Exploring the Universe from your armchair with the Greatest Movie of All Time!

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University of Washington
Rubin Obs. Construction Director

BH Futures
Apr 6, 2022

Thank you for inviting me, and thank you for taking your time to attend!

The Bosnia & Herzegovina Futures Foundation was founded in 2015 with a vision to transform young talents into future leaders and break down ethnic barriers in Bosnia & Herzegovina through technology and education access.

These are noble pursuits! “I am with you!”

Outline

- A few words about me
- Why to survey the night sky?
  - fundamental physics: why is the Universe expanding?
  - are there any asteroids on a collision course with Earth?
- The construction of Rubin Observatory
  - why Legacy Survey of Space and Time (LSST)?
  - Rubin Obs. construction tour
- Exploring the Universe from your armchair
  - examples from Sloan Digital Sky Survey
  - plans for Rubin Obs. and LSST

Seattle downtown

I am a professor of astronomy at the University of Washington, Seattle

Zagreb

I grew up in Zagreb, finished my studies of mechanical engineering and physics at the University of Zagreb, and then left for Kentucky to get my Ph.D in astrophysics.

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And then fell in love...

Vedrana

Stanzie

Pamela

Nikola Tesla bar in Sarajevo

Fun fact: I was actually born in Sarajevo (and my father in Sanski Most), and I spent a year in Banja Luka. I still use every chance I have to visit Bosnia!

Sebilj

Gazi Husrev-beg Mosque

- What is astronomy about?
  - understanding the Universe

Over the last three of decades, astronomers have discovered about 4,000 extra-solar planets (or exoplanets). These are planets outside of our Solar System, with its 8 planets. It is possible that some of them could support life. Are we alone?

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  - understanding the Universe

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We have known for about 100 years that the Universe is expanding. About a decade ago, it was discovered that this expansion is accelerating. We are uncertain about what this acceleration means; the two most plausible explanations are some mysterious and weird fluid called dark energy, or perhaps Einstein’s general theory of relativity fails!

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Generally speaking, astronomy (or astrophysics - but not astrology!) studies the formation and evolution of structure in the Universe (we apply laws of physics to observations).

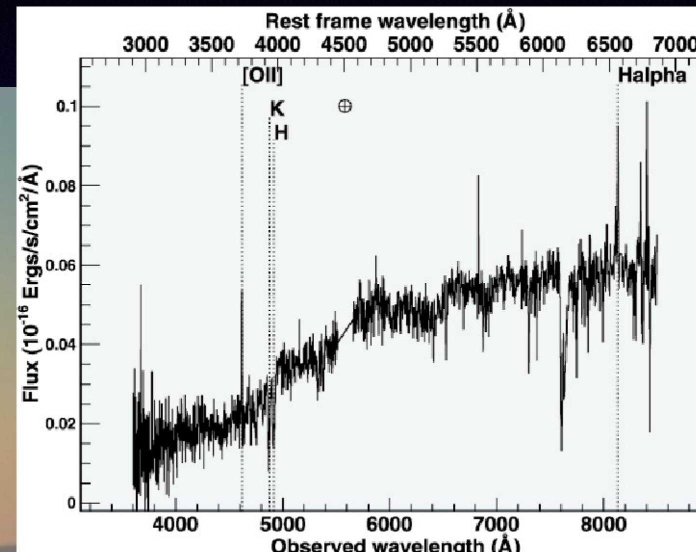
Modern observational methods in astronomy

- Telescopes above the atmosphere: high angular resolution (e.g., the Hubble Space Telescope, soon JWST) and probe other wavelength regions (X-ray, radio, infrared)


The HST in orbit and an example of a galaxy image

Modern observational methods in astronomy

- Large telescopes (~10m, soon 30-40m):
  faint objects, especially spectroscopy

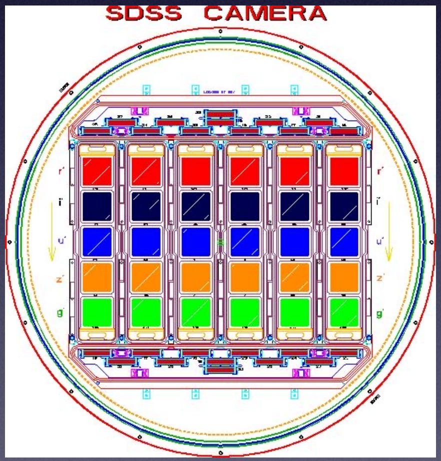


The Keck telescopes on Mauna Kea (Hawaii)

Modern observational methods in astronomy:

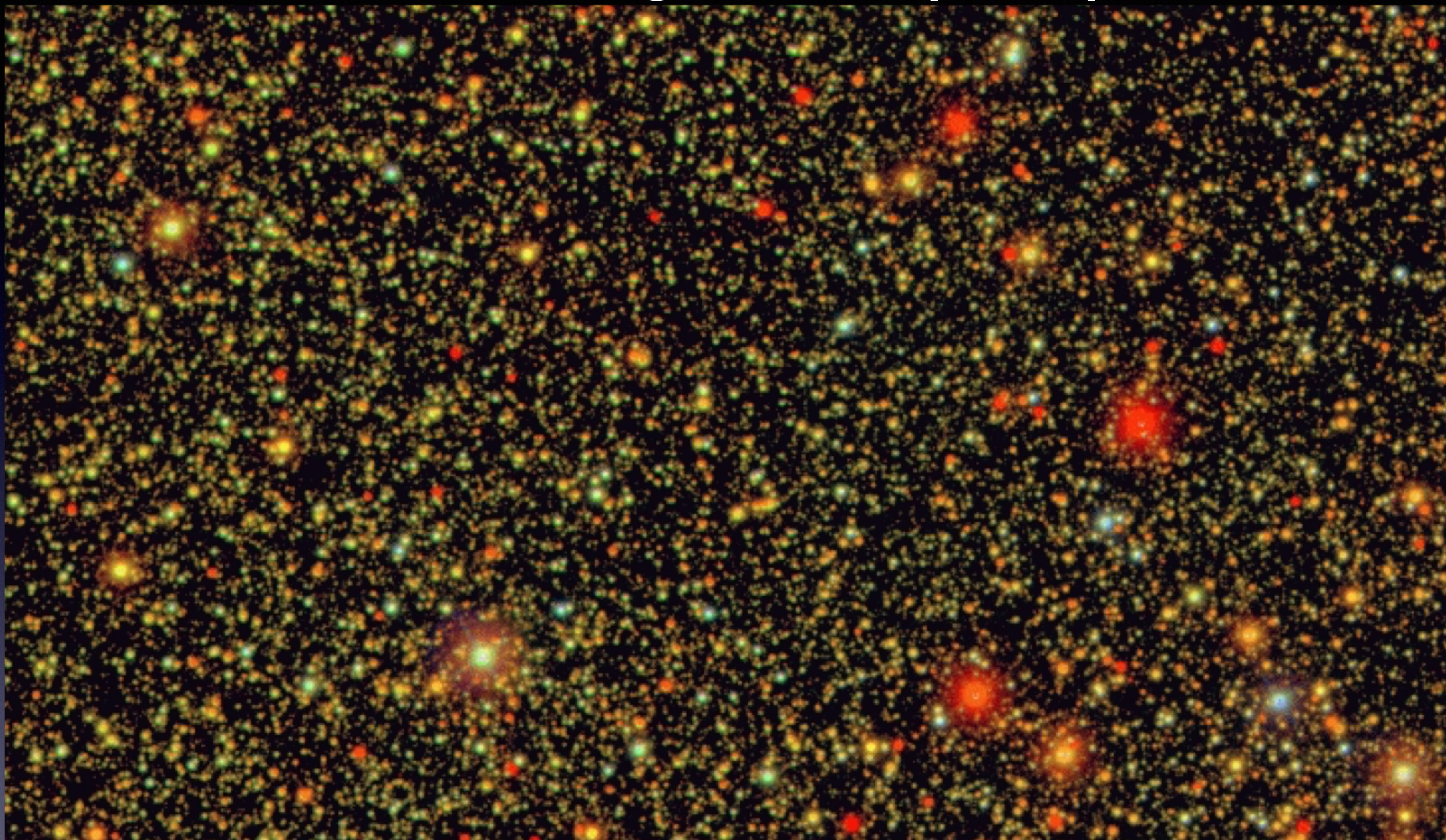
- Large telescopes on the ground
- Telescopes above the atmosphere (spacecrafts)
- Large sky surveys: digital sensor technology (CCD), information technology (data processing and data distribution), many objects observed at the same time

SDSS



Modern astronomical surveys detect billions of objects: huge statistical power for studying the history and structure of the Universe

SDSS view along the Milky Way Disk



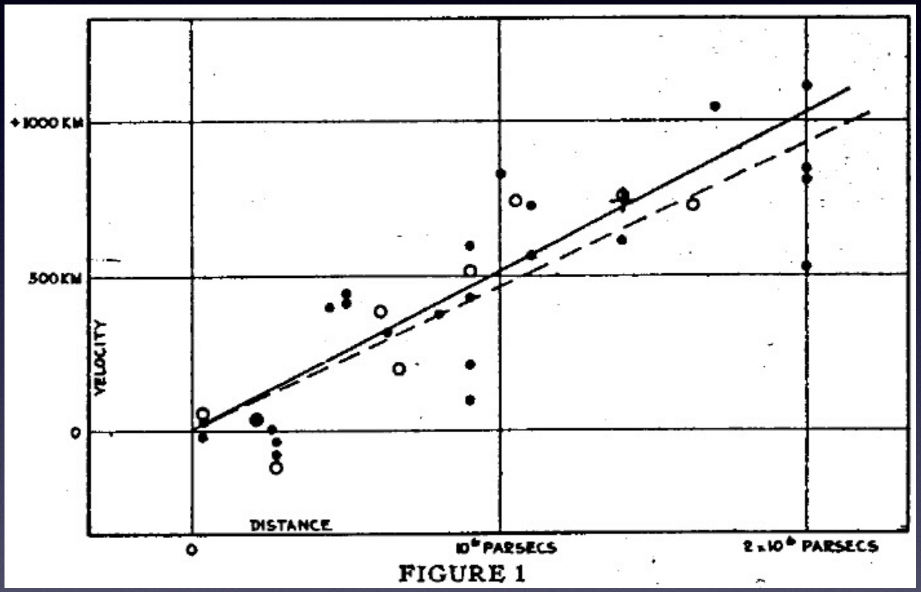
Moon for scale

Naked eye: 1 star in 200x larger area

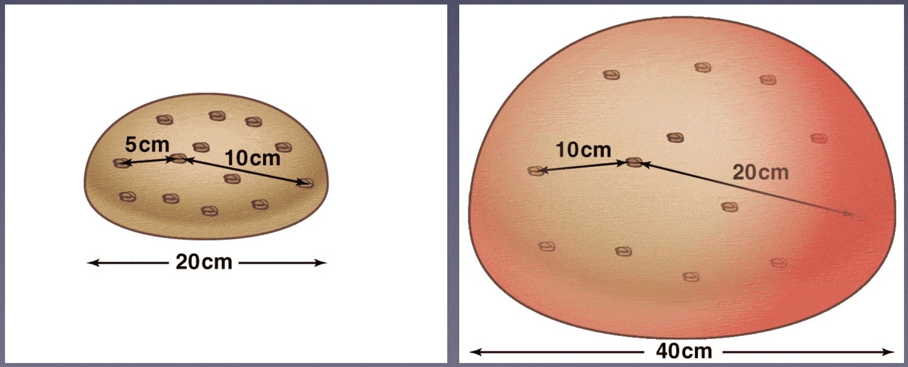
What did we learn so far?

- the Universe is expanding! (early XX century)
- it was expected that this expansion slows down with time because of gravity

recession speed



distance



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- it was expected that this expansion slows down with time because of gravity, but
- this expansion is accelerating! (late XX century)
- it was expected that we knew enough physics to explain everything, but
- there is no theoretical explanation for the accelerated expansion of the Universe!
- if one assumes that Einstein’s general relativity theory, which describes gravity and the Universe at the largest scales, is correct then one is led to postulate the so-called dark energy, but
- Einstein could be wrong, too…   “We need more data!”

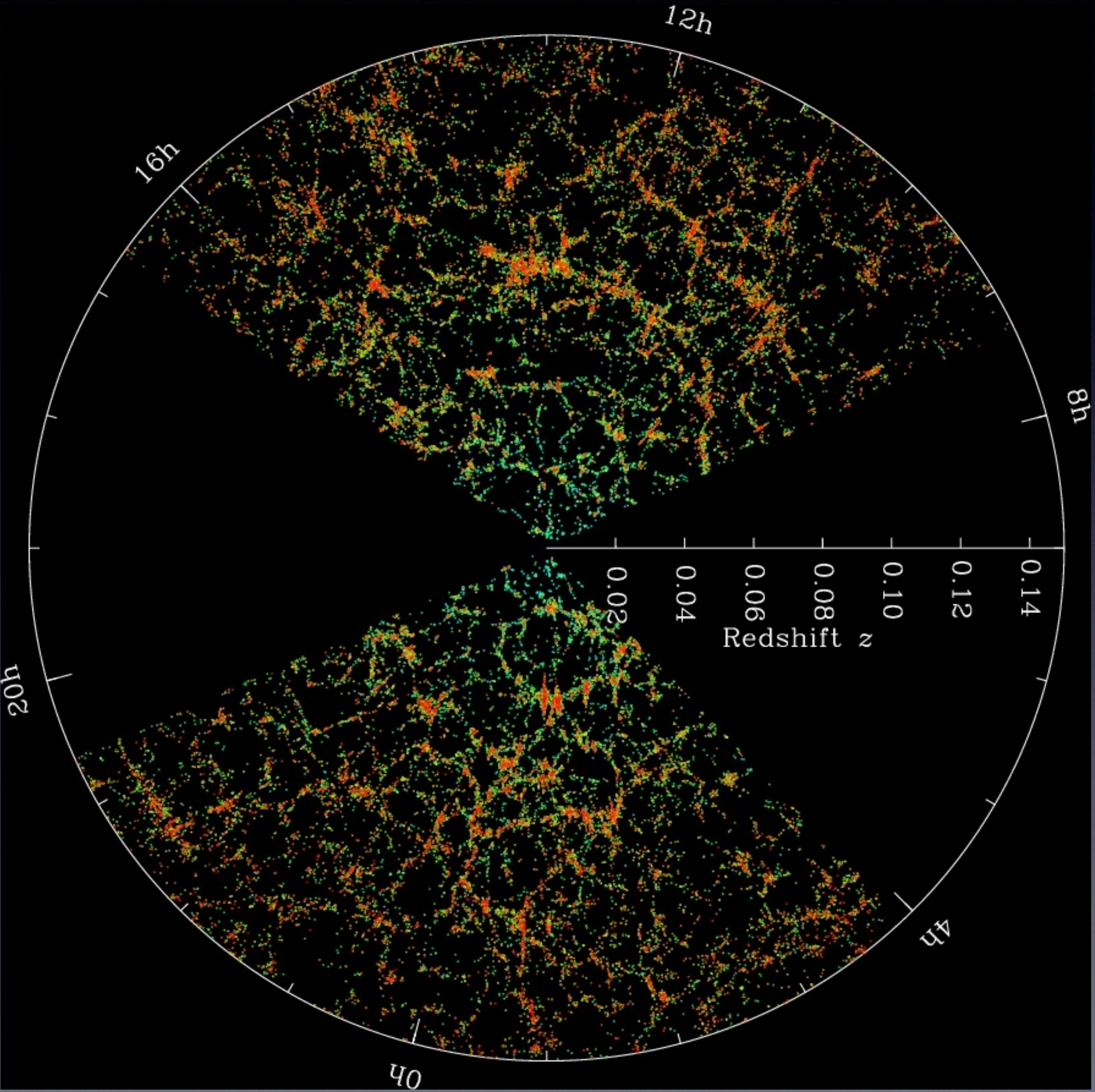
What do we need for the next step?

- we potentially have a new major (70%) constituent of mass-energy in the Universe - or perhaps Einstein was wrong?
- with existing data, we cannot tell which explanation is more likely solution: to change this, we need to obtain precise data for about 10 billion galaxies and millions of supernovae
- we need a very unique observatory: Rubin Observatory and LSST
- in a nutshell, we need

  1) a large telescope mirror to be sensitive, and

  2) a large field-of-view for sky scanning speed

Spatial distribution of galaxies

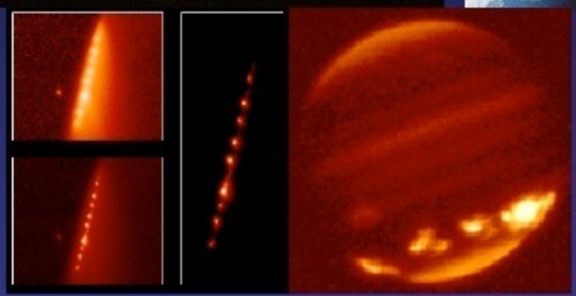


Left: each dot is one galaxy from SDSS

Note that the galaxy distribution is highly **inhomogeneous:** statistical details of that distribution contain rich cosmological information

Killer asteroids: the impact probability is not 0!

photomontage!



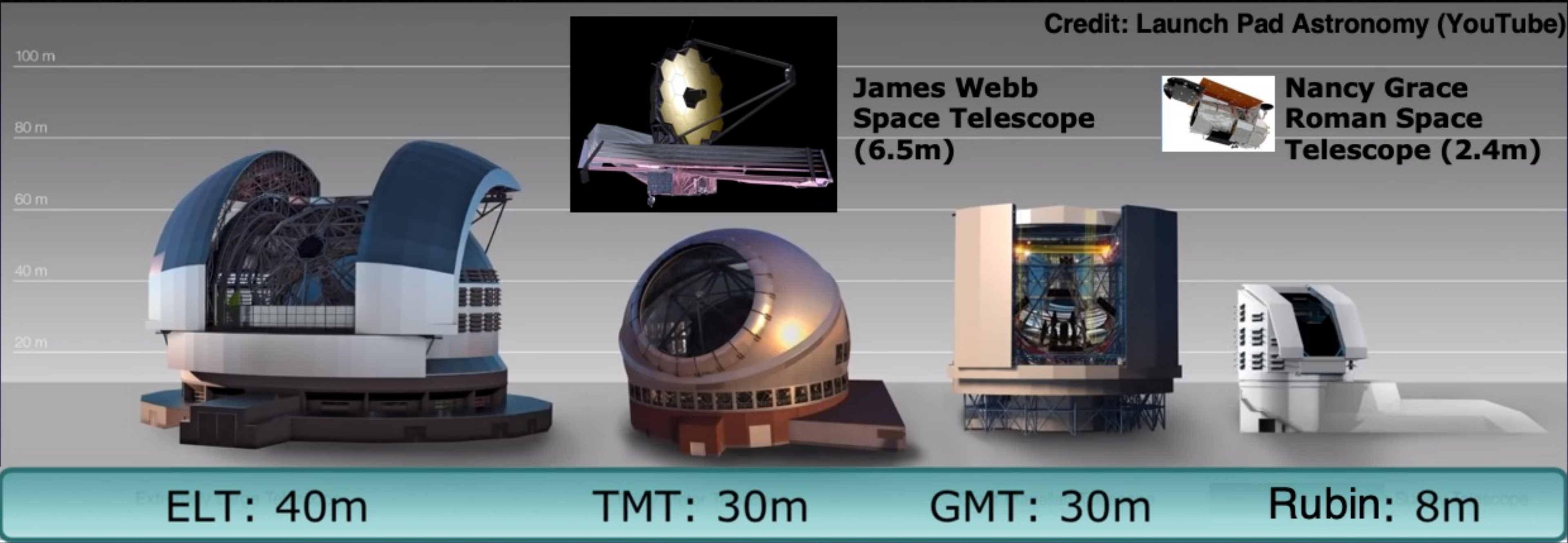
Shoemaker-Levy 9 (1994)

Tunguska (1908)

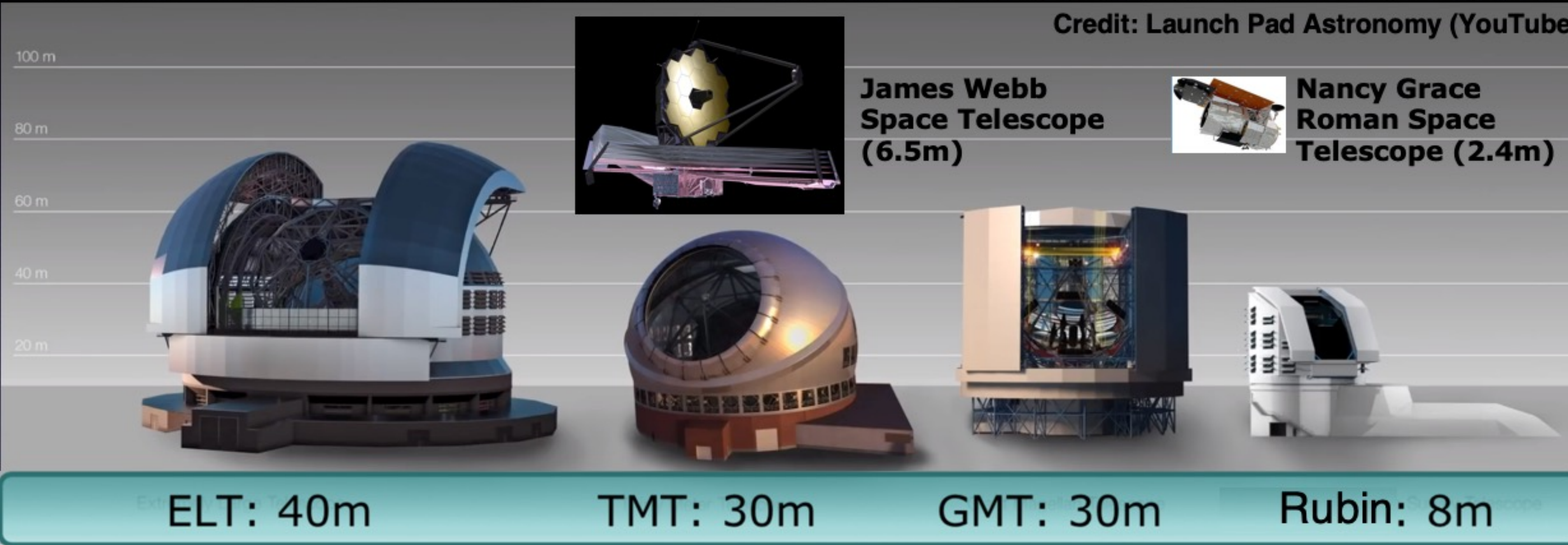
Asteroids larger than 140m collide with Earth every 20,000 years on average. Typical impact energy of such a collision is 500 Megaton TNT (10x the largest bomb: Tsar Bomba from 1961)

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: about 40m object 50,000 yr. ago

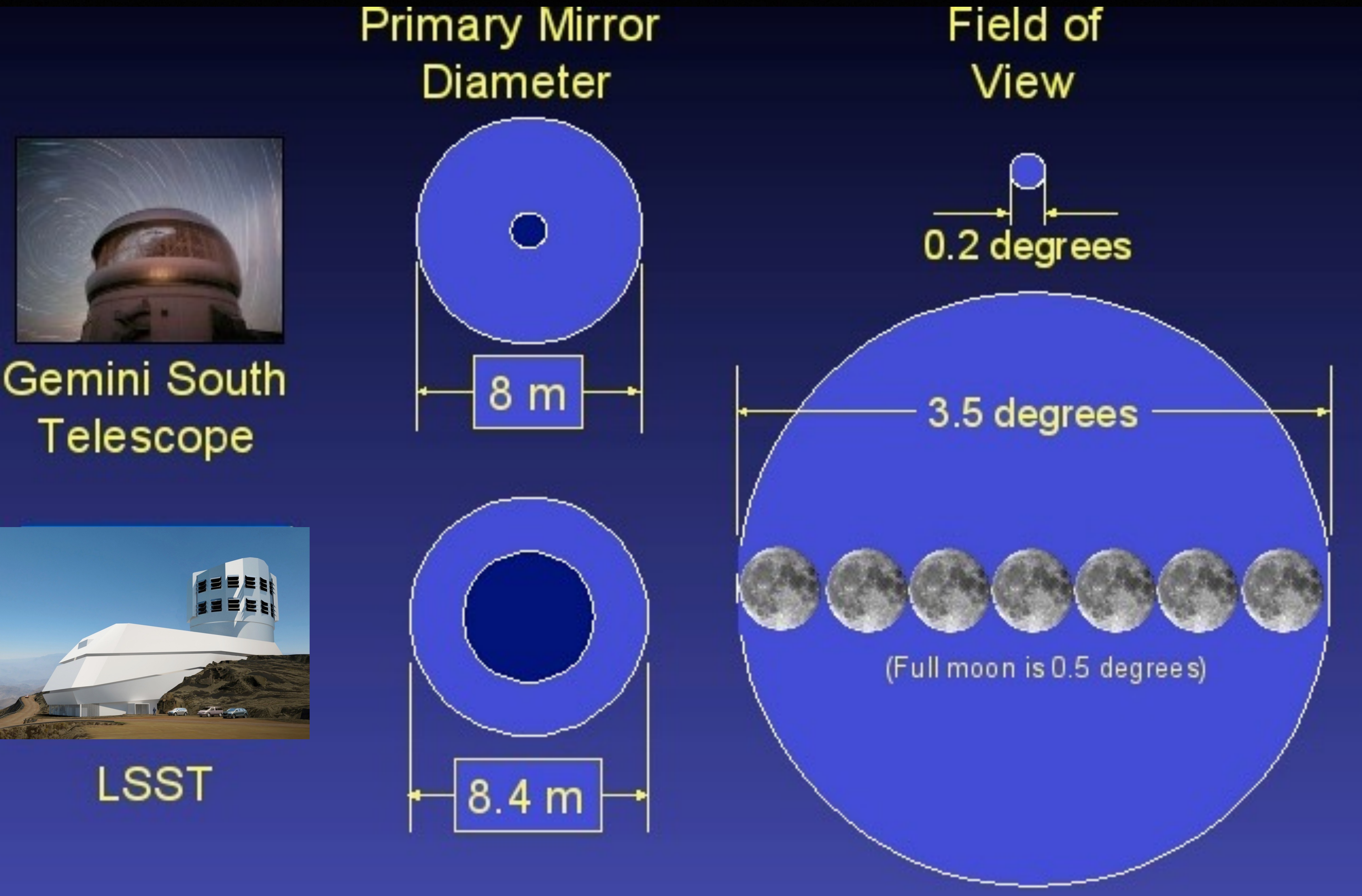


LSST will be delivered by the Vera C. Rubin Observatory, as its first, 10-year, project

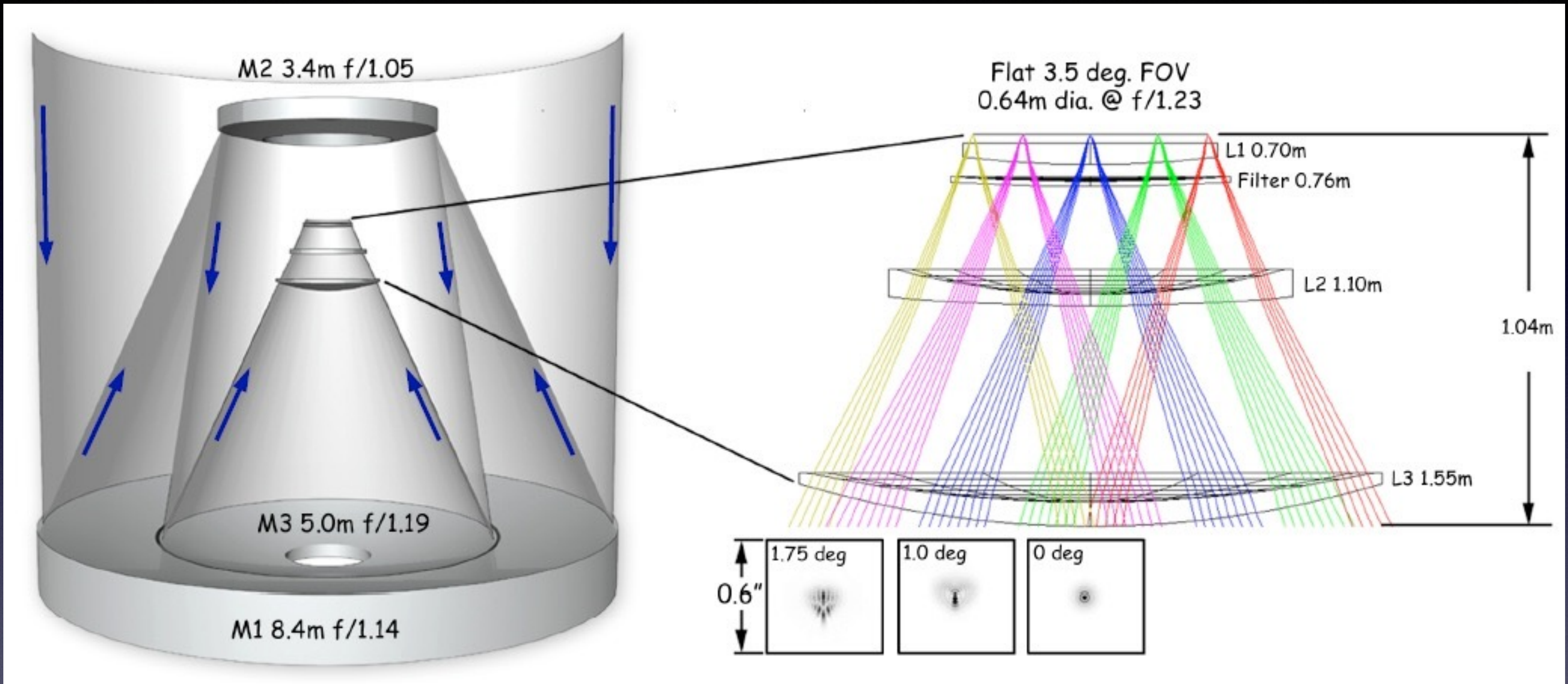


Rubin Obs. will not have the largest mirror but will have by far the largest product of the mirror area and the field-of-view size (etendue or throughput)

The field-of-view comparison: Gemini vs. LSST

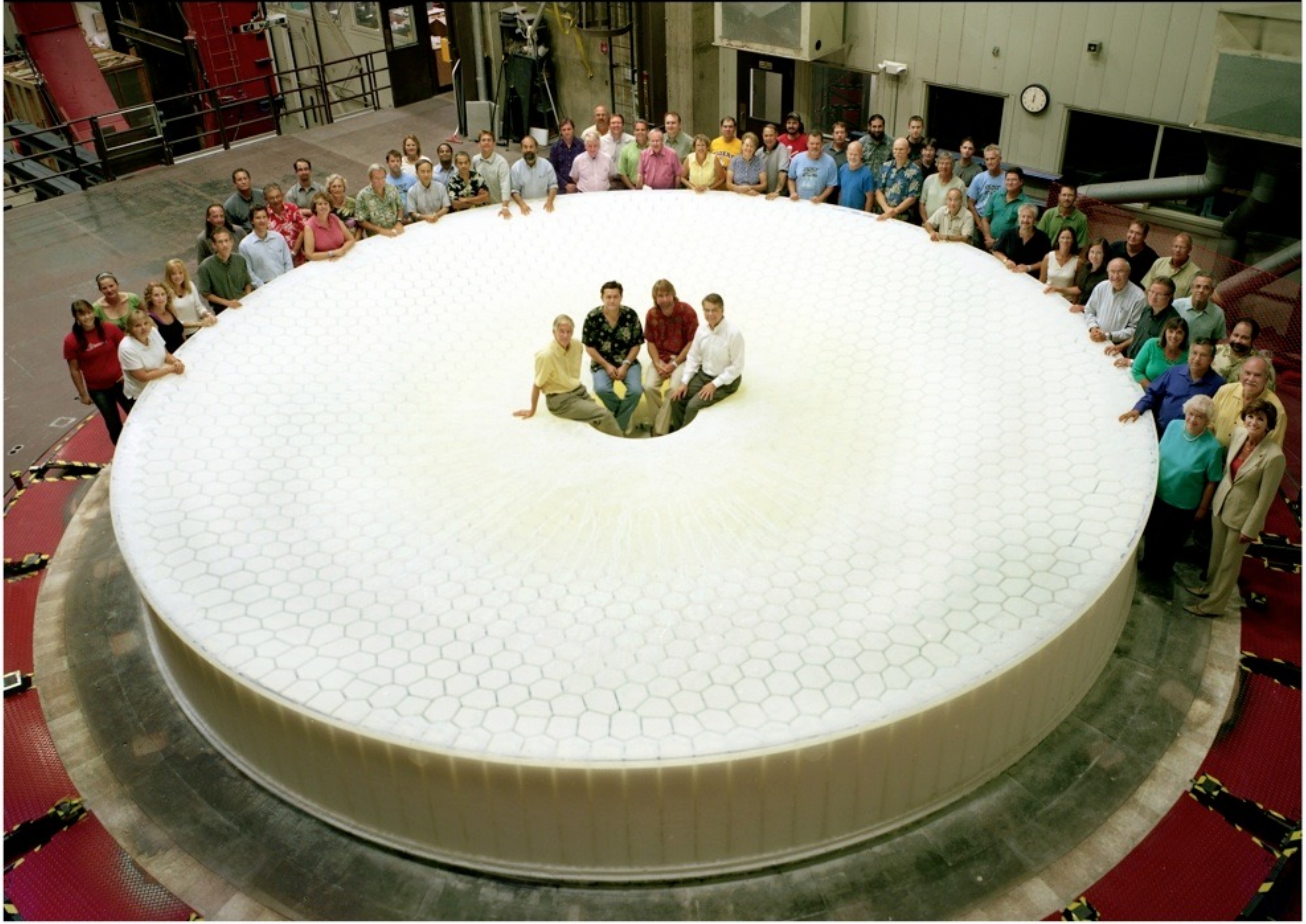


Optical Design for LSST



Three-mirror design (Paul-Baker system)
enables large field of view with excellent image quality:
delivered image quality is dominated by atmospheric seeing

Large Synoptic Survey Telescope



LSST Primary/Tertiary Mirror Blank
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

The University of Arizona. Tucson Arizona   SOML

Large Synoptic Survey Telescope

LSST will not have the largest mirror but will have by far the largest product of the mirror area and the field-of-view size (etendue or throughput)

SDSS
gri
3.5’x3.5’
r~22.5

3 arcmin is 1/10 of the full Moon’s diameter

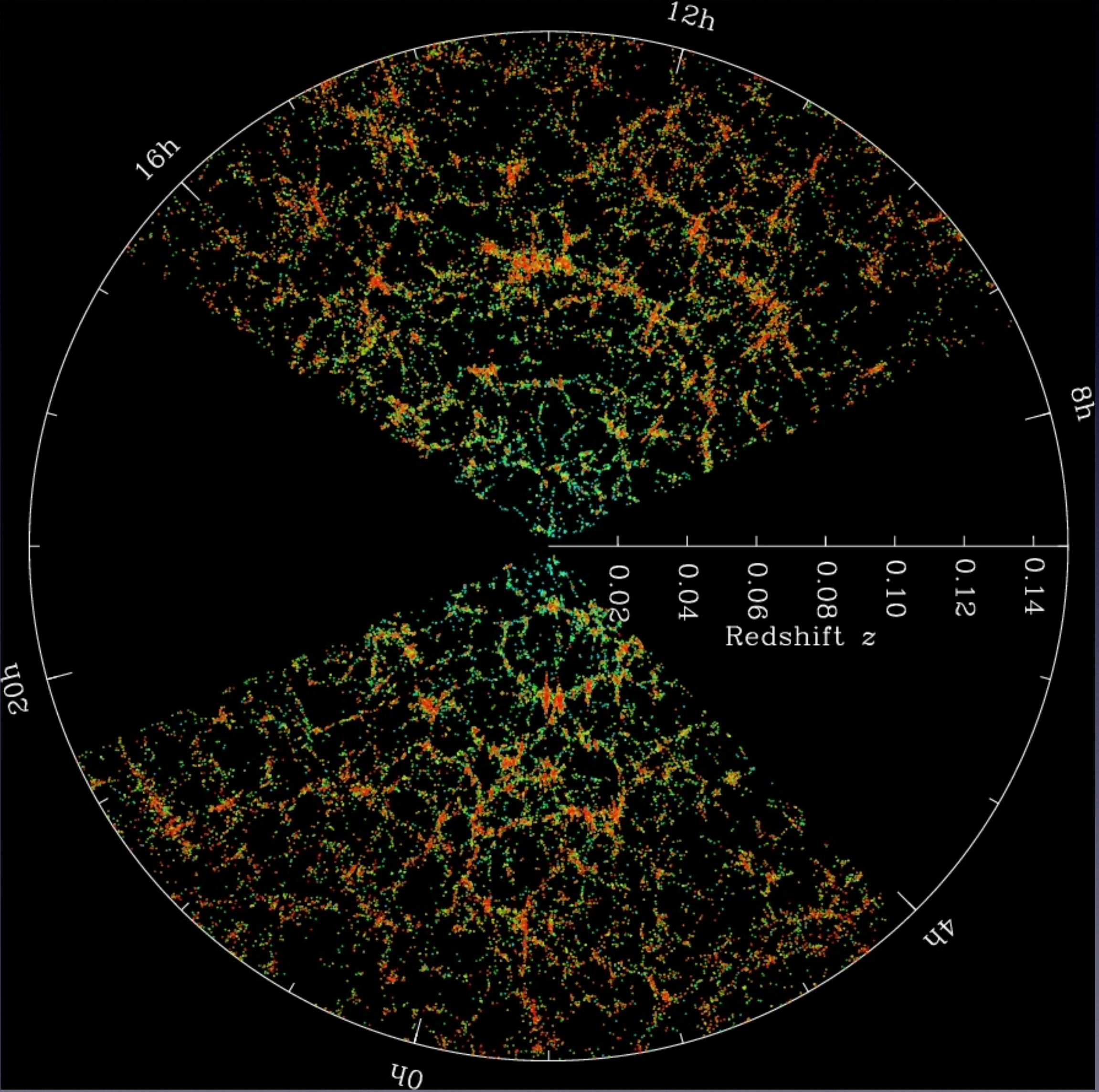
HSC
gri
3.5'x3.5'
r~27

3 arcmin is 1/10 of the full Moon's diameter

like LSST depth (but tiny area)

LSST will deliver 5 million such images

Spatial distribution of galaxies



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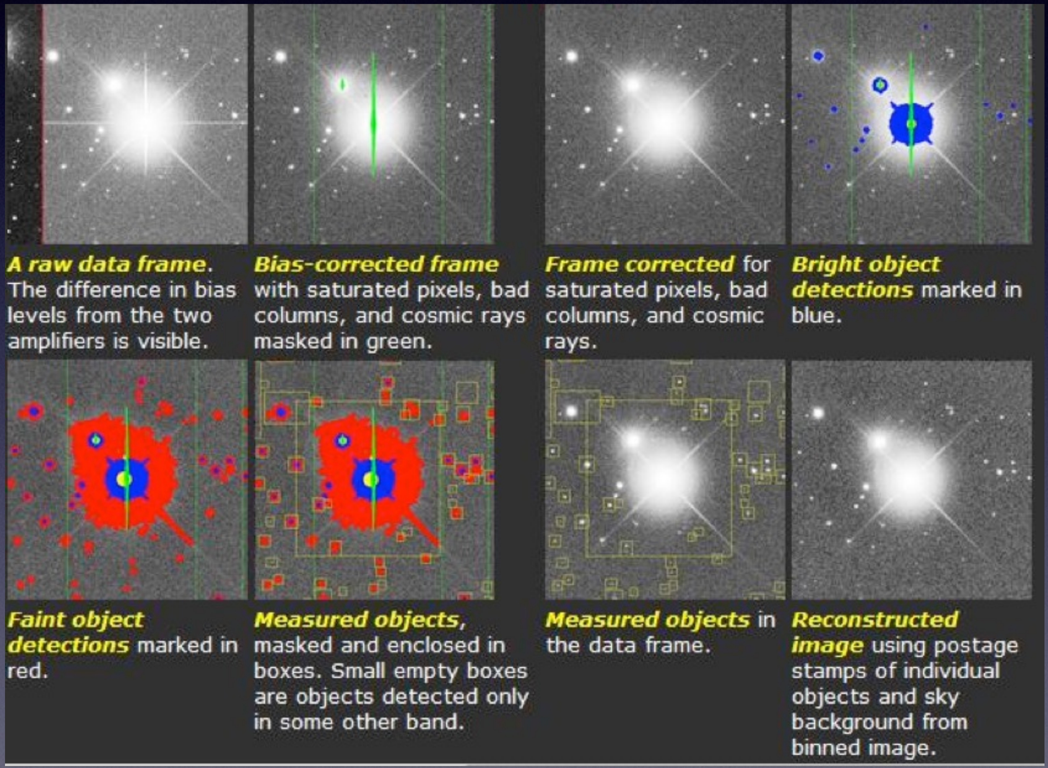
- Astronomical catalogs: what and how
  - a list of all detected objects (stars, galaxies, ...)
  - measured parameters (size, color, brightness,...)

Basic steps in astronomical image processing (example: Sloan Digital Sky Survey):



All these (complicated) steps are already done: "science-ready database"

LSST
Large Synoptic Survey Telescope
LSST Operations:
Sites & Data Flows
HQ Site
Science Operations
Observatory Management
Education & Public Outreach
Base Site
Base Center
Long-term storage (copy 1)
Data Access Center
Data Access & User Services
French Site
Satellite Processing Center
Data Release Production
Long-term Storage (copy 3)
Archive Site
Archive Center
Alert Production
Data Release Production
Calibration Products Production
EPO Infrastructure
Long-term Storage (copy 2)
Data Access Center
Data Access and User Services
Summit Site
Telescope & Camera
Data Acquisition
Crosstalk Correction
National Center for Supercomputing Applications
United States
Mexico
Gulf of Mexico
Cuba
Dominican Republic
Puerto Rico
Guatemala
Honduras
Nicaragua
Costa Rica
Panama
Venezuela
Guyana
Suriname
French Guiana
Colombia
Ecuador
Peru
Brazil
Bolivia
Paraguay
Chile
La Serena
Cerro Pachón
Uruguay
Argentina
Google

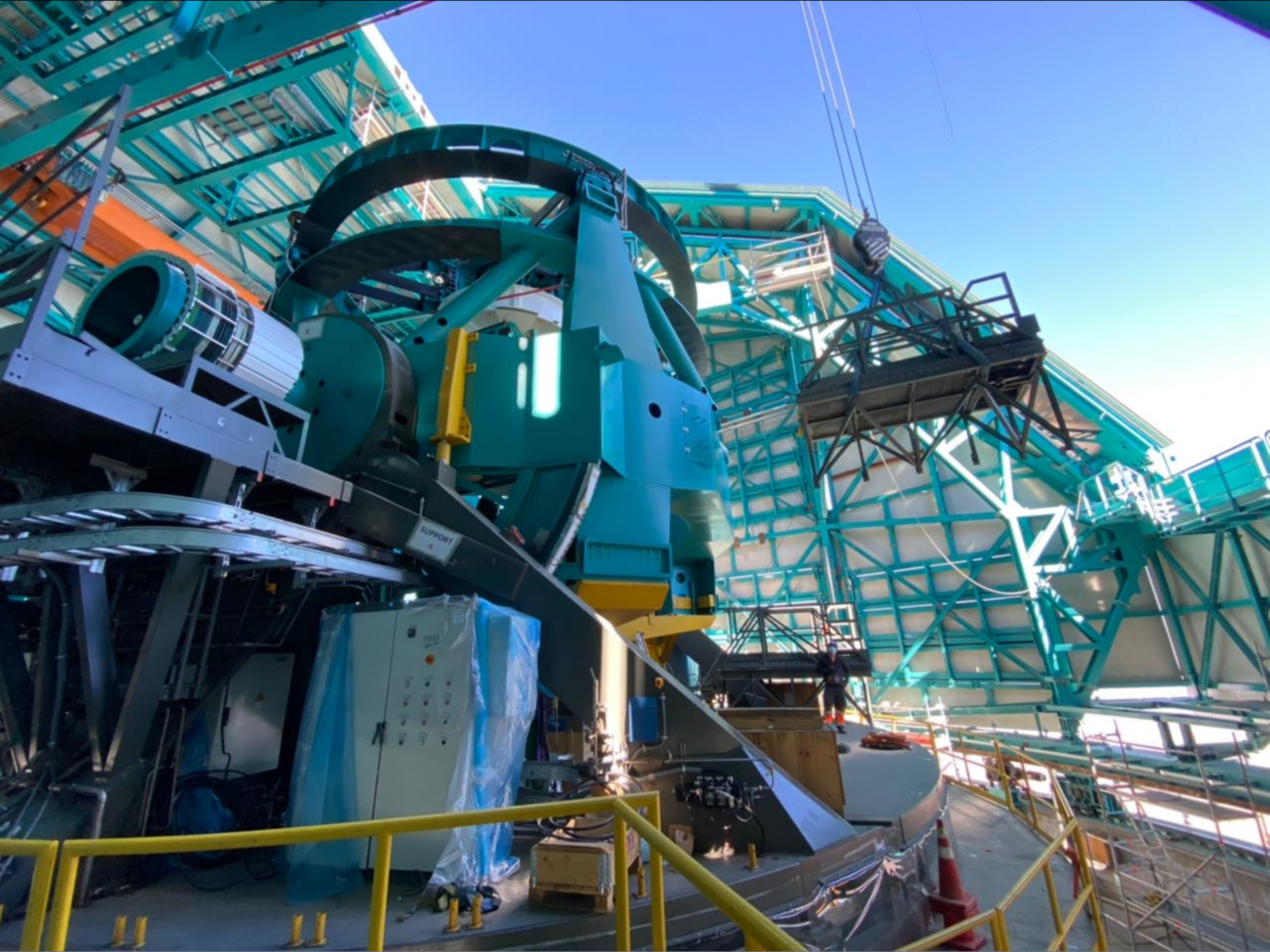

April 14, 2015
LSST
Large Synoptic Survey Telescope
STD14F
SOOSAN
SOOSAN

The rise of Vera C. Rubin Observatory: 2011-2021

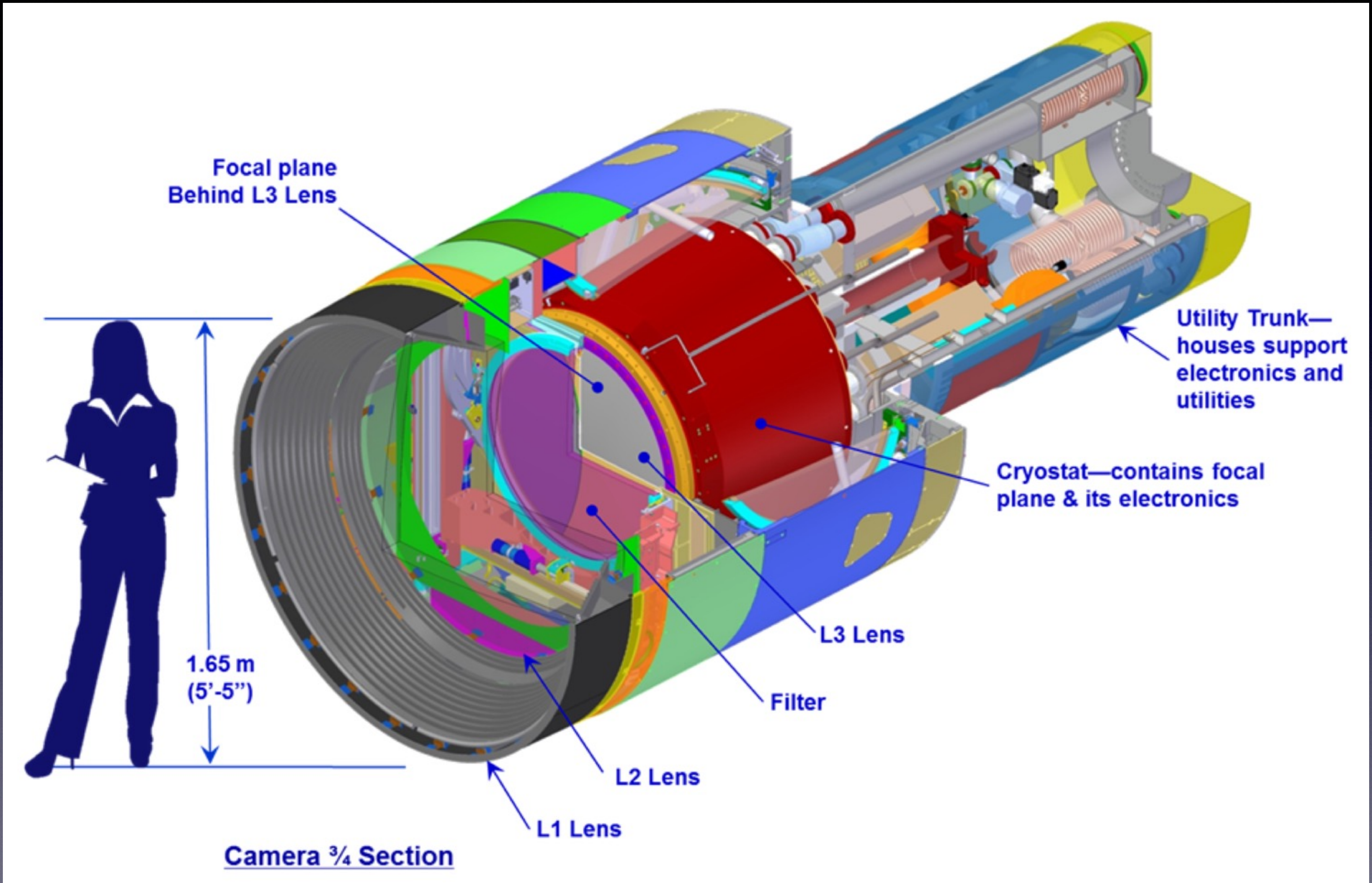
8.4m, 6.7m effective

5 sec slew & settle

Telescope Mount Assembly before going from Spain to Chile

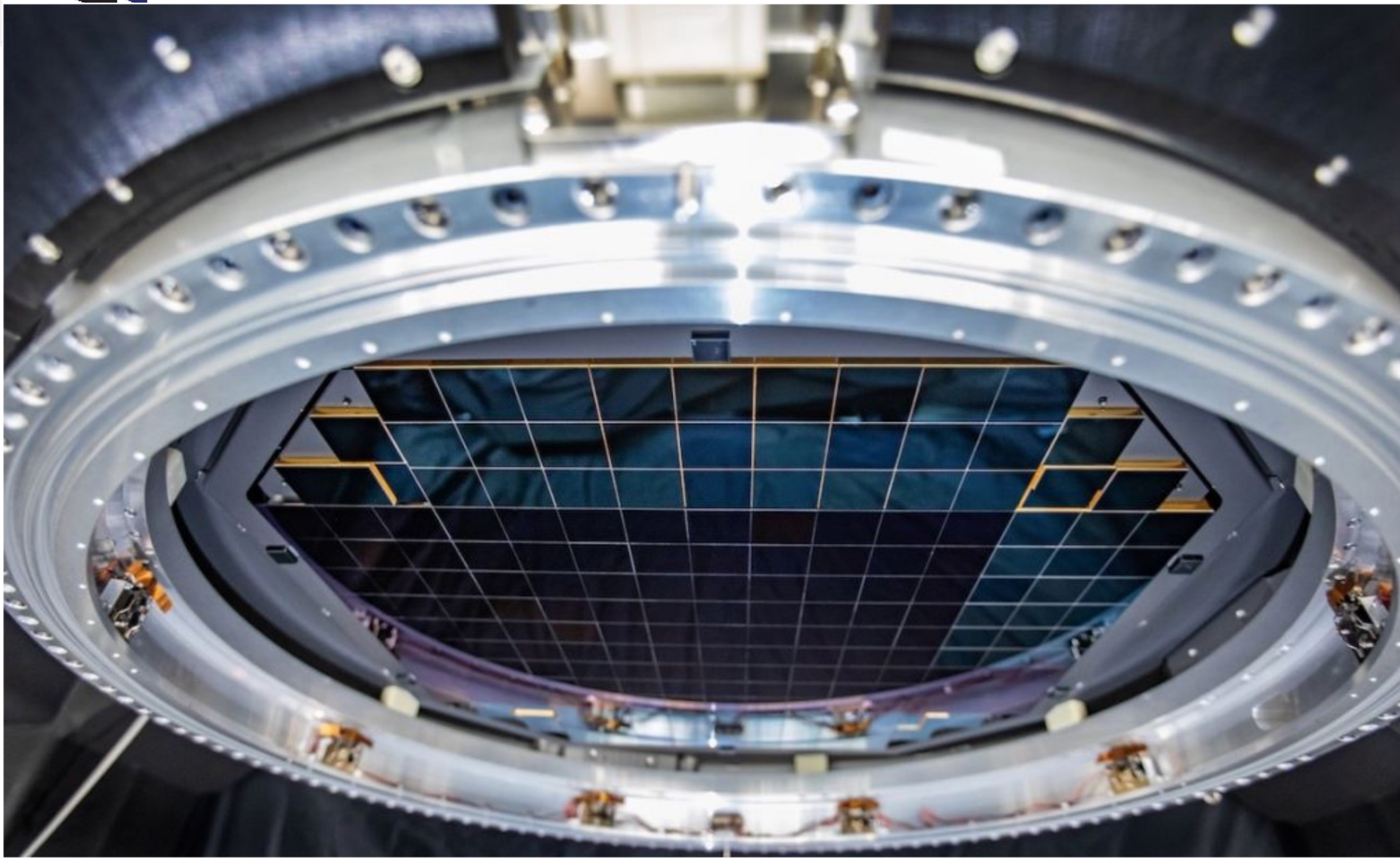

SUPPORT

LSST camera



The largest astronomical camera: 2800 kg, 3200 Megapix

L-1, the largest lens ever produced, is the front lens of the LSST camera



The complete focal plane of the future LSST Camera is more than 2 feet wide and contains 189 individual sensors that will produce 3,200-megapixel images.

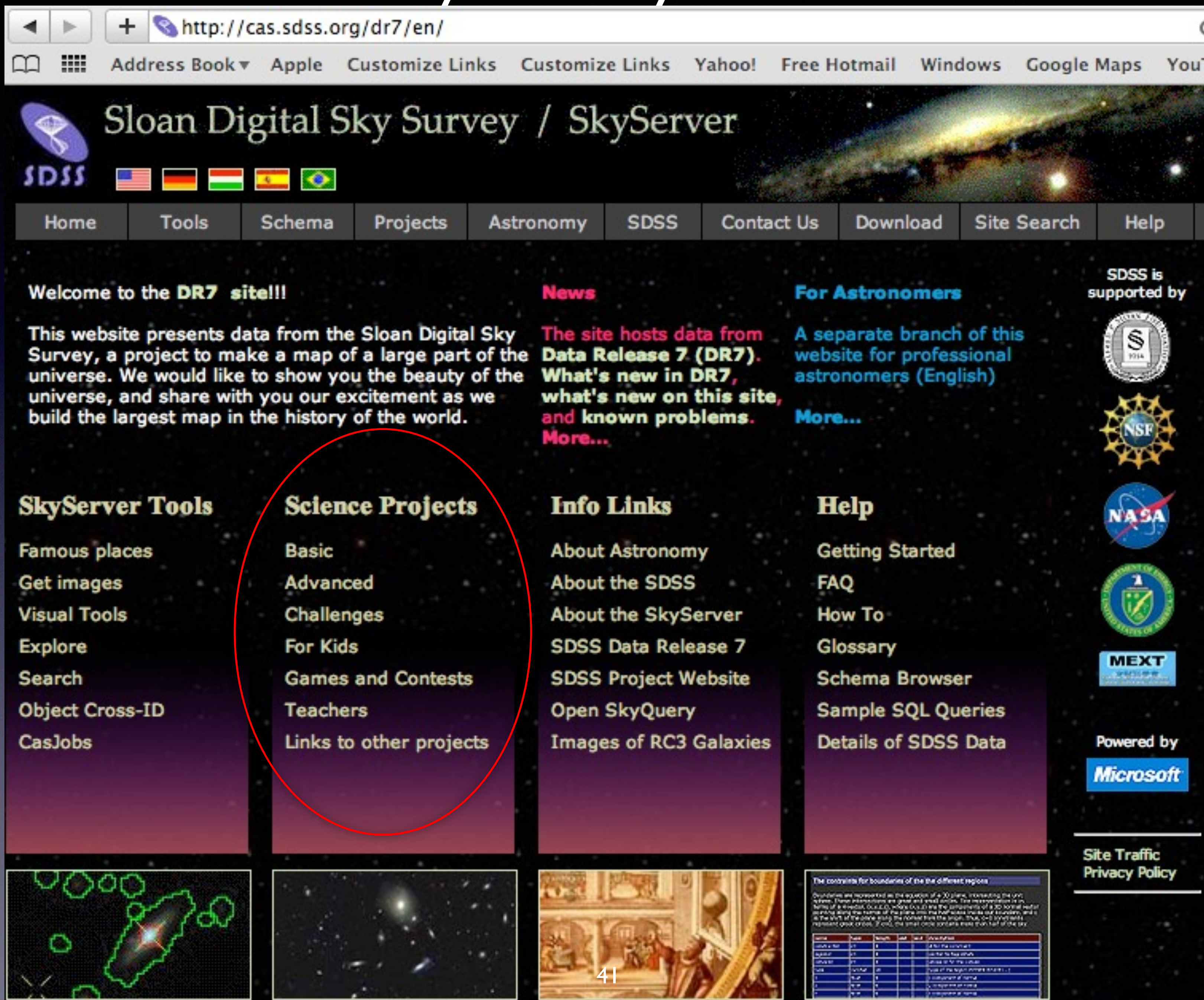
It would take about 1,500 HDTVs to display one image from LSST camera.

Disclaimer: I am unaware of any building with 1,500 HDTVs on its walls so we had to do this in PowerPoint…

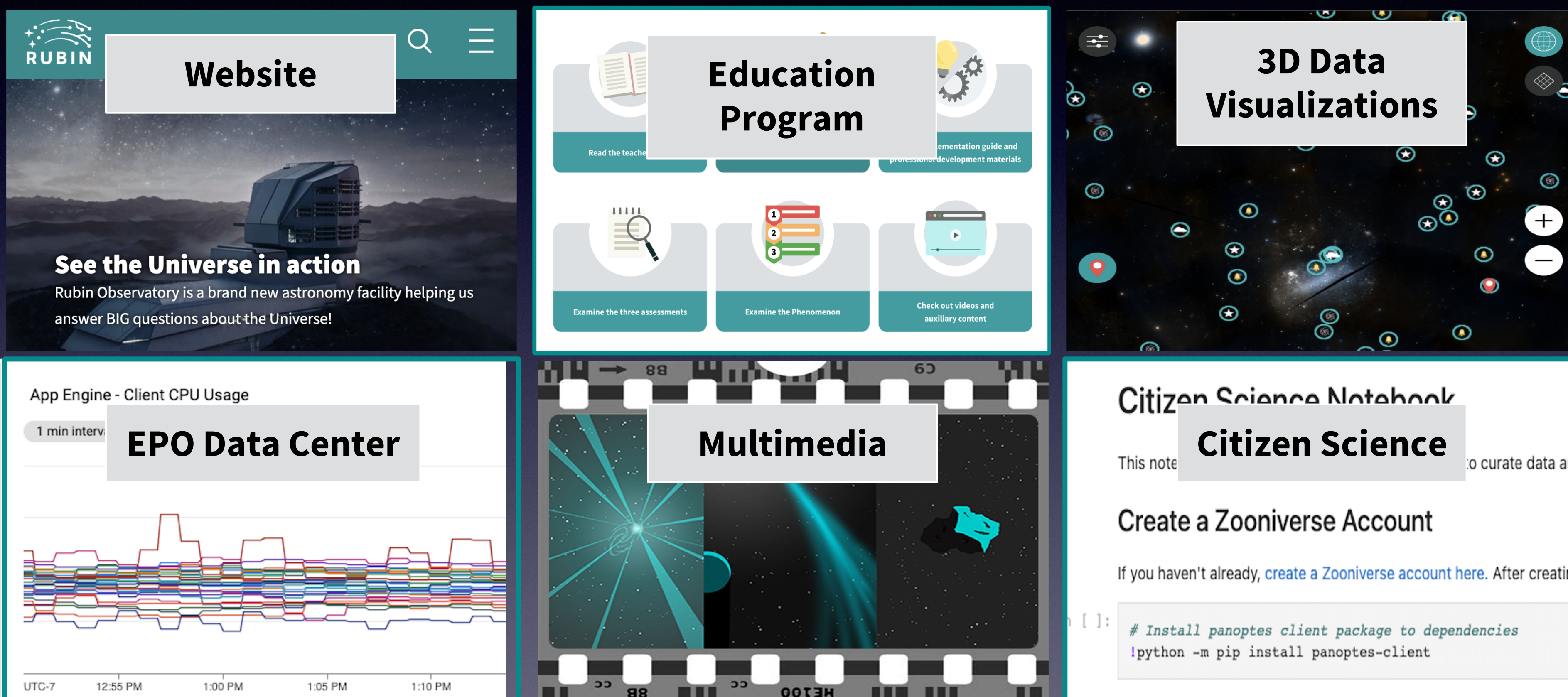
To view all images one a HDTV with 30 frames per second, it would take 11 months!

The greatest movie of all time!

Astronomy "from your armchair"



Rubin Observatory and LSST
Education and Public Outreach Program



For more info: http://rubineducation.org

Public rollout later this year, stay tuned!

Astronomy "from your armchair"

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Coloring the Universe: Page 1 of 23

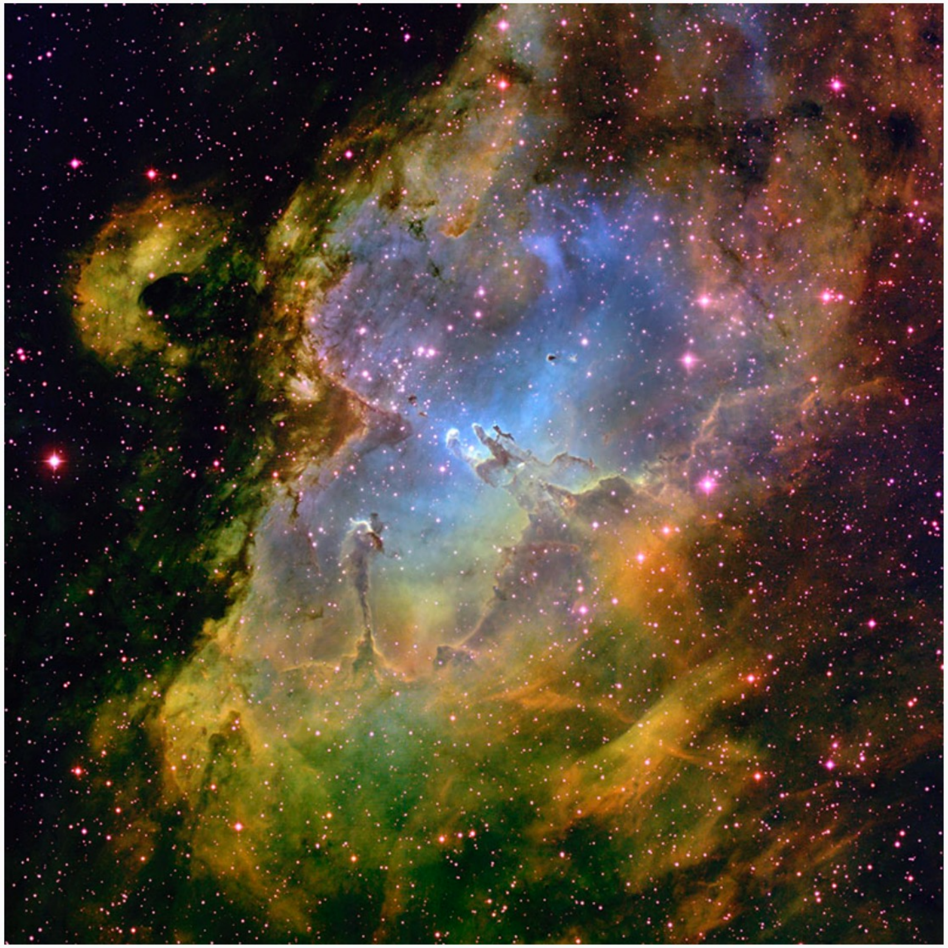
RUBIN

Introduction

Have you ever wondered how astronomers learn about objects in the Universe if they can't visit them in person? Nearly everything astronomers know about the stars and galaxies in the Universe comes from the light we receive from these objects. Fortunately, that light contains a wealth of information. In this investigation, you will learn how astronomers use light and filters to understand distant cosmic objects like galaxies, dusty nebulae, and star-forming regions.

Essential Questions

- How are filters used to create color images?
- How are filters used to conduct astronomical research?
- What can astronomers learn by using these filters?



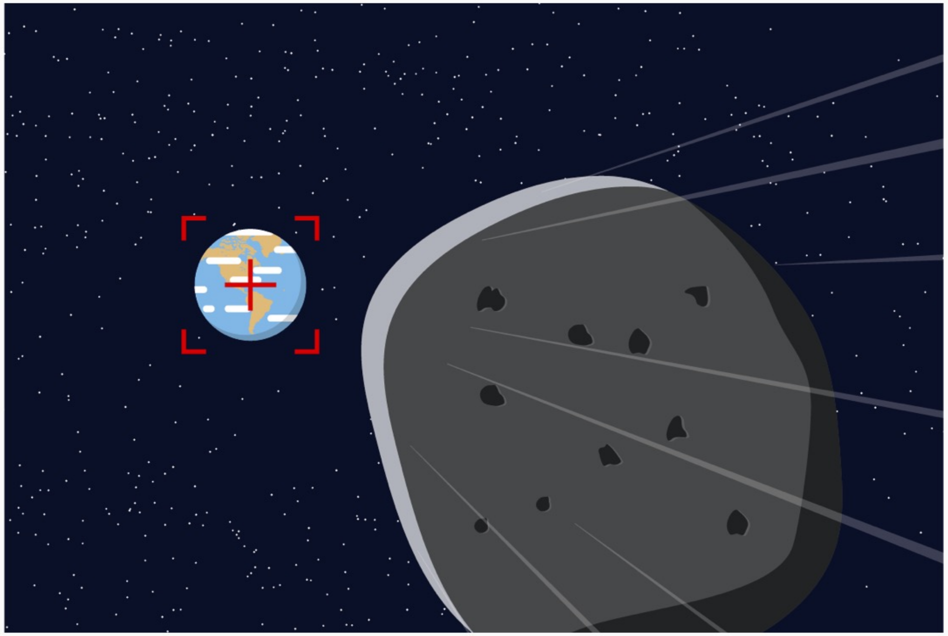
The Eagle Nebula is a very luminous open cluster of stars surrounded by dust and gas. The three pillars at the center of the image, made famous in an image by the Hubble Space Telescope, are being sculpted by the intense radiation from the hot stars in the cluster.
Source: Astrophysics & Astrophotography

Astronomy “from your armchair”

Introduction

Every so often you hear in the news about an asteroid that is passing close to Earth. Or maybe you’ve seen a movie about a killer asteroid headed our way, with catastrophic consequences if it hits us. Are there asteroids out there that might hit us? How do astronomers find them? And what would happen if one hit us?

Early detection of an asteroid that may pose a threat to Earth allows scientists more time to accurately determine its orbit and properties, and then choose the most effective intervention strategy. Vera C. Rubin Observatory excels at discovering new asteroids because it monitors large areas of the sky every night and can detect very dim moving objects. In this investigation you will learn how to decide if an asteroid poses a threat to hit Earth, and how much damage an impact could cause. Then you will have the opportunity to evaluate whether a newly-discovered asteroid by Rubin Observatory presents a threat to Earth.



Essential Questions

- **What factors determine if an asteroid could hit Earth?**
- **What is needed to accurately define the orbit of a newly-discovered Solar System object?**
- **What factors determine the amount of damage from an asteroid impact?**

Astronomy "from your armchair"

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Hazardous Asteroids: Page 2 of 30

RUBIN

Looking at Asteroids Close to Earth

Most asteroids orbit the Sun between the planets Mars and Jupiter, but some have orbits closer to Earth. The diagram at right shows the orbits of three asteroids and the Earth. Click on the names of the asteroids (Amor, Apollo, and Atira) to see their orbits.

Note: you can scroll to zoom in and out, and right click and drag to change the location of the objects in the window.

1. In this top-down view, which of the three objects appears to have an orbit that crosses Earth's orbit?

Apollo

2. Which of these three asteroids could hit Earth based on the orbit shown in this top-down view?

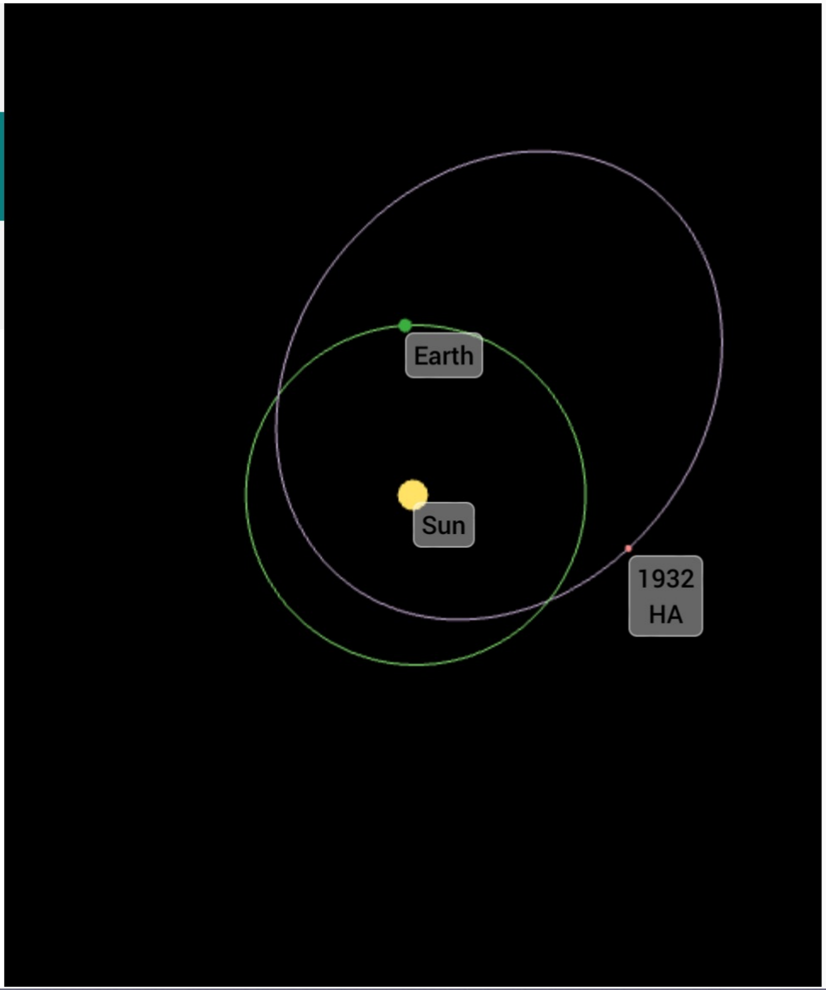
Apollo

Apollo

Amor

Apollo

Atira



Summary

Thanks to the rapid development of computer, sensor and telescope technologies, modern astronomical surveys detect and measure **tens of billions** of celestial objects.

It takes hundreds of experts (astronomers, physicists, mechanical and electronics engineers, software) to build a billion-dollar observatory.

Data mining and machine learning are playing an increasingly important role in astronomy and physics.

- LSST: a 10-year sky survey from Chile, starting in 2024
- multi-color time-resolved faint sky map
  - 20 billion galaxies
  - 20 billion stars
  - 10 billion alerts
  - "millions and millions" of supernovae, quasars, asteroids…

Backup slides…

- How could **you** become an astronomer?
  - curiosity
  - education

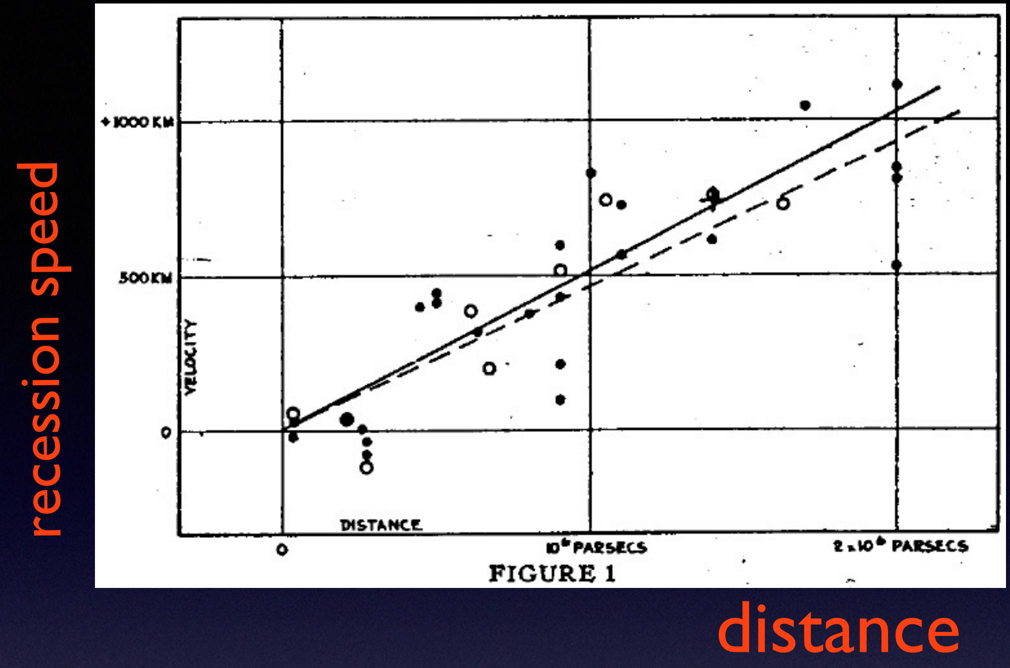
Not just in the case of astronomy but in general: if you want to be happy in life, aim for a job that you will love and like!

Being a scientist allows you to explore and understand the world around yourself, and use your brains, and have a reasonably comfortable life.

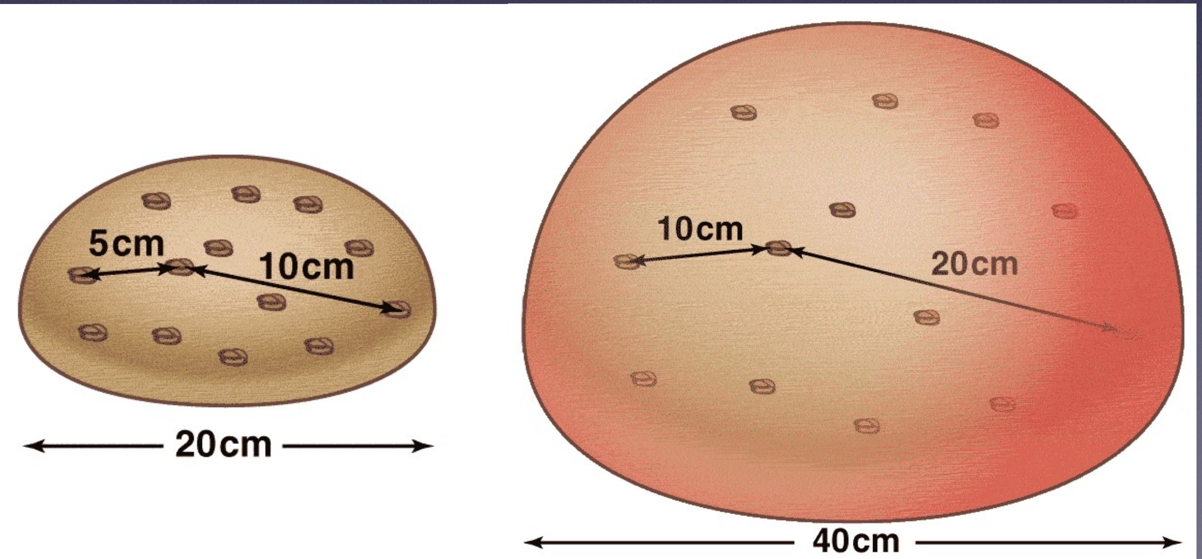
Education:

1) As with any quantitative science, lots and lots of math!
2) Physics - we apply the laws of physics to celestial objects.
3) And in this day and age, there is no way to avoid computers!
4) But also must have writing and reading skills, and communication skills, and be good at collaborative team work.

Old Cosmological Puzzles

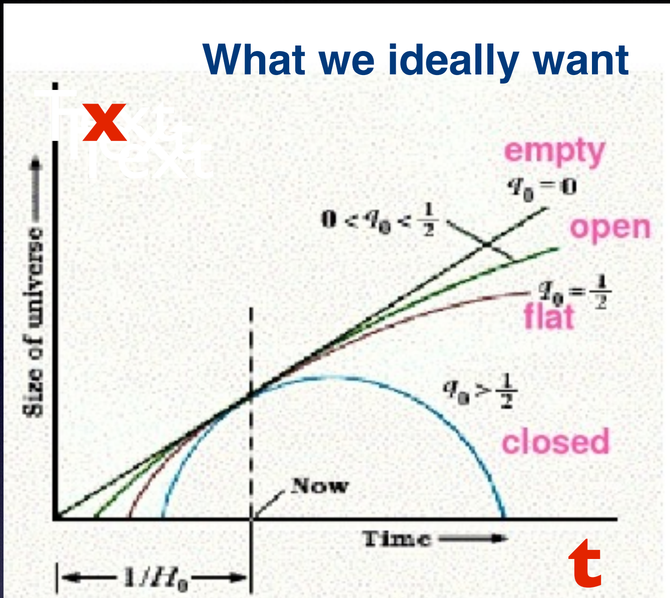


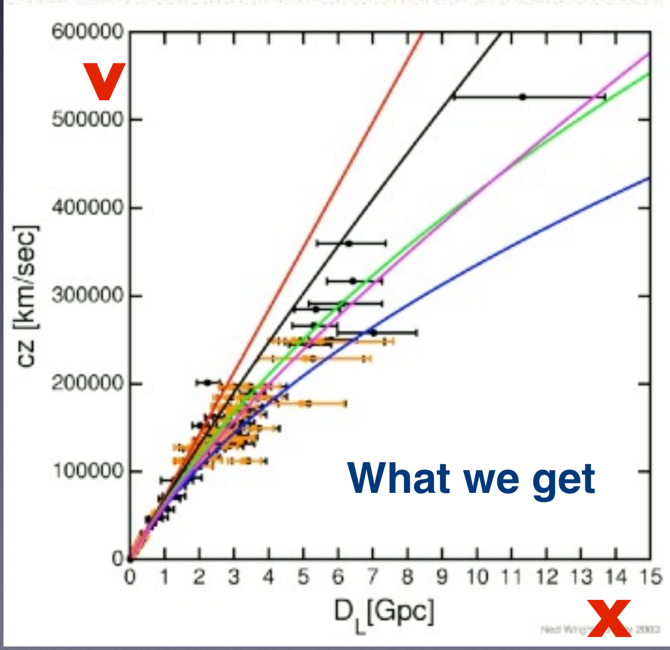
Edwin Hubble (1929): the Universe is expanding!



The Universe is expanding and it was expected that this expansion slows down with time because of gravity.

How do we measure expansion of the Universe?





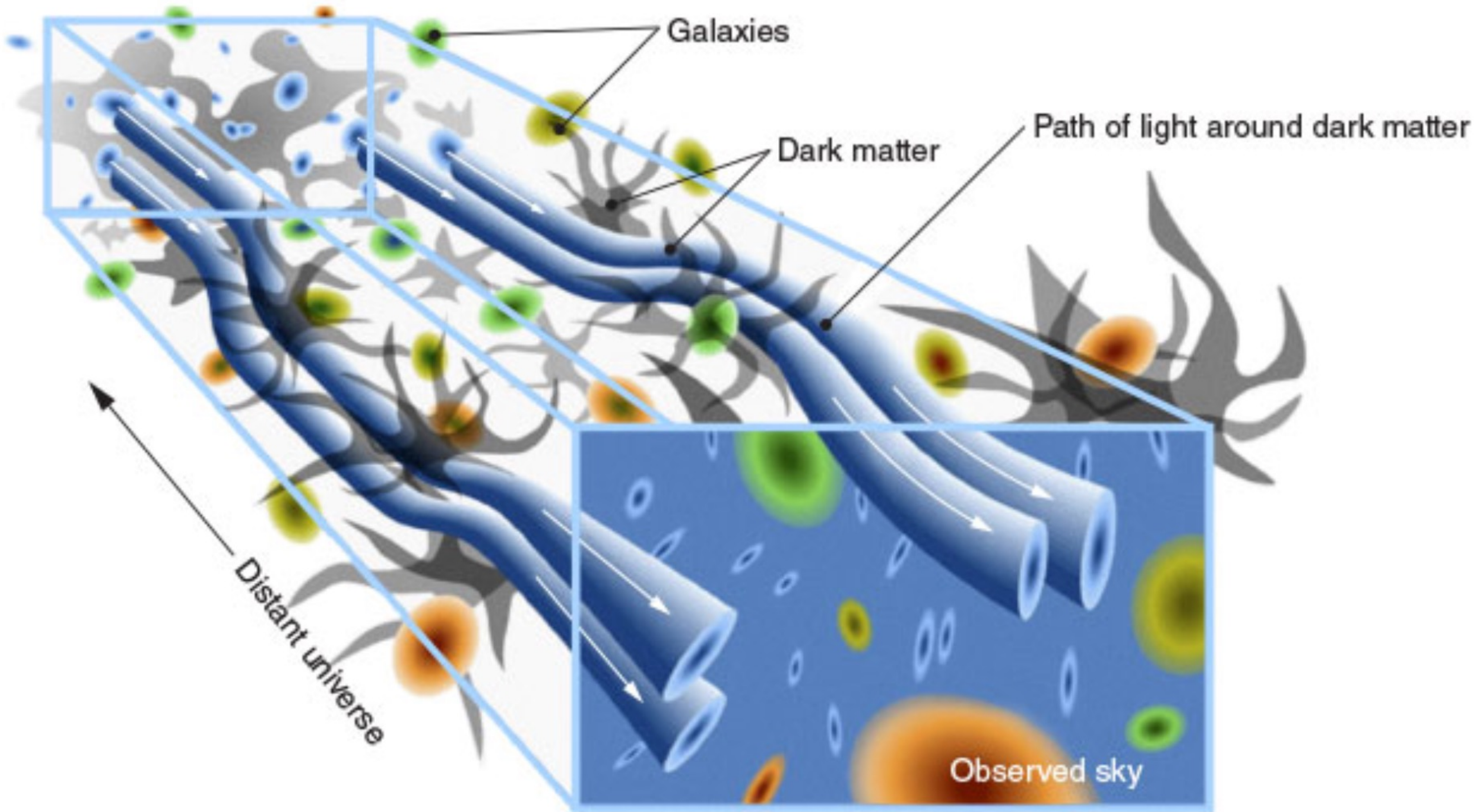
Ideally, we'd like to measure the size of the Universe as a function of time, x(t), but we can't.

Instead, we measure the distance to objects, x, and their velocity, v. That is, we have v(x).

And then we use our knowledge of physics (v = dx/dt) and models of the Universe (given what we assume the Universe is made of, how should it expand?) to get x(t) and v(t): **dt = dx / v(x)**

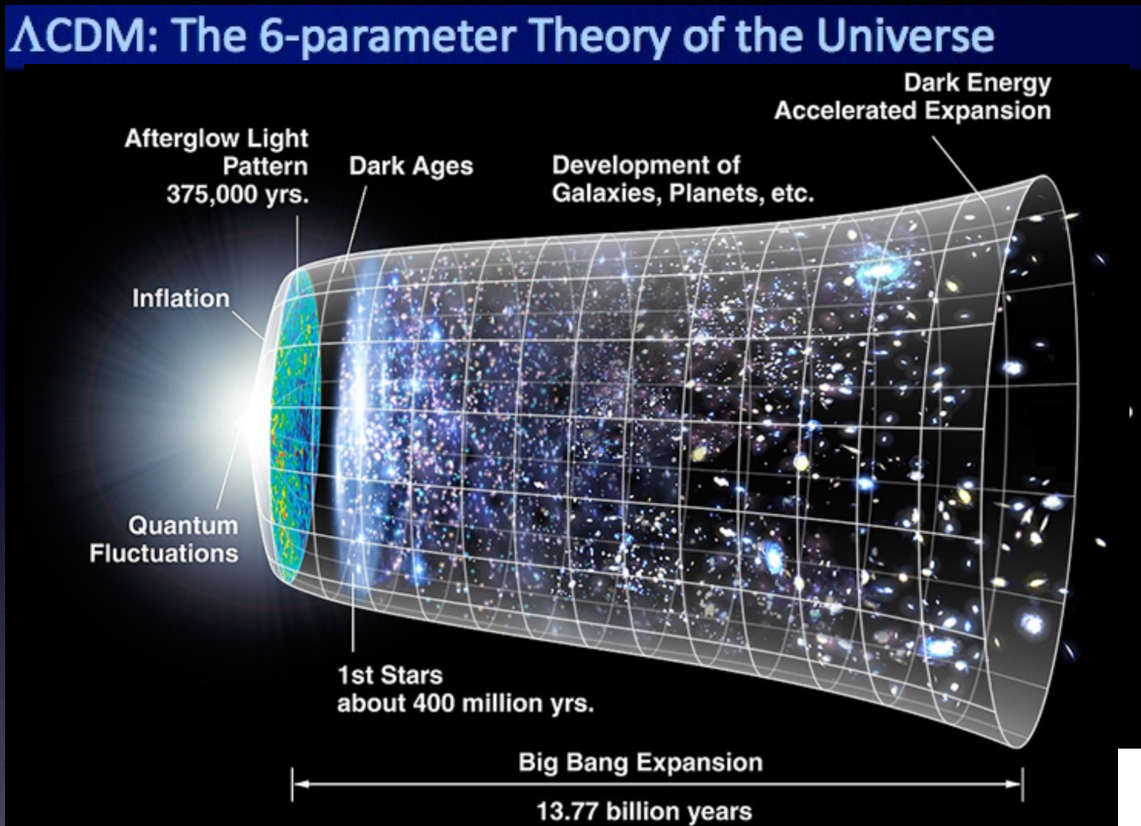
In other words, our knowledge of physics enables us to interpret astronomical measurements using **models** of the Universe and in turn, understand the makeup and history of the Universe!

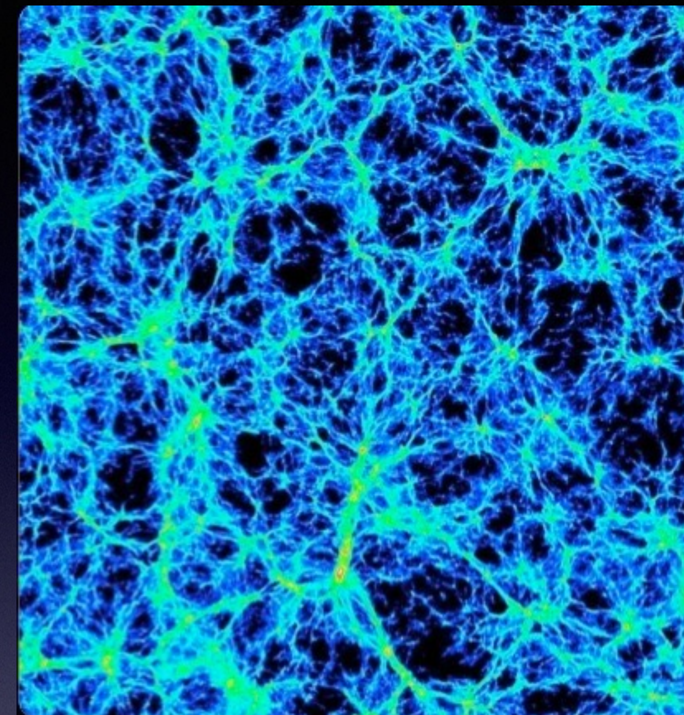
Weak gravitational lensing of galaxies

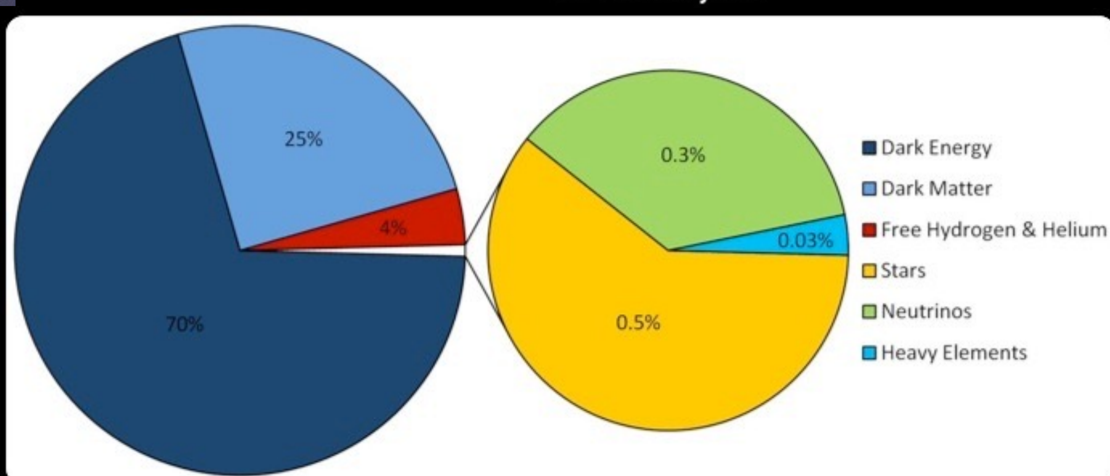


Light traveling to Earth from galaxies in the distant universe is bent by the gravitational force of dark matter encountered along the way—a phenomenon called gravitational lensing. (Image courtesy of LSST Corporation.)

New Cosmological Puzzles







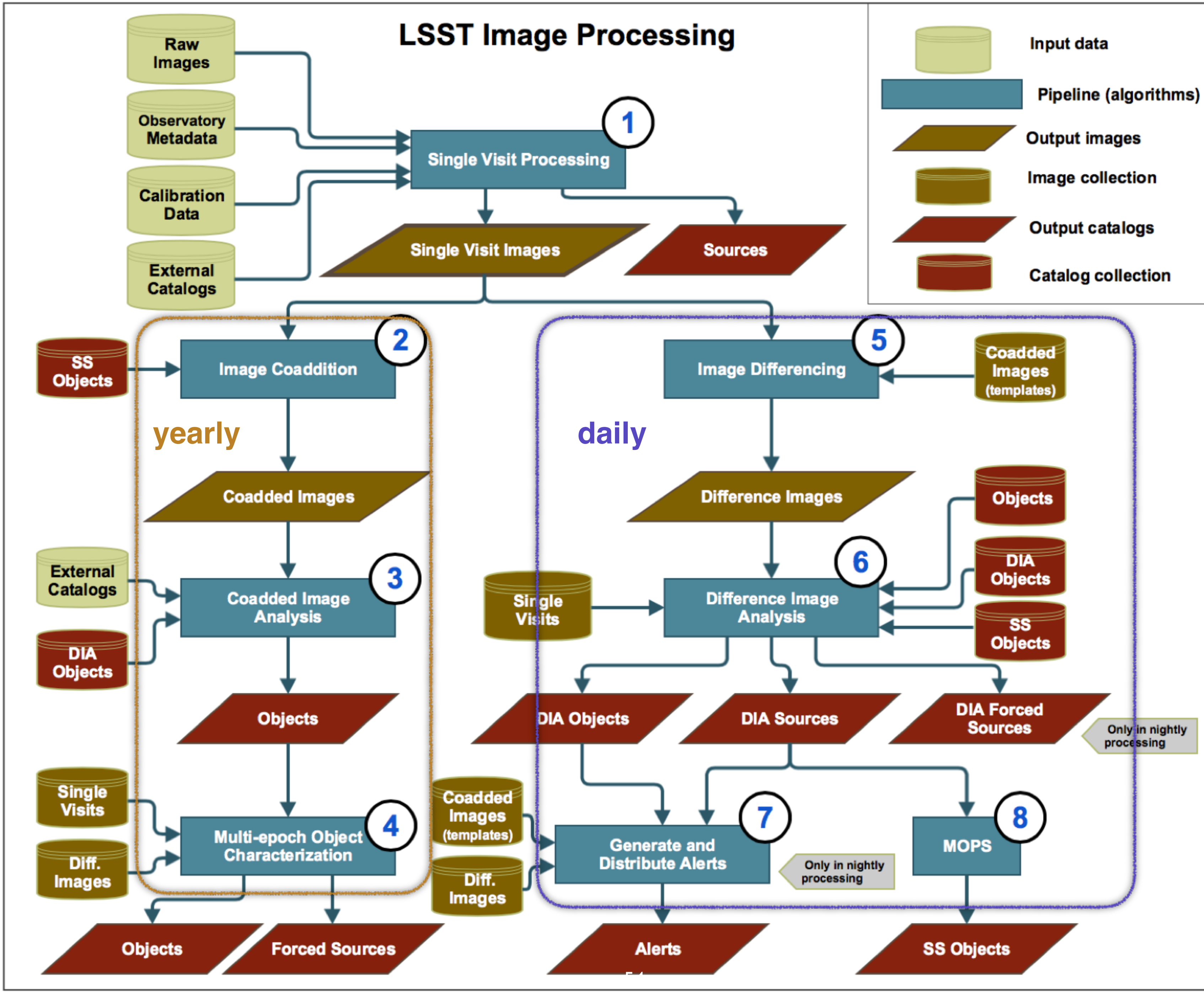
The modern cosmological models can explain all observations, but need to **postulate** dark matter and dark energy (though gravity model could be wrong, too)

Modern Cosmological Probes

LSST

- **Cosmic Microwave Background (CMB)** (the state of the Universe at the recombination epoch, at redshift ~1000) ✗
- **Weak Lensing:** growth of structure ✓
- **Galaxy Clustering:** growth of structure ✓
- **Baryon Acoustic Oscillations:** standard ruler ✓
- **Supernovae:** standard candle ✓

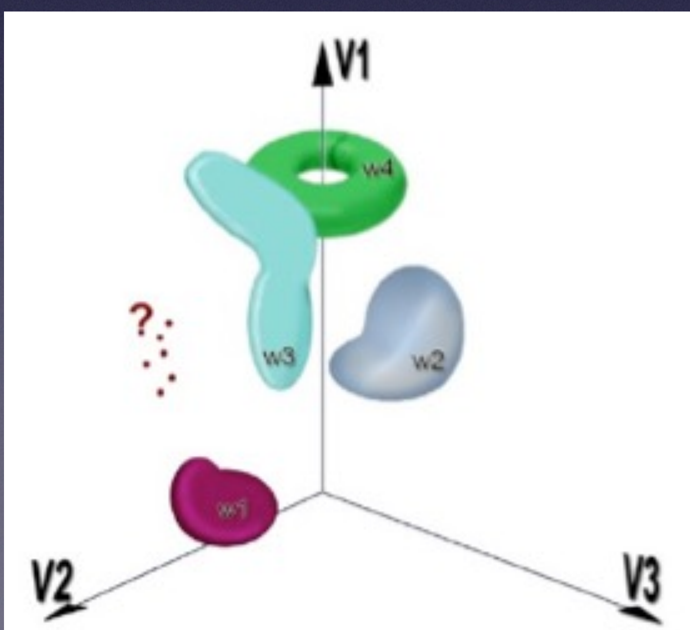
Except for CMB, for precise cosmological measurements need to detect and precisely measure properties of billions of galaxies and millions of supernovae


LSST Image Processing
Input data
Pipeline (algorithms)
Output images
Image collection
Output catalogs
Catalog collection
Raw Images
Observatory Metadata
Calibration Data
External Catalogs
Single Visit Processing
1
Single Visit Images
Sources
yearly
daily
SS Objects
Image Coaddition
2
Coadded Images
External Catalogs
DIA Objects
Coadded Image Analysis
3
Objects
Single Visits
Diff. Images
Multi-epoch Object Characterization
4
Objects
Forced Sources
Image Differencing
5
Coadded Images (templates)
Difference Images
Objects
DIA Objects
SS Objects
Single Visits
Difference Image Analysis
6
DIA Objects
DIA Sources
DIA Forced Sources
Only in nightly processing
Coadded Images (templates)
Diff. Images
Generate and Distribute Alerts
7
Only in nightly processing
MOPS
8
Alerts
SS Objects

Statistical analysis of a massive LSST dataset

- A large (100 PB) database and sophisticated analysis tools: for each of 40 billion objects there will be about 1000 measurements (each with a few dozen measured parameters)

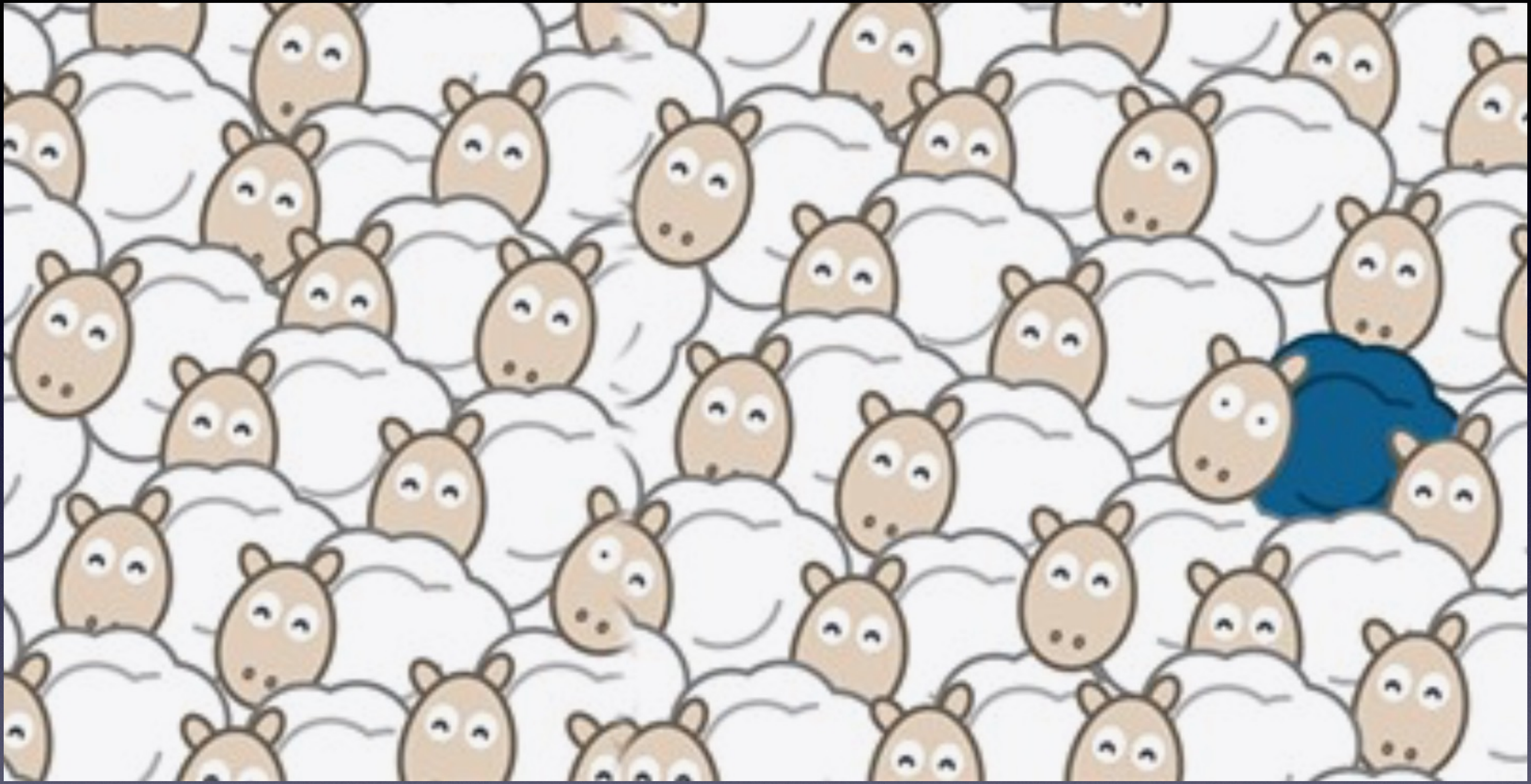
Data mining and knowledge discovery



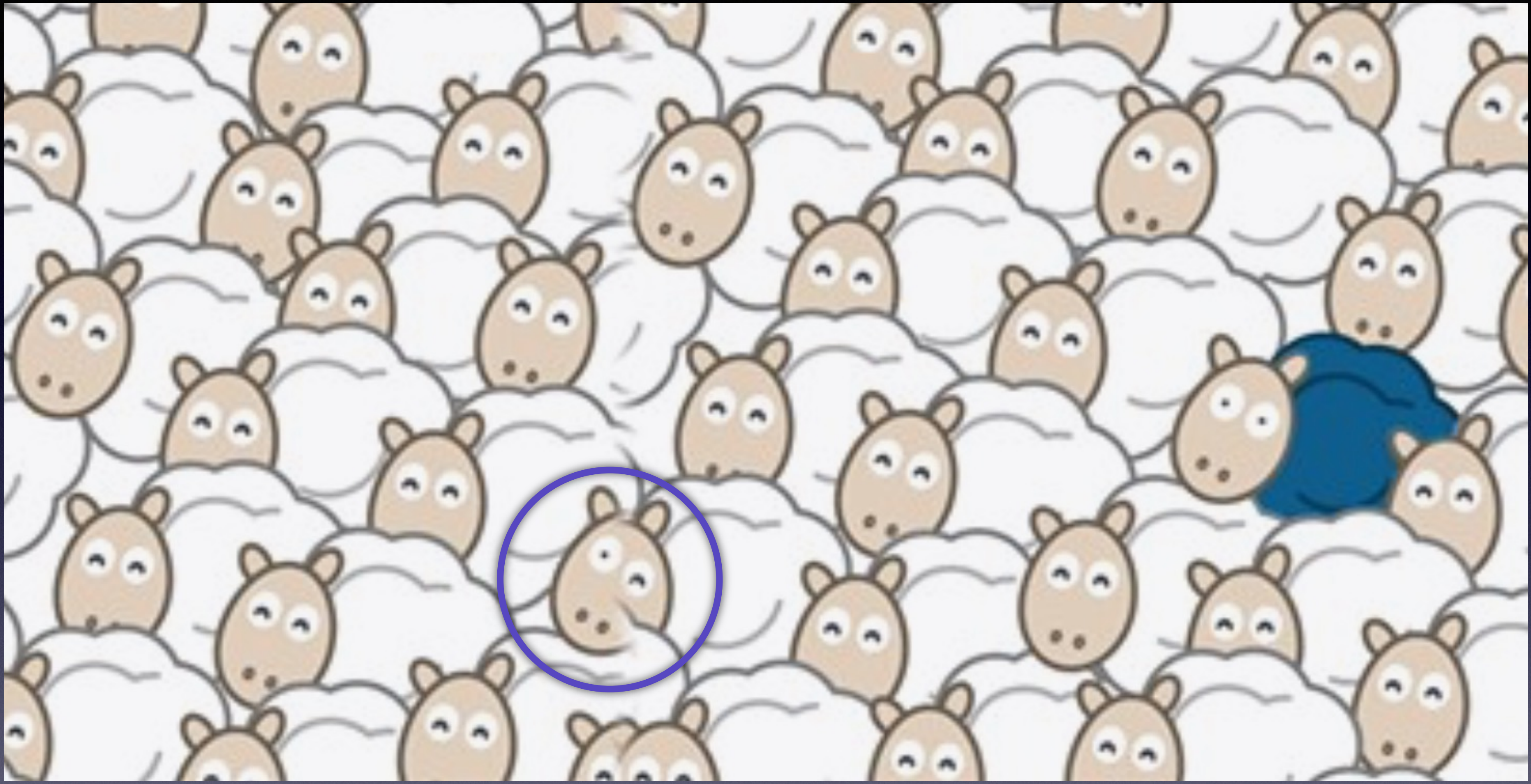
- 10,000-D space with 40 billion points
- Characterization of known objects
- Classification of new populations
- Discoveries of unusual objects

Clustering, classification, outliers

Statistical analysis: search for outliers (anomalies)



Statistical analysis: search for outliers (anomalies)



Automated scheduling of LSST observations