

Fiat Lux III

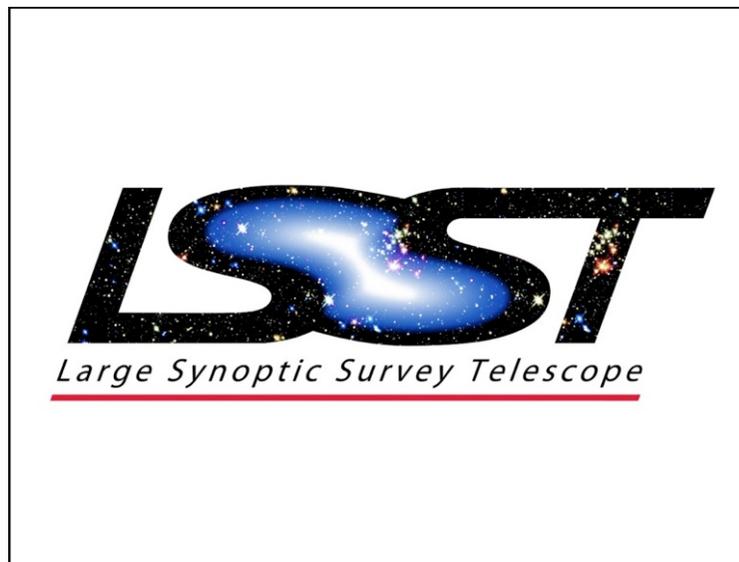


Contents

	Nature of Light Colours of Light
Lenses and Mirrors Telescope Optics	
	Large Synoptic Survey Telescope (LSST)

 UNIVERSITY OF LIVERPOOL

2



Fiat Lux III

Contents

Sky Surveys	<ul style="list-style-type: none">• Why survey the sky?• Existing surveys
LSST	<ul style="list-style-type: none">• Why another survey?• Why another telescope?
Science	<ul style="list-style-type: none">• What the LSST will tell us• The big questions
Technology	<ul style="list-style-type: none">• Novel telescope optics• Novel CCD camera
Operation	<ul style="list-style-type: none">• Survey strategy• Handling the data

 5

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.

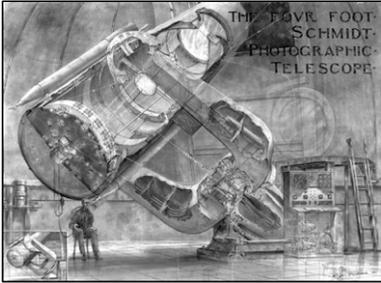
 6

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



 7

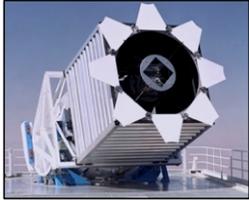
Sky Surveys

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)
- 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



 8

Fiata Lux III

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)
- Palomar Observatory Sky Survey II (1985 – 1999)
- Sloan Digital Sky Survey (2000 – 2014)
- Pan-STARRS (2010 – 2014)

Panoramic Survey Telescope and Rapid Response System



UNIVERSITY OF LIVERPOOL 9

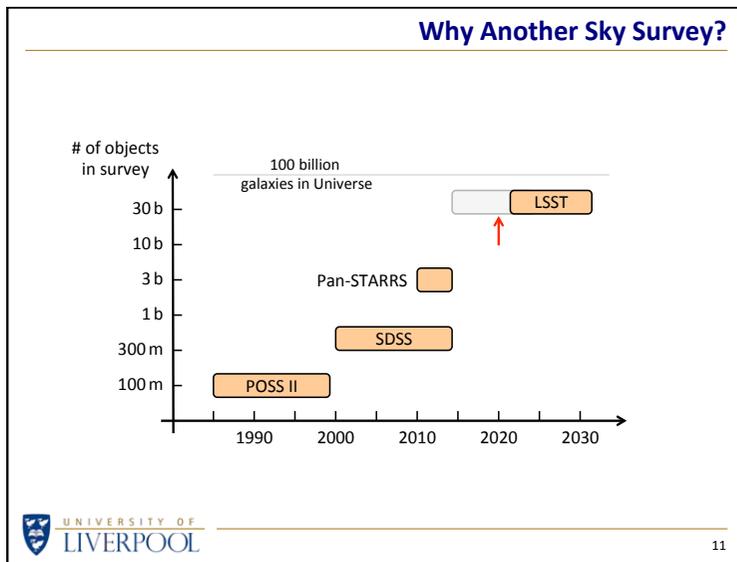
Sky Surveys

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)
- Palomar Observatory Sky Survey II (1985 – 1999)
- Sloan Digital Sky Survey (2000 – 2014)
- Pan-STARRS (2010 – 2014)
- Large Synoptic Survey Telescope (2022 – 2032)



UNIVERSITY OF LIVERPOOL 10



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.

UNIVERSITY OF LIVERPOOL 12

Fiats Lux III

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?

	Exposure	<i>f</i> -number			
Faster ↑ ↓ Slower	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	

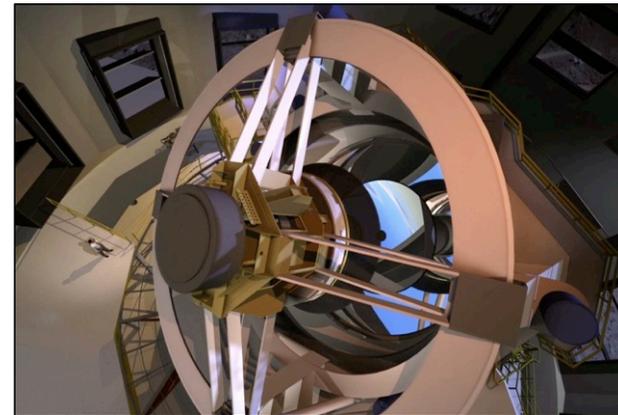
HST = Hubble Space Telescope D = 2.4 m FL = 57 m
 EELT = European Extremely Large Telescope D = 40 m FL = 750 m

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?



Fiat Lux III

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

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

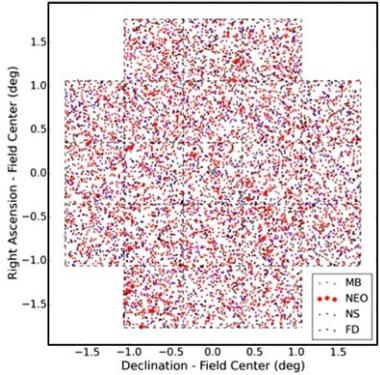
Fiat Lux III

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.

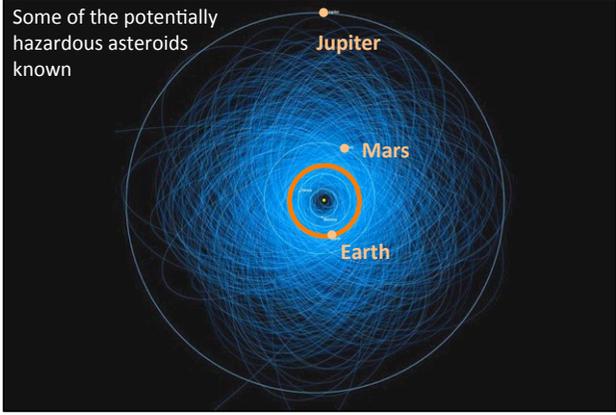


UNIVERSITY OF LIVERPOOL

21

LSST Science – Solar System

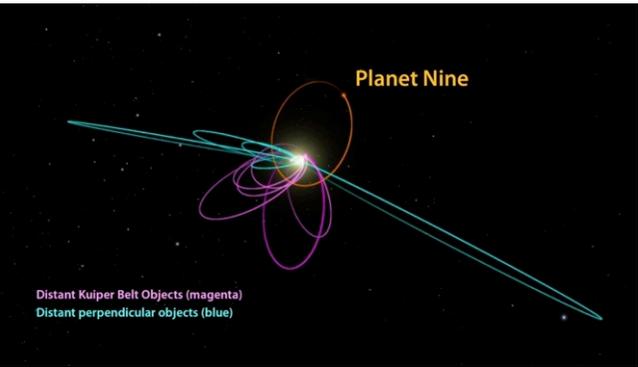
Some of the potentially hazardous asteroids known



UNIVERSITY OF LIVERPOOL

22

LSST Science – Solar System

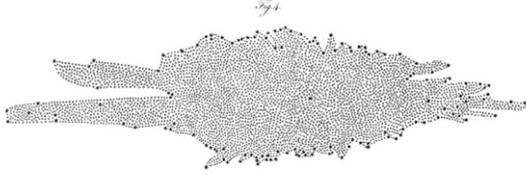


UNIVERSITY OF LIVERPOOL

23

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).

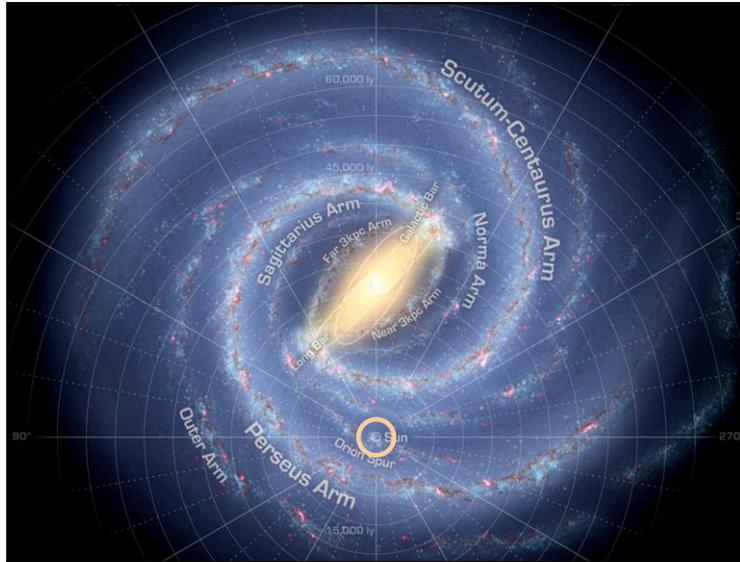


Herschel's structure of the Milky Way (1785)

UNIVERSITY OF LIVERPOOL

24

Fiat Lux III



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).

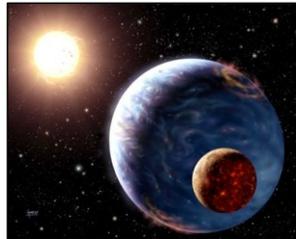
A **single** exposure of the survey area (taken over three nights) will map a volume more than 10 times larger than all previous surveys.

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.

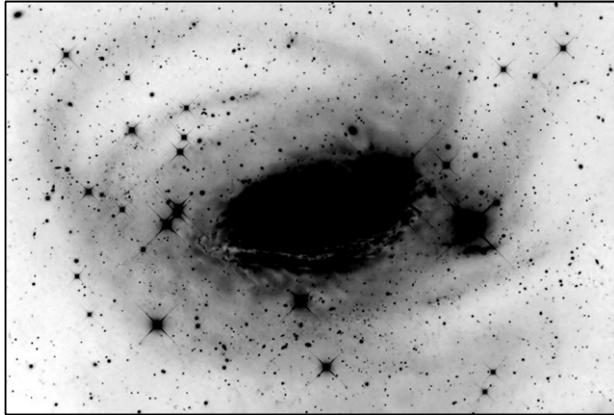
LSST Science – Galaxies

Interactions between galaxies are more common than we first thought.

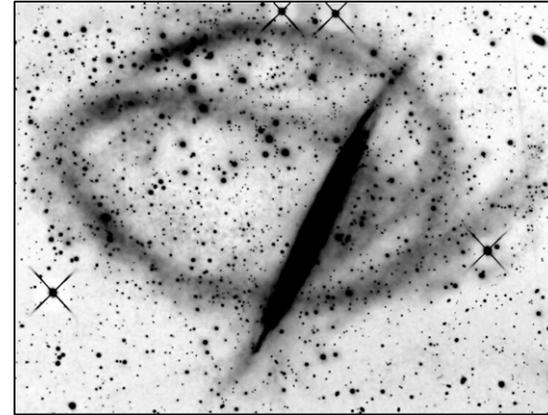


Fiat Lux III

LSST Science – Galaxies



LSST Science – Galaxies



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**.

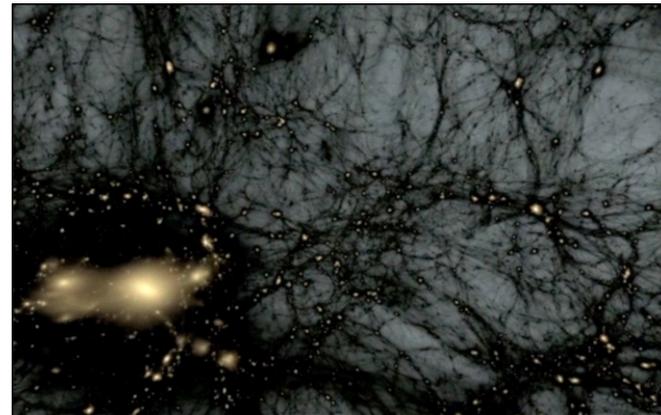
We know it's out there. We don't know *what* it is or exactly *where* it is.

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.

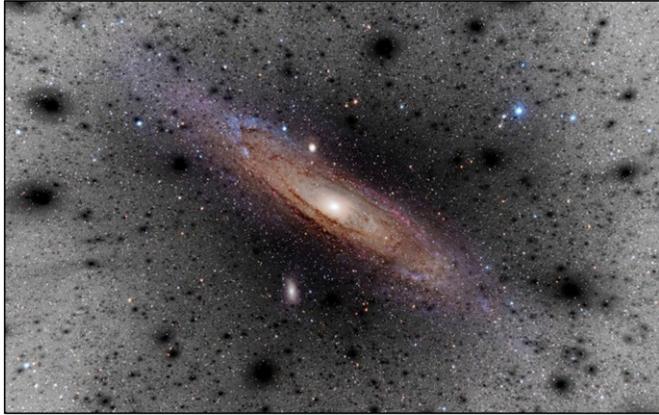
If this so-called 'dark sector' accounts for 95% of the Universe, we really ought to understand more about it.

LSST Science – Dark Matter

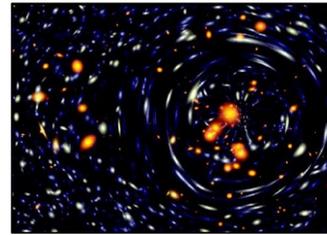


Fiat Lux III

LSST Science – Dark Matter

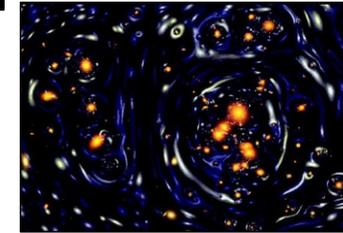


LSST Science – Dark Energy

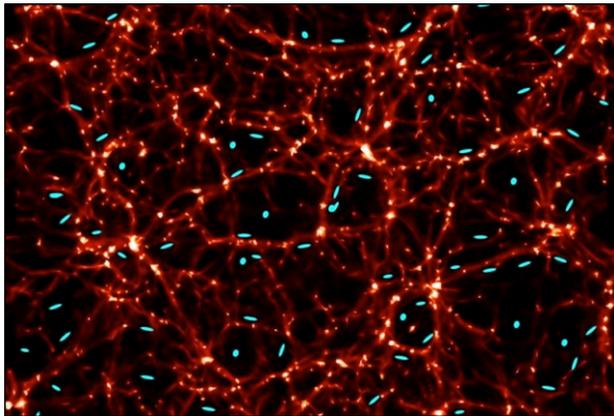


Simulation of foreground galaxies (orange) lensing background galaxies (blue).

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.



Fiat Lux III

Cerro Pachón



UNIVERSITY OF LIVERPOOL

37

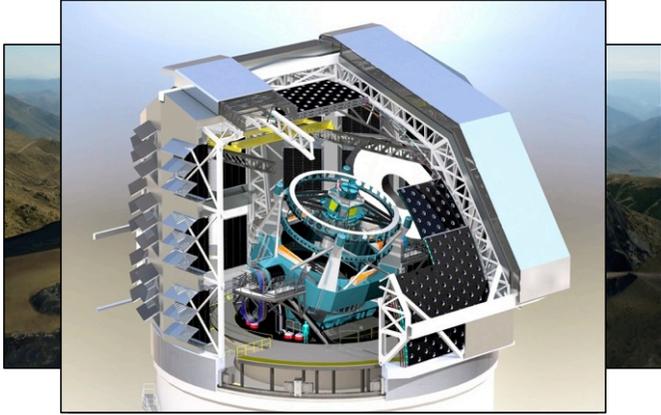
The Site



UNIVERSITY OF LIVERPOOL

38

The Observatory



UNIVERSITY OF LIVERPOOL

39

Optical Design

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

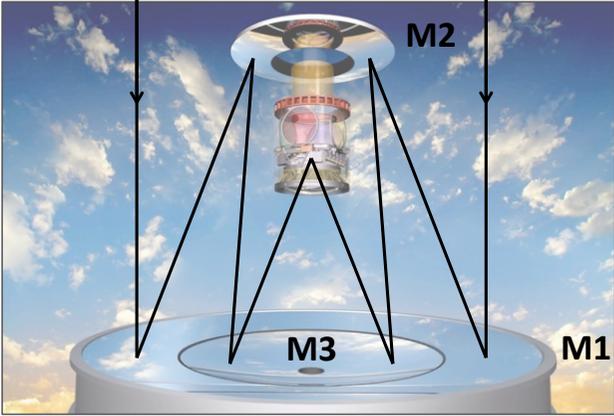
Primary mirror diameter = 8.4 m
Effective focal length = 10.3 m
Telescope focal ratio = $f/1.2$

UNIVERSITY OF LIVERPOOL

40

Fiat Lux III

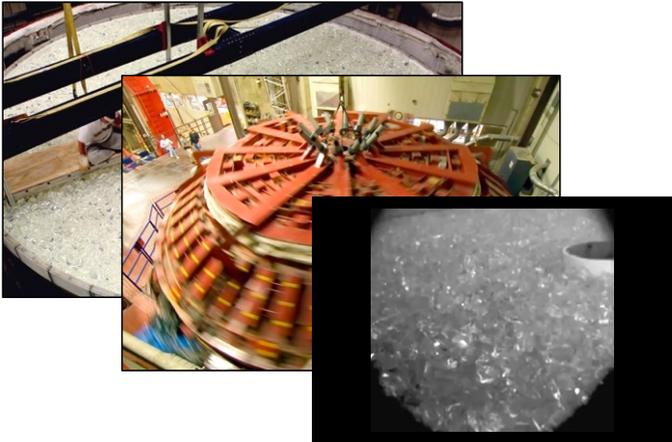
Optical Design



UNIVERSITY OF LIVERPOOL

41

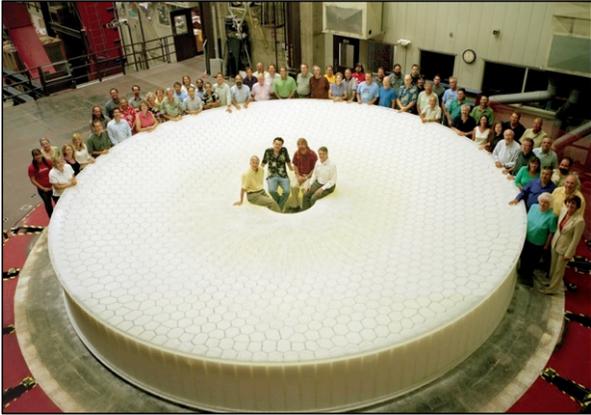
Primary (and Tertiary) Mirror



UNIVERSITY OF LIVERPOOL

42

Primary (and Tertiary) Mirror



UNIVERSITY OF LIVERPOOL

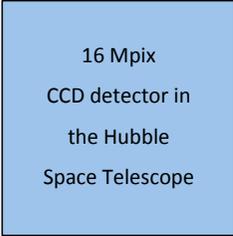
43

Camera CCD

Camera module from a mobile phone



... and at the same scale



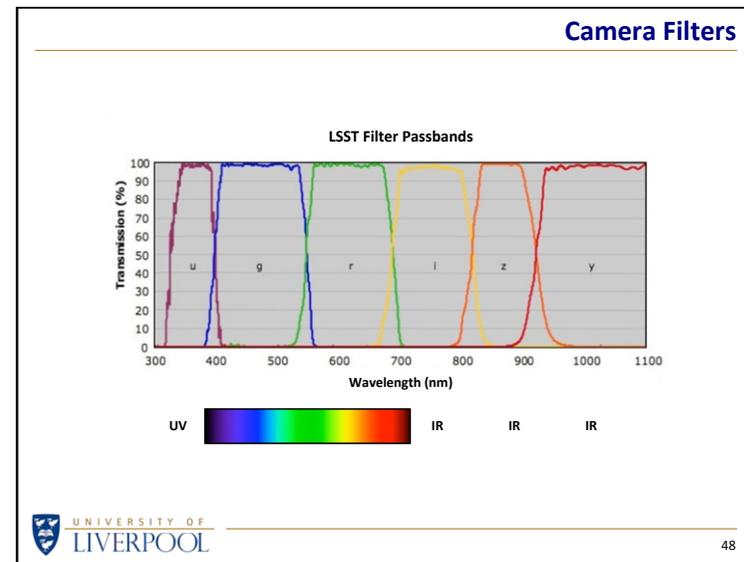
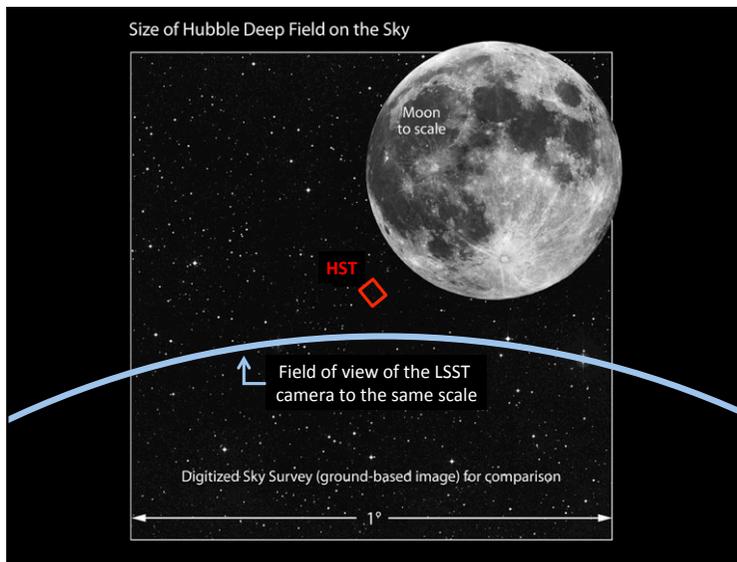
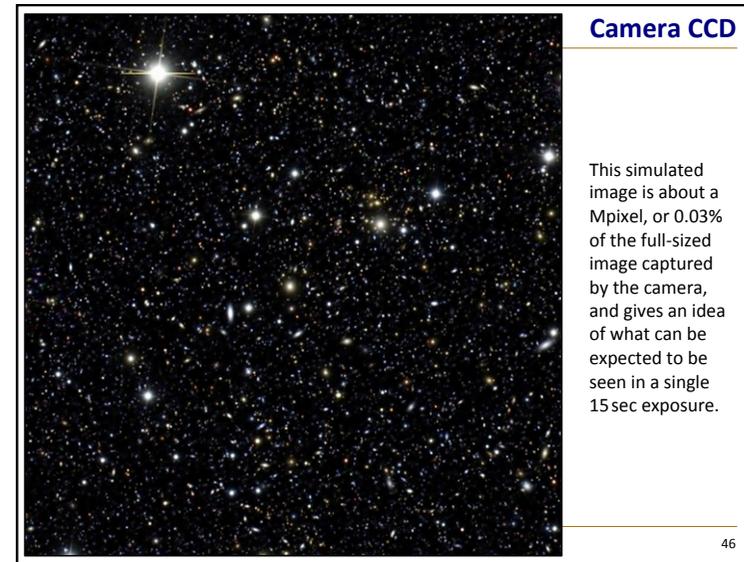
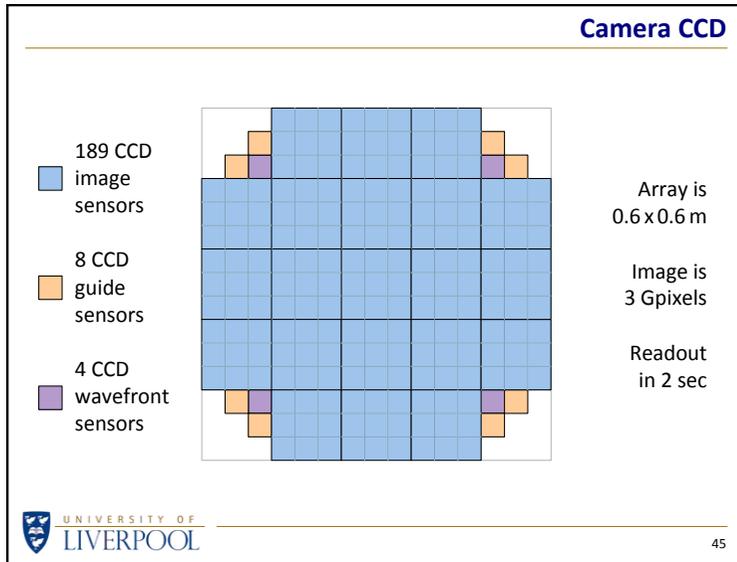
16 Mpix
CCD detector in
the Hubble
Space Telescope

40 mm

UNIVERSITY OF LIVERPOOL

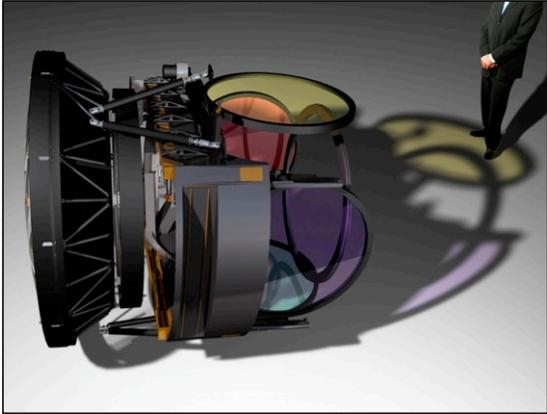
44

Fiata Lux III



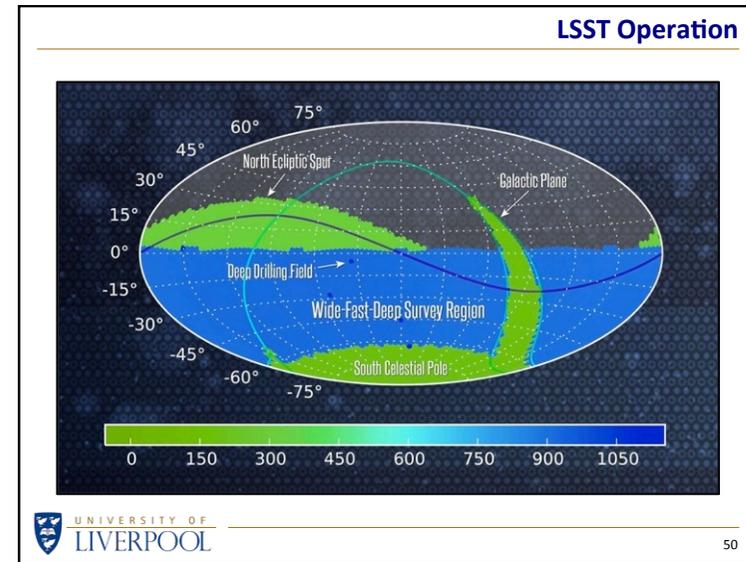
Fiat Lux III

Camera Filters



UNIVERSITY OF LIVERPOOL

49



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)



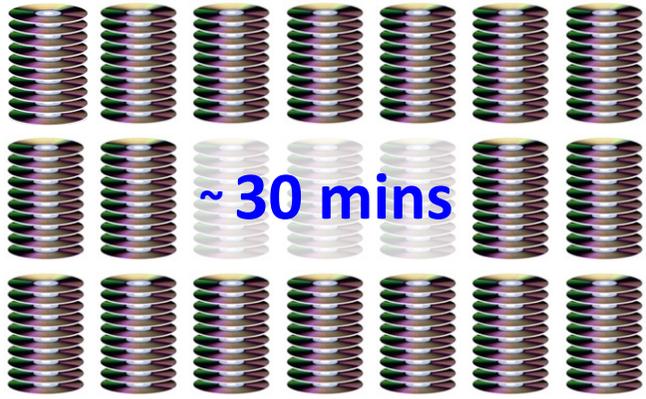
(enough for 1000s of digital photos)

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?

UNIVERSITY OF LIVERPOOL

51

LSST Data



~ 30 mins

UNIVERSITY OF LIVERPOOL

52

Fiata Lux III

1 TB = 1000 GB

1 TB disk = 200 DVDs

UNIVERSITY OF LIVERPOOL

53

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.

UNIVERSITY OF LIVERPOOL

54

Data Transmission

Every 30 seconds ...

~ 15 GB

100 Gb/s intranet

1 s

Base Site La Serena (Chile)

4 s

2 x 40 Gb/s internet

NCSA Champaign (USA)

10 million 'events' per night

Catalogue

- 20 billion galaxies
- 17 billion stars

UNIVERSITY OF LIVERPOOL

55

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?

UNIVERSITY OF LIVERPOOL

56

Fiat Lux III

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 the influence of dark matter on galaxy rotation in the 1960s.

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) !**

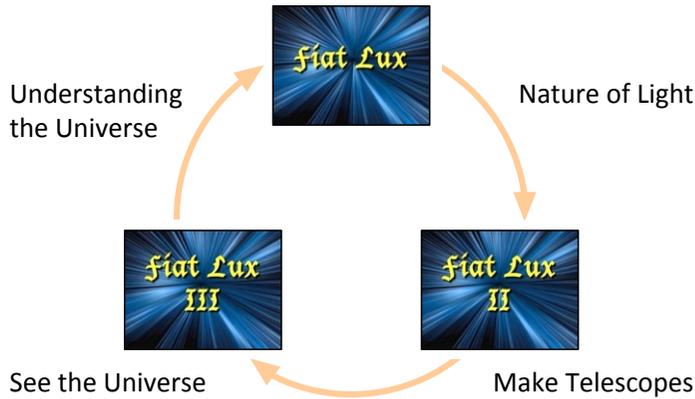
 UNIVERSITY OF LIVERPOOL 57

Summary

Sky Surveys	<ul style="list-style-type: none">• Why survey the sky?• Existing surveys
LSST	<ul style="list-style-type: none">• Why another survey?• Why another telescope?
Science	<ul style="list-style-type: none">• What the LSST will tell us• The big questions
Technology	<ul style="list-style-type: none">• Novel telescope optics• Novel CCD camera
Operation	<ul style="list-style-type: none">• Survey strategy• Handling the data

 UNIVERSITY OF LIVERPOOL 58

Fiat Lux Trilogy



Understanding the Universe

Nature of Light

See the Universe

Make Telescopes

 UNIVERSITY OF LIVERPOOL 59



Fiat Lux III

www.liverpool.ac.uk/~sdb/Talks

Dr Steve Barrett NAS 7 Oct 2021