	FLOAT		nmgy	stat.error;phot.count	Uncertainty of gPsFlux.	rPsFlux	FLOAT		nmgy	phot.count	Calibrated flux for Point Source model for r filter.
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<http://ls.st/s91>

# Data

## Images

Persisted: **~38 PB**

Temporary: **~½ EB**



- ★ **~3 million “visits”**
- ★ **~47 billion “objects”**
- ★ **~9 trillion “detections”**

- ★ **Largest table: ~5 PB**
- ★ **Tallest table: ~50 trillion rows**
- ★ **Total (all data releases, compressed):  
~83 PB**

Ad-hoc user-generated data  
Rich provenance

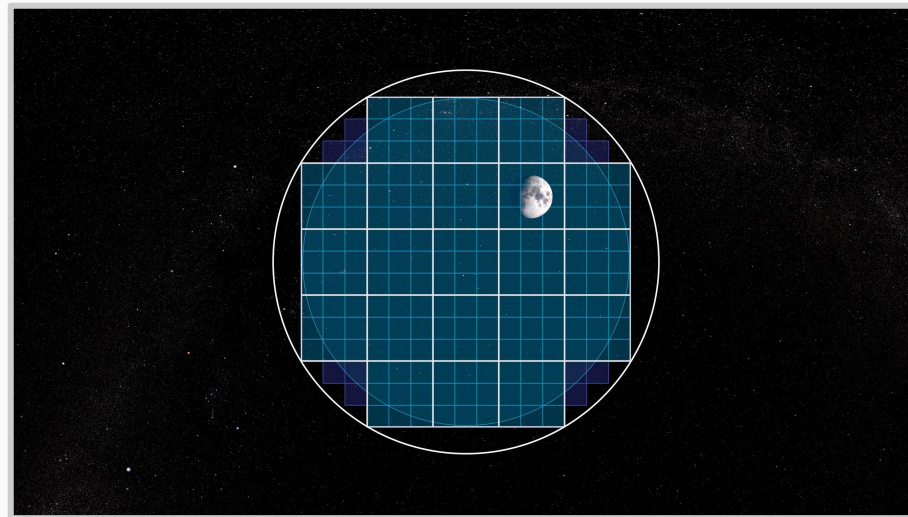
# Production data

## Database

- ★ Real-time Alert DB.  
No-overwrite updates between Data Releases  
Real-time replica of Alert Prod DB for analytics.  
No long-running analytics here
- ★ **Immutable Database (+user workspaces)**  
Released annually. Immutable  
2 most recent releases on disk

## Images

- ★ raw: 2 most recent visits for each filter
- ★ coadds and templates: for 2 most recent releases
- ★ raw calibration: most recent 30 days
- ★ science calibrated: most recent 30 days
- ★ observatory telemetry: all





# Analytics

**Aiming to enable majority of analytics via database**

**Aiming to enable rapid turnaround on exploratory queries**

## **In a region**

Get an object or data for small area - <10 sec

## **Across entire sky**

Scan through 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

## **Time series analysis**

Source, ForcedSource scans - ~12 hours

## **Cross match & anti-cross match with external catalogs**

~1 hour

Sizing the system for  
~100 interactive +  
~50 complex  
simultaneous DB queries.

Same for images

# APIs

## Metadata

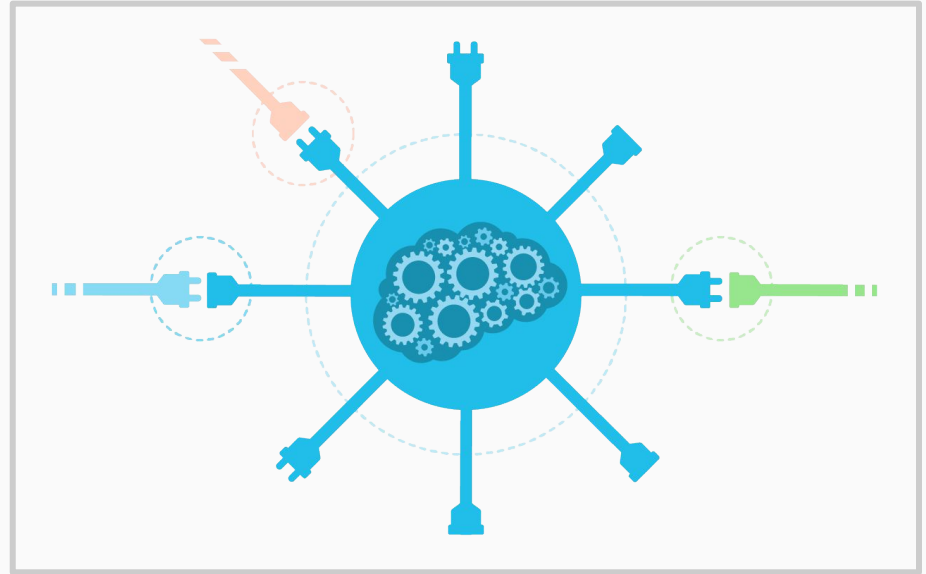
- ★ RESTful WebServ

## Images

- ★ RESTful ImageServ

## Databases

- ★ RESTful DbServ
- ★ SQL92 +/-, **MySQL-like DBMS**
- ★ Next-to-database python-based



# Additions (SQL92 +)

## Spatial constraints

- ★ `qserv_areaspec_box(lonMin, latMin, lonMax, latMax)`
- ★ `qserv_areaspec_circle(lon, lat, radius)`
- ★ `qserv_areaspec_ellipse(semiMajorAxisAngle, semiMinorAxisAngle, posAngle)`
- ★ `qserv_areaspec_poly(v1Lon, v1Lat, v2Lon, v2Lat, ...)`

```
SELECT objectId  
FROM Object  
WHERE qserv_areaspec_box(2,89,3,90)
```

# Current restrictions (SQL92 +)

## Only a SQL subset is supported

For example:

- ★ Spatial constraints (must use User Defined Functions, must appear at the beginning of WHERE, only one spatial constraint per query, arguments must be simple literals, OR not allowed after area qserv\_areaspec\_\*)
- ★ Expressions/functions in ORDER BY clauses are not allowed
- ★ Sub-queries are NOT supported
- ★ Commands that modify tables are disallowed
- ★ MySQL-specific syntax and variables not supported
- ★ Repeated column names through \* not supported

# Selected Common Query Types

SELECT sth FROM Object

massively parallel

SELECT sth FROM Object WHERE qserv\_areaspec\_box(...)

selection inside chunks that cover requested area, in parallel

SELECT sth FROM Object JOIN SOURCE USING (objectId)

massively parallel without any cross-node communication

SELECT sth FROM Object WHERE objectId = <id>

quick selection inside one chunk

Common queries – see <http://ls.st/ed4>

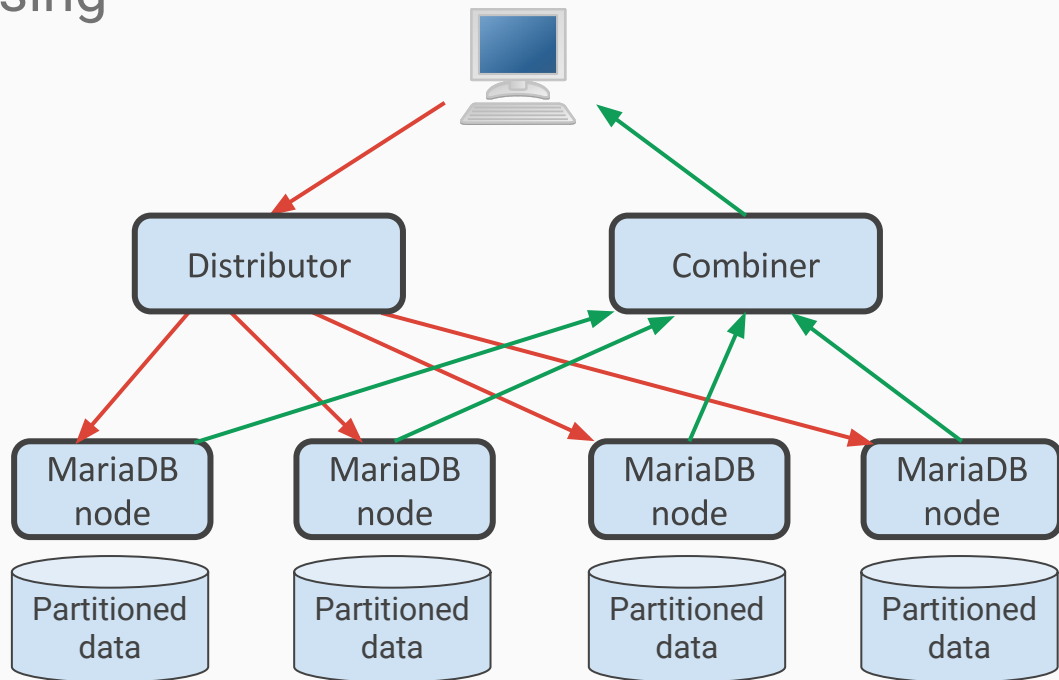
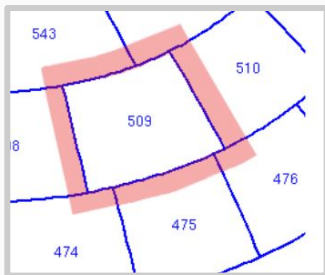
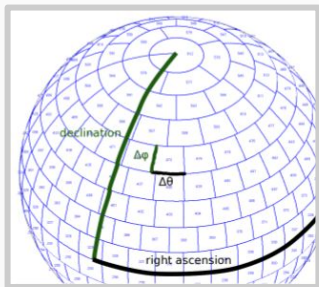
# Qserv under the hood

# Implementation Strategy

- ★ 100% Open source
- ★ Keep it flexible
- ★ Hide complexity
- ★ Reuse existing components:
  - MariaDB, MySQL Proxy, XRootD, Google protobuf, Flask
- ★ Plus custom glue
  - C++, a bit of python, some ANTLR
  - Lots of multithreading, callbacks, mutexes and sockets
- ★ And custom UDFs

# Qserv design

- ★ Relational database, spatially-sharded with overlaps
- ★ Map/reduce-like processing





# Key Features

## Scalable spherical geometry

- ★ 0/360 RA wrap around, pole distortion, convex polygons,
- ★ accurate distance computation, functions for distance (angle),
- ★ point-in-spherical-region tests (circle, ellipse, box, convex polygon)
- ★ Custom (HTM-based) UDFs <https://github.com/wangd/scisql>

## Optimized spatial joins for neighbor queries, cross-match

- ★ Spherical partitioning with overlap
- ★ Director table, secondary index
- ★ Two-level, 2nd level materialized on-the-fly

## Shared scans

- ★ Continuous, sequential scans through data, including L3 distributed tables
- ★ (Non-interactive) queries attached to appropriate running scan

## All internal complexity transparent to end-users

# Tests and demonstrations

Target for production

*~500 nodes clusters in 2 international data-centers*

Running now

**Development platform (CC-IN2P3)**

*400 cores, 800 GB memory*

*500 TB storage,*

★ *~35 TB data set on 2\*25 nodes*

★ *Computing KPI on ~70TB dataset*

**Prototype Data Access Center (NCSA)**

*500 cores, 4 TB memory*

*700 TB storage,*

*SDSS Stripe 82 and*

*Wide-Field Infrared Survey Explorer (WISE) data loaded*



# Scale testing to date @IN2P3

## S15 large scale tests

Data: replicated SDSS Stripe 82

~10% DR1 (~2B Object, ~35B Source, ~172B F. Source)

Hardware: 25 nodes @ IN2P3, 2 x 1.8GHz 4 core, 16G RAM

Simul. 50 low-volume queries + 5 high-volume queries:

<1s for low-volume queries

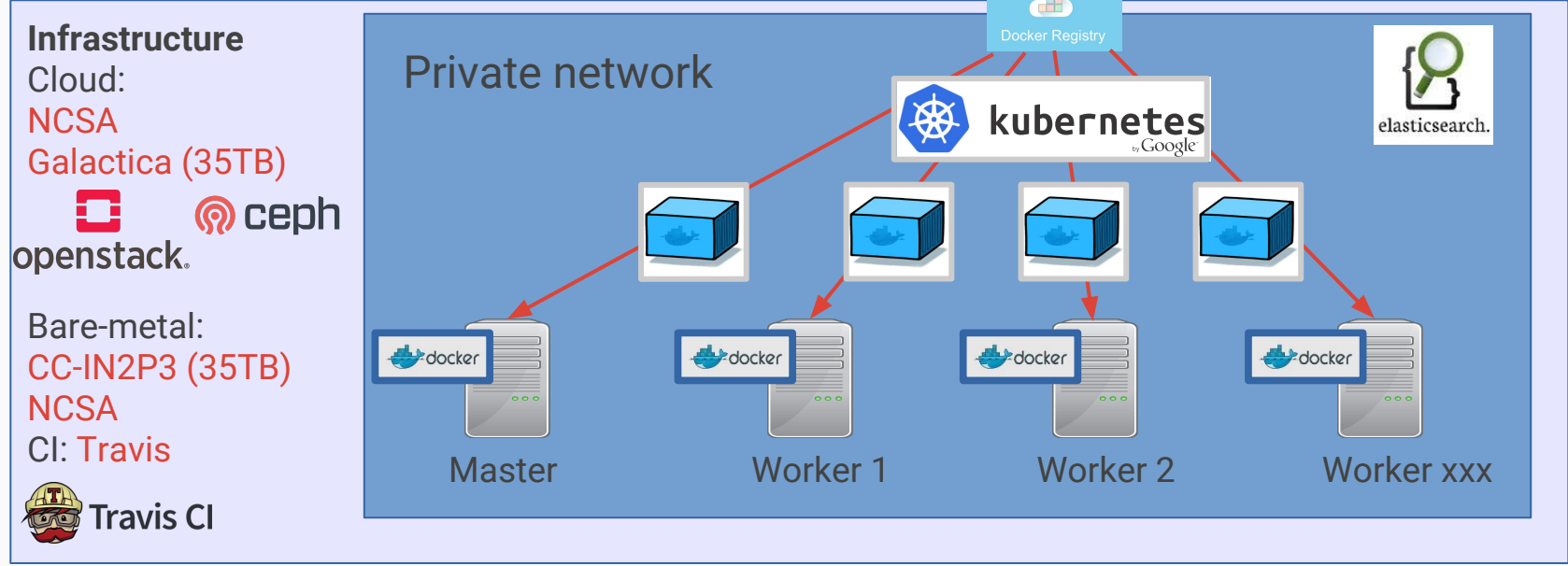
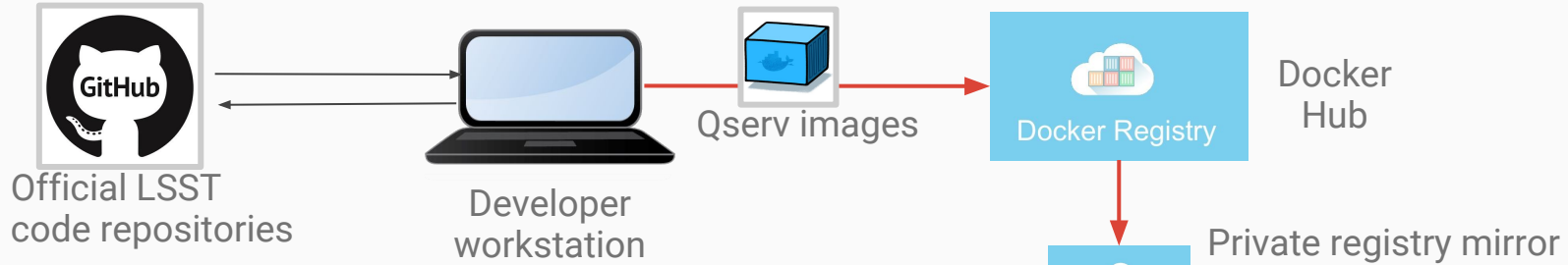
~15m for high-volume Object scans

~1h for Source scans

=> Promising performances

See [S15 Large Scale Tests](#)

# Automated Qserv deployment



# Summary

- ★ Big Data with Complex Analytics
- ★ Spatially-sharded, map/reduce-like RDBMS
- ★ Open source + custom glue
- ★ Optimized for astronomical data sets at scale
- ★ Have working prototype
- ★ Turning it into a production system
- ★ Want to learn more?
  - <http://ls.st/4gh> (Database Design doc)
  - <http://ls.st/6ym> (User Manual)
- ★ Are you an adventurous super early adopter? You can try it now
  - <http://ls.st/89y> (Qserv Documentation)

# Thanks!

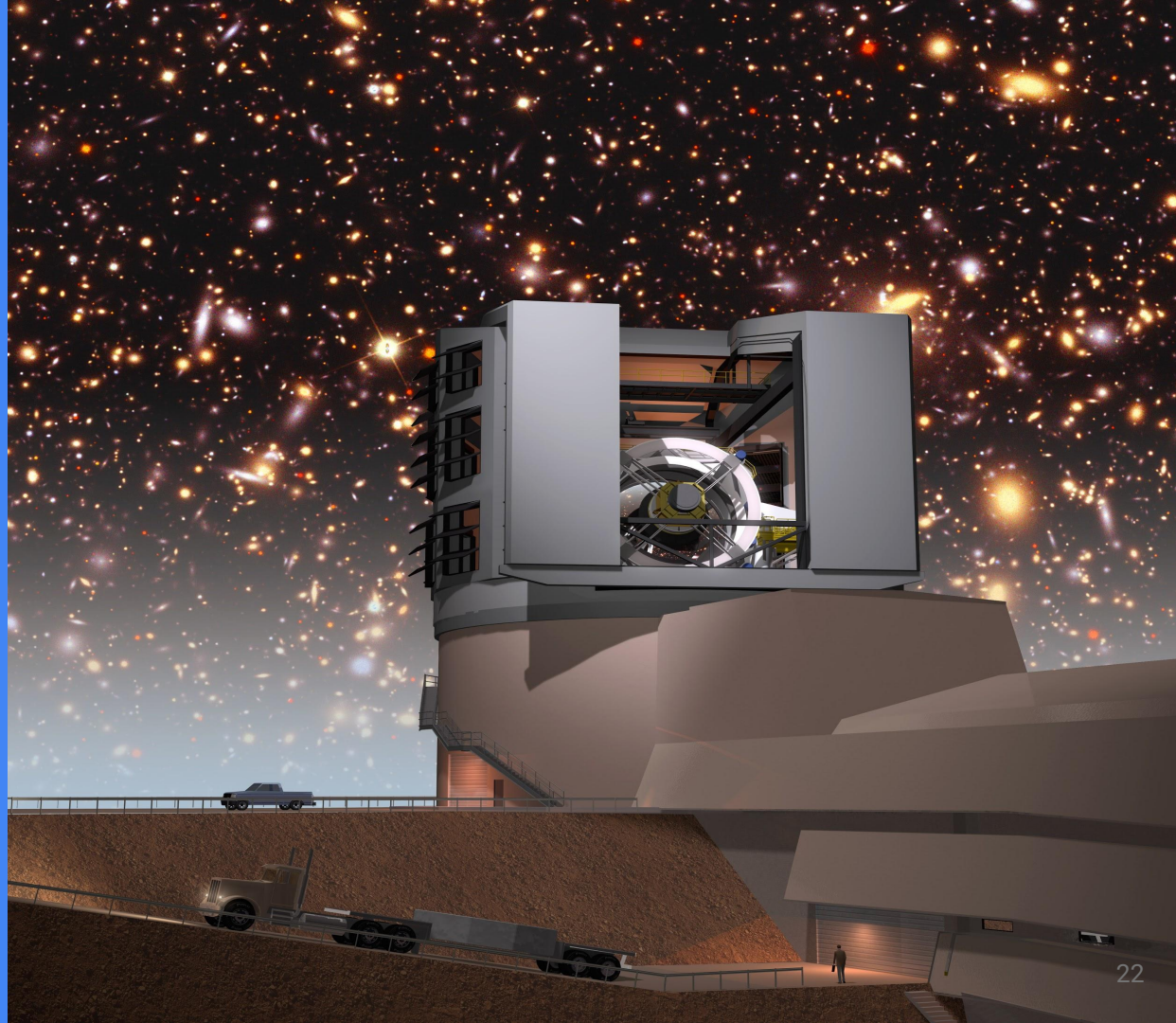
Contact:

Fabrice JAMMES

LPC

Clermont-Ferrand

[fabrice.jammes@in2p3.fr](mailto:fabrice.jammes@in2p3.fr)



# Implementation Details

