Large Synoptic Survey Telescope

LSST

Legacy Survey of Space and Time

Dr Steve Barrett CAS 9 Feb 2022

Contents

What's Out There?

So don't **all** telescopes try to answer that question? No, not really.

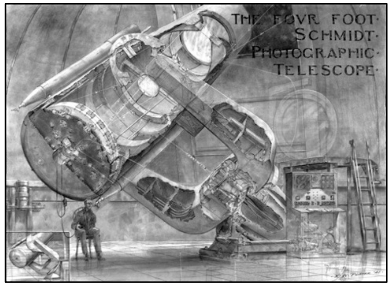
Most research telescopes look in detail at **known** objects – objects that have **already** been observed and catalogued.

Sky Surveys

Surveys of everything in the sky (down to a certain limiting brightness) have been carried out at various times in the past century:

- Palomar Observatory Sky Survey (1949 – 1958)

2000 photographic plates taken on the 48" Schmidt camera at Mount Palomar



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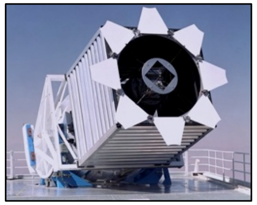
- Palomar Observatory Sky Survey (1949 – 1958)
- Palomar Observatory Sky Survey II (1985 – 1999)

- Sloan Digital Sky Survey (2000 – 2014)

Plates replaced by CCD cameras

1 million images taken on two telescopes with 1.8 m mirrors



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Sky Surveys

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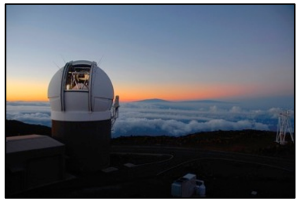
- Pan-STARRS (2010 – 2014)

Panoramic **S**urvey **T**elescope **a**nd **R**apid **R**esponse **S**ystem



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Sky Surveys

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- Pan-STARRS (2010 – 2014)

- Large Synoptic Survey Telescope (2022 – 2032)

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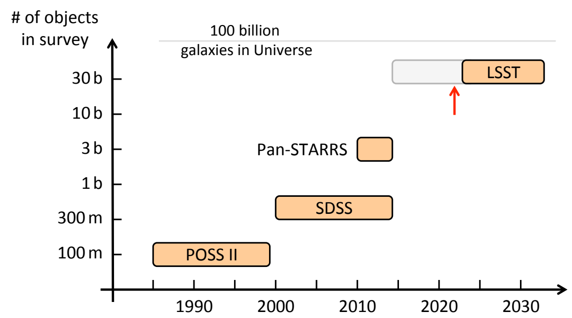
Why Another Sky Survey?



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Wide – Fast – Deep

Why can't an existing telescope be used?

To be able to survey the sky a telescope/camera must have three basic characteristics:

- **Wide** – it must have a wide field of view
- **Fast** – the optics must be fast to keep exposures short
- **Deep** – it must be able to detect faint objects

A little bit of horse-trading between these characteristics might be possible, but for a telescope to be an effective instrument to survey the sky it must excel in each of these categories.

Aside – What Does 'Fast' Mean?

What does 'fast' mean in this context?

The word is often used when describing camera lenses or telescope optics and is quantified by the ratio of the focal length to the diameter of the lens or mirror (the 'f-number')

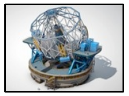
$$f = \frac{\text{Focal Length (FL)}}{\text{Diameter (D)}}$$

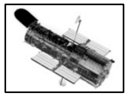
A lens or mirror with a low f-number has a larger diameter (relative to its focal length) and so produces a brighter image. This means that photographic exposures can be shorter. The resultant faster shutter speeds led to such optics being labelled 'fast'.

Aside – What Does 'Fast' Mean?

Faster ↑ … ↓ Slower

Exposure	*f*-number	
1 min	f/2	<
2	f/2.8	<
4	f/4	<
8	f/5.6	
15	f/8	
30	f/11	
60	f/16	< **EELT**
120	f/22	< **HST**





HST = Hubble Space Telescope D = 2.4 m FL = 57 m

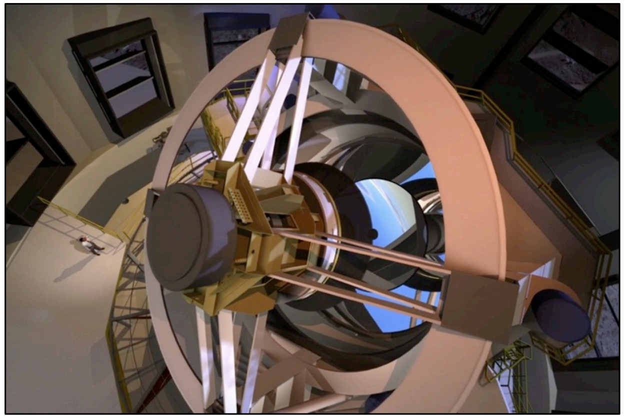
EELT = European Extremely Large Telescope D = 40 m FL = 750 m

Why a New Telescope?

	Wide	Fast	Deep
DSLR + wide-angle lens	✓	?	✗
DSLR + telephoto lens	✗	?	✓
Hubble Space Telescope	✗	✗	✓
Extremely Large Telescope	✗	✗	✓
Large Synoptic Survey Telescope	✓	✓	✓

Hence the mantra of the LSST is "Wide – Fast – Deep"

Why a New Telescope?



Why a Survey Telescope?

One of the key aspects of the LSST project is that the whole sky will be imaged **every three nights**.

Hence every patch of sky will be imaged many times during the 10-year project and so changes (in position, brightness or colour) of all the objects imaged will be recorded and catalogued.

This idea of making a survey that is comprehensive in terms of both the **number** of objects catalogued and the **time scale** over which the survey runs makes the LSST project unique.

Why a Survey Telescope?

The LSST project will survey the sky and provide scientists with a wealth of data on:

- Objects within the Solar System
- Stars in the Milky Way
- Galaxies throughout the Universe

The project will involve the development of novel telescope optics, the largest digital camera yet constructed, and push data processing capabilities to the limit.

The LSST will generate the largest catalogue of astronomical objects ever compiled and the data will underpin many strands of scientific research to improve our understanding of the Universe.

LSST Science

What are the principal scientific aims of the LSST project?

On a (relatively) local scale …

Solar System

- Take an inventory of the Solar System
- Clarify the formation history of our Solar System
- Understand how other solar systems may form

Milky Way

- Determine the structure and evolution of the Milky Way
- Find the properties of all the stars in the Sun's neighbourhood

Legacy Survey of Space and Time

LSST Science

On a galactic scale …

Galaxies

- Catalogue 20 billion galaxies
- Understand galaxy collisions and star formation processes

Dark Matter

- Use gravitational lensing to find and study dark matter
- Determine how it is distributed throughout the Universe

Dark Energy

- Understand what is ripping the Universe apart by studying …
- Thousands of supernova and billions of galaxies

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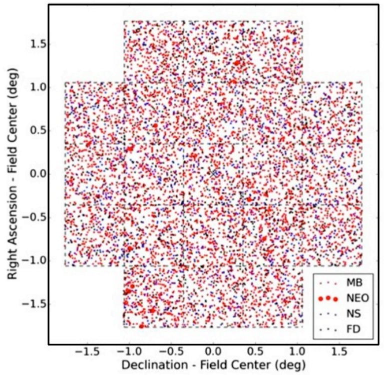
LSST Science – Solar System

In a **single** exposure LSST could detect up to **5000** moving objects!

Over the 10-year survey it is expected to find many **millions** of asteroids and trans-Neptunian objects, plus over 100,000 NEOs (Near-Earth Objects).

About 10% of these are the biggest ones that we already know about. It's the smaller ones that we need to keep an eye on.



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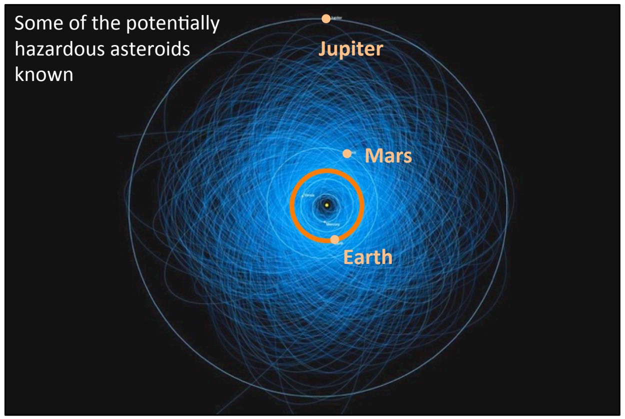
LSST Science – Solar System



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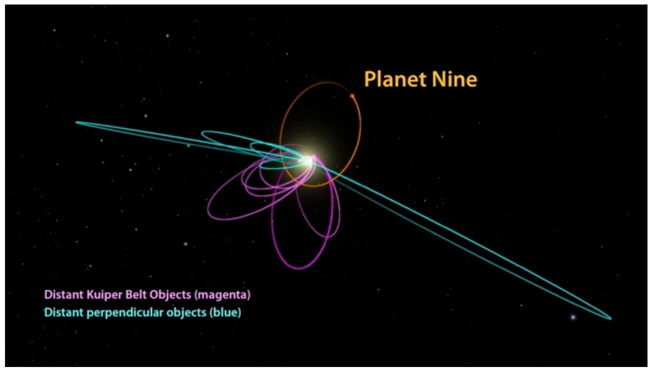
LSST Science – Solar System



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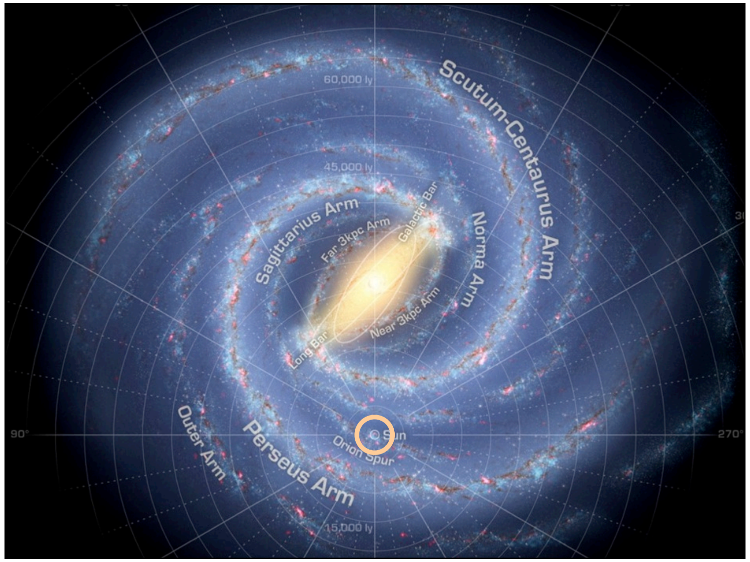
LSST Science – Milky Way

Observing a galaxy from the *inside* is not easy. For example, even the question of whether the Milky Way has 4 spiral arms or 2 has only been settled relatively recently (it has 4).

Herschel's structure of the Milky Way (1785)



LSST Science – Milky Way

Observing a galaxy from the *inside* is not easy. For example, even the question of whether the Milky Way has 4 spiral arms or 2 has only been settled relatively recently (it has 4).

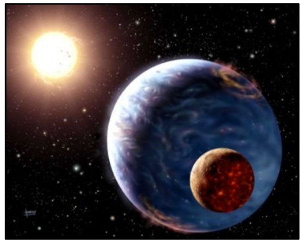
A **single** exposure of the survey area (taken over three nights) will map a volume more than 10 times larger than all previous surveys.

Over the 10-year survey it will map a volume 1000 times larger.

LSST Science – Milky Way

Another spin-off (rather than a primary aim) of the survey of stars is the identification of potentially thousands of new exoplanets.

Although not what the LSST was designed for, the fact that it will monitor the brightness of many billions of stars as a function of time means that it will inevitably find some planets that happen to transit their parent stars.



If the star is in one of the Magellanic Clouds, then this would be the first discovery of a planet in another galaxy.

LSST Science – Galaxies

Interactions between galaxies are more common than we first thought.

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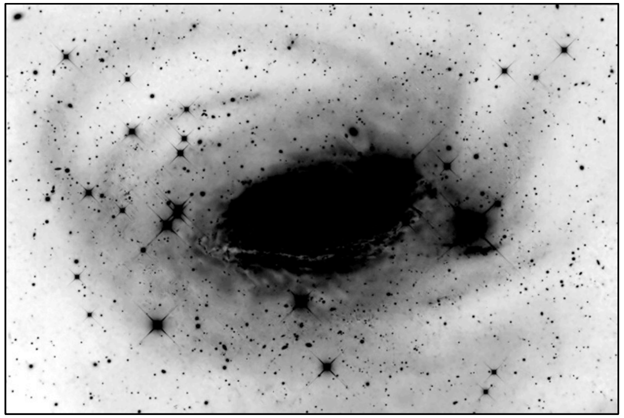
LSST Science – Galaxies



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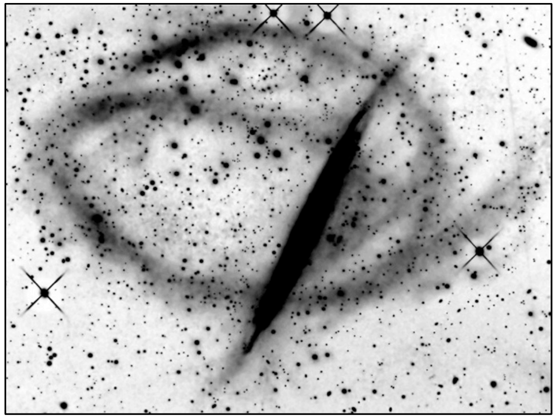
LSST Science – Galaxies



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LSST Science – Dark Universe

It seems that only about 5% of the Universe is made up of 'ordinary' matter with which we are so familiar.

27% is mysterious **dark matter**.

We know it's out there. We don't know *what* it is or exactly *where* it is.

68% is the even more mysterious **dark energy**.

It is thought to be why the expansion of the Universe is accelerating. Eventually, it will rip the Universe apart. We don't know *what* it is.

If this so-called 'dark sector' accounts for 95% of the Universe, we really ought to understand more about it.

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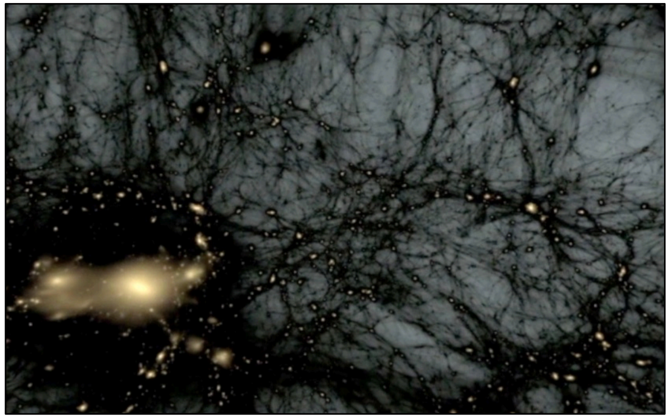
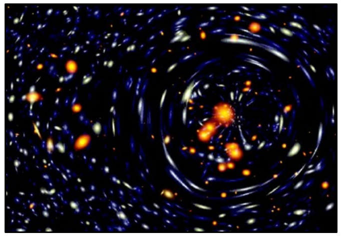
LSST Science – Dark Matter

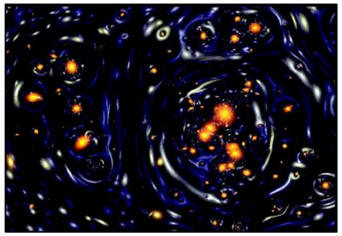


LSST Science – Dark Matter

LSST Science – Dark Energy

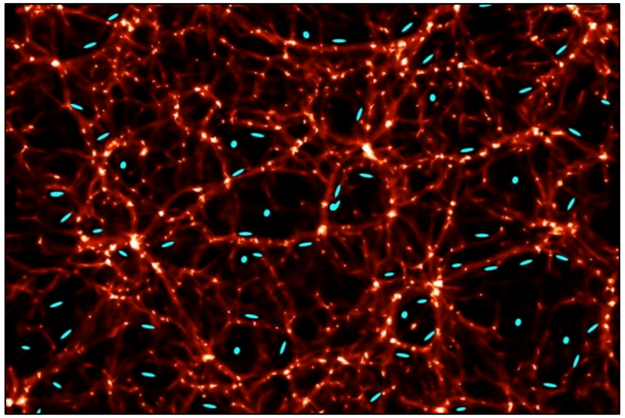


Simulation of foreground galaxies (orange) lensing background galaxies (blue).



Same again, but this time with dark matter added to the foreground galaxies.

LSST Science – Dark Energy

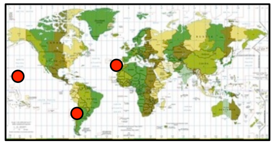


Delivering the Science

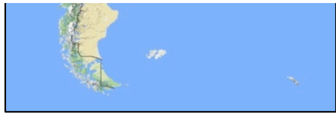
How can the science be delivered? It will need …

- A unique optical design for the telescope
- The world's largest CCD camera
- An outstanding observatory site

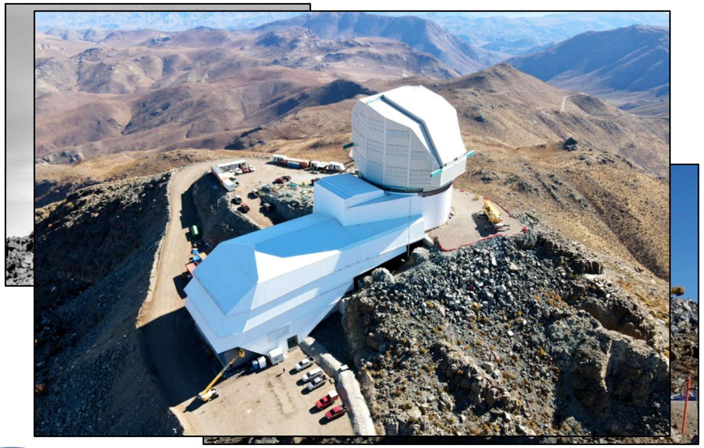
The best observatory sites in the world are volcanic islands (Hawaii, La Palma and Tenerife) and the Atacama desert in Chile. The latter was chosen as the site for LSST.



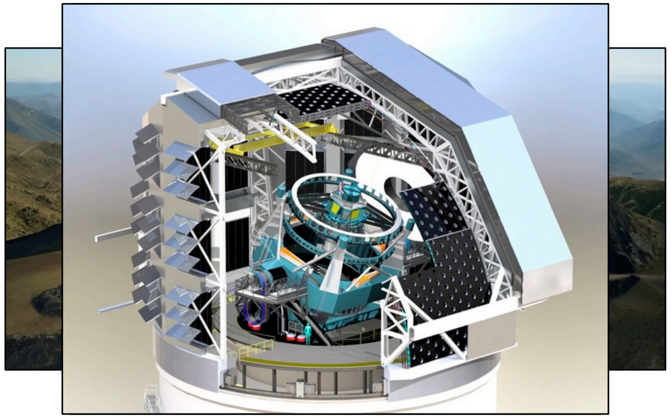
Cerro Pachón



The Site



The Observatory



Optical Design

Creating an aberration-free field of view over such a wide field (> 3°) required a novel **three**-mirror design.

Primary mirror diameter	=	8.4 m
Effective focal length	=	10.3 m
Telescope focal ratio	=	f / 1.2

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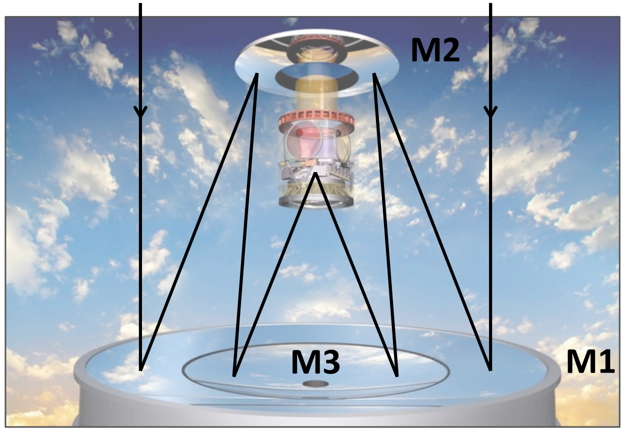
Optical Design



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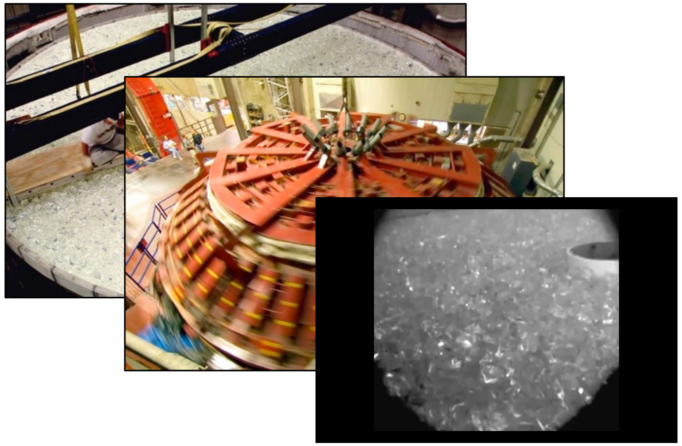
Primary (and Tertiary) Mirror



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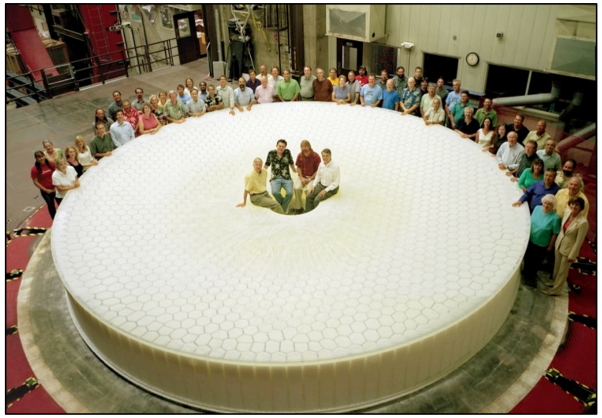
Primary (and Tertiary) Mirror



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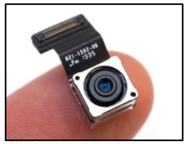
Camera CCD

Camera module from a mobile phone



... and at the same scale

16 Mpix
CCD detector in
the Hubble
Space Telescope

40 mm

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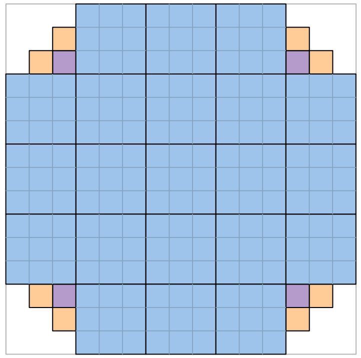
Camera CCD

189 CCD image sensors

8 CCD guide sensors

4 CCD wavefront sensors



Array is 0.6 x 0.6 m

Image is 3 Gpixels

Readout in 2 sec

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Camera CCD

This simulated image is about a Mpixel, or 0.03% of the full-sized image captured by the camera, and gives an idea of what can be expected to be seen in a single 15 sec exposure.

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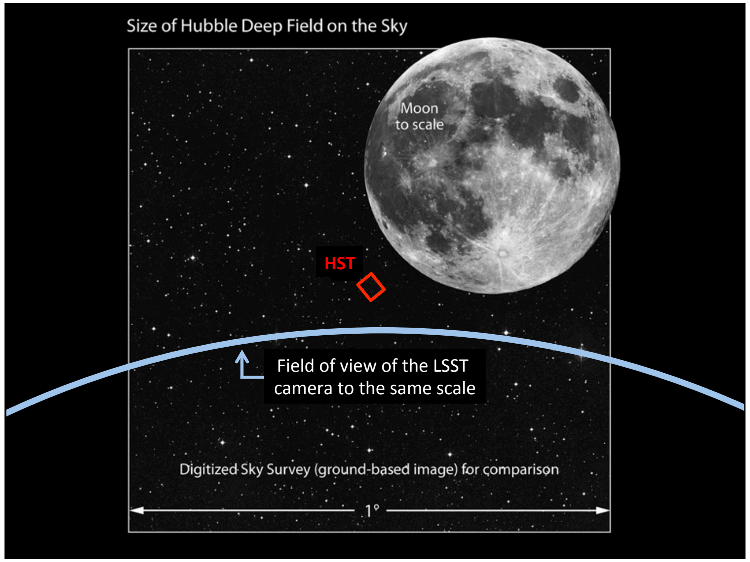
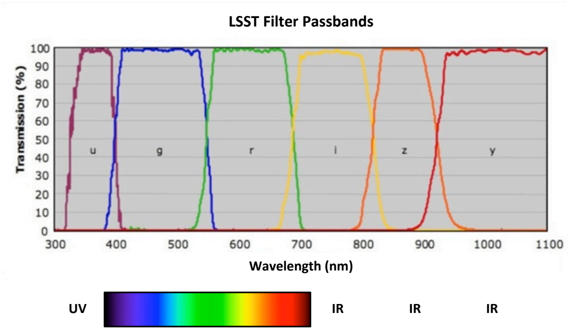


Camera Filters



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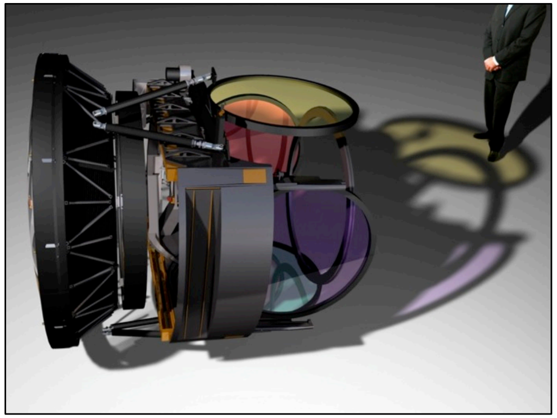
Camera Filters



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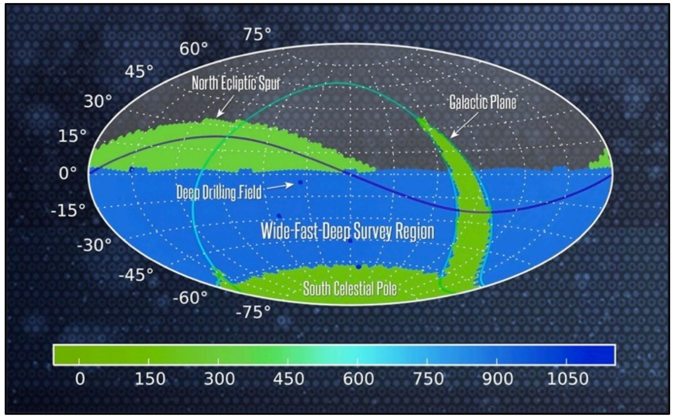
LSST Operation



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LSST Data

The LSST will generate shed-loads of data.

A reminder of disk storage options for personal computers…

Floppy disks can store about a MB
(1 MB = 1 million bytes)

(barely enough for
one digital photo)

DVDs can store a few GB
(1 GB = 1000 MB)

(enough for 1000s
of digital photos)

For personal use DVDs can be used to store thousands of images from our digital cameras, but how quickly would the LSST fill them up?

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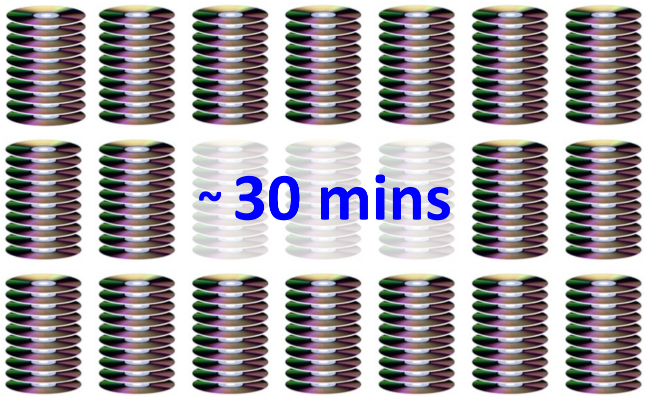
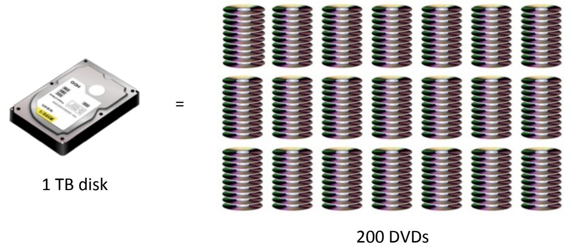
LSST Data



1 TB = 1000 GB



LSST Data

One night of observations will need **20 TB** of disk space.

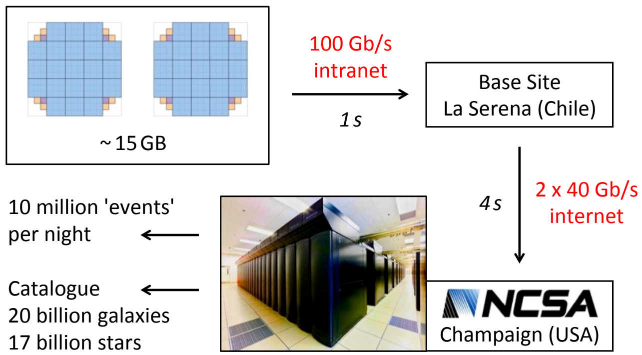
Multiply that by the number of nights in a year (say 300+) and then again by the 10 years that the survey project will run.

Add in other technical data, and the total disk space needed is about **500,000 TB**.

That's a lot of disks.

Data Transmission

Every 30 seconds ...

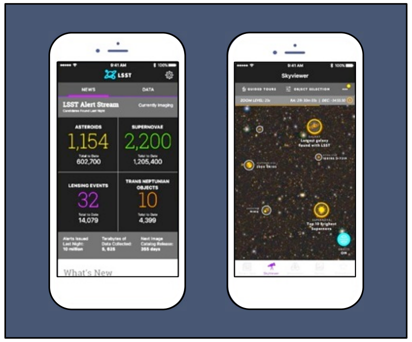


There's An App For That

What is the LSST doing right now?

What was found last night?

What are the totals to date?



What does the LSST sky look like?

Where are the objects of interest?

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Addendum

Just to confuse everybody, in 2019 the LSST observatory was renamed the

Vera C Rubin Observatory

in recognition of the contributions that Vera Rubin made in measuring dark matter in the 1960s.

VERA C. RUBIN OBSERVATORY

The telescope itself has been renamed the

Simonyi Survey Telescope

to acknowledge private donors.

The survey described in this talk has been renamed the

Legacy Survey of Space and Time (LSST) !

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Summary

Sky Surveys	• Why survey the sky? • Existing surveys
LSST	• Why another survey? • Why another telescope?
Science	• What the LSST will tell us • The big questions
Technology	• Novel telescope optics • Novel CCD camera
Operation	• Survey strategy • Handling the data

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