Legacy Survey of Space and Time: the Greatest Movie of All Time!

Željko Ivezić, University of Washington/AURA
Rubin Observatory Construction Director
LSST Head of Science

VERA C. RUBIN OBSERVATORY

University of Nova Gorica, Vipava, May 12, 2023

Outline

- What is modern astronomy about?
- Why do astronomers and physicists want Legacy Survey of Space and Time?
- Rubin Observatory construction status

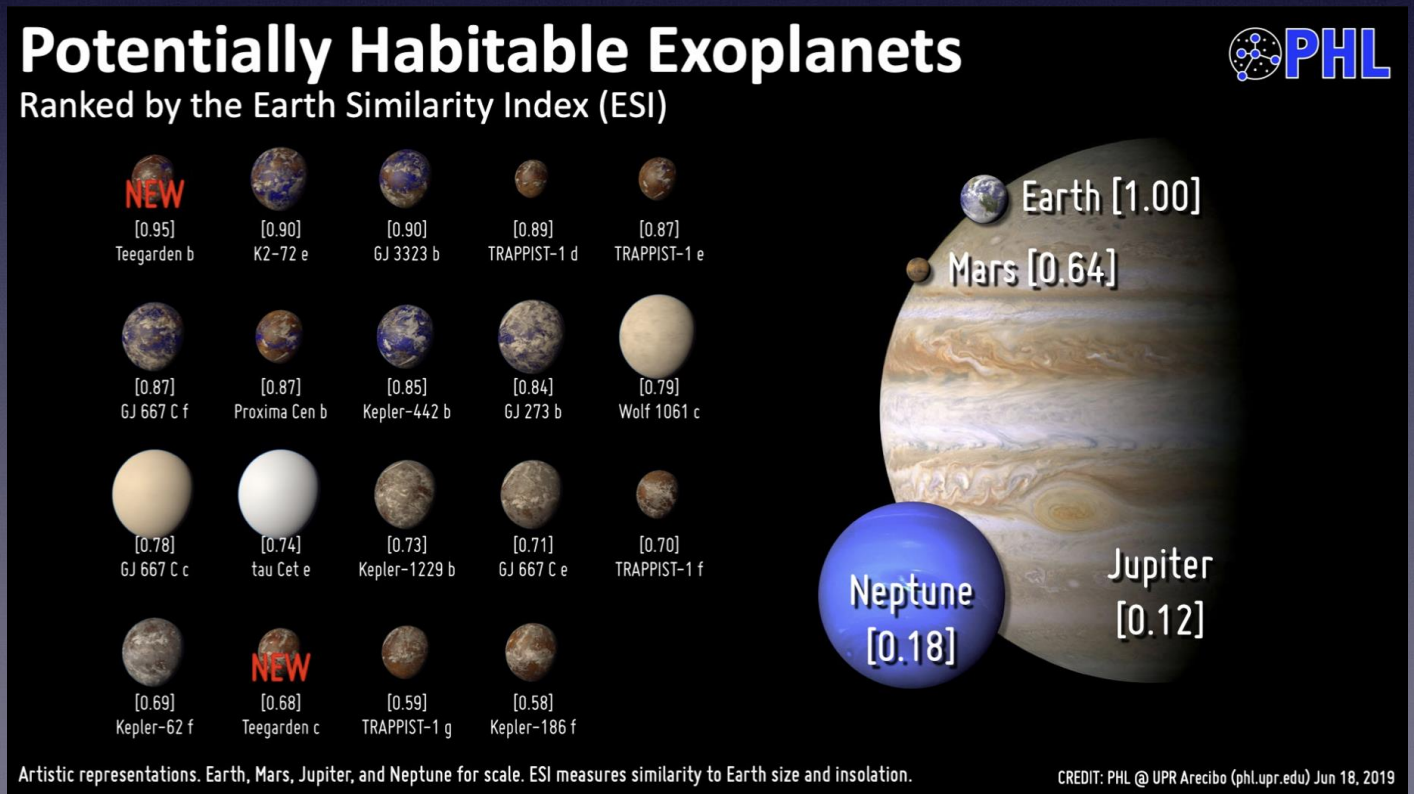
Legacy Survey of Space and Time (LSST) will be the first 10-year project at the Vera C. Rubin Observatory, starting next year (I hope!)

- # What is modern astronomy about?
  ## - search for life elsewhere

Over the last few 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?

What is modern astronomy about?
- search for life elsewhere

Over the last few 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?



- What is modern astronomy about?
  - search for life elsewhere
  - understanding the Universe

We have known for about 100 years that the Universe is expanding.

Hubble (1929)

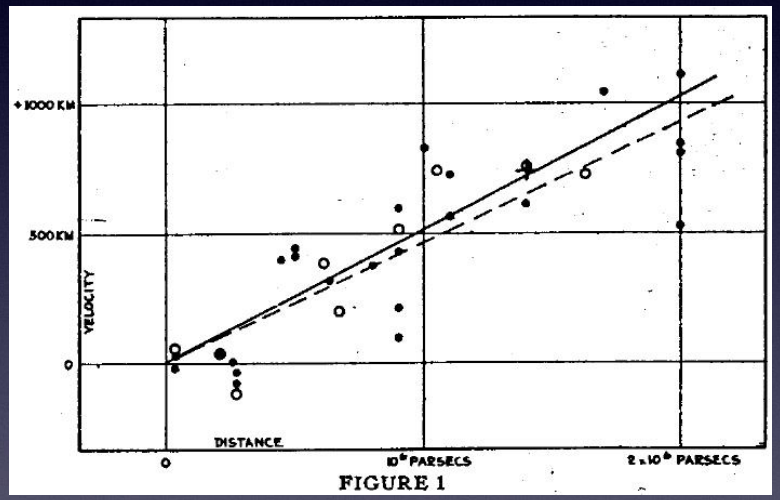
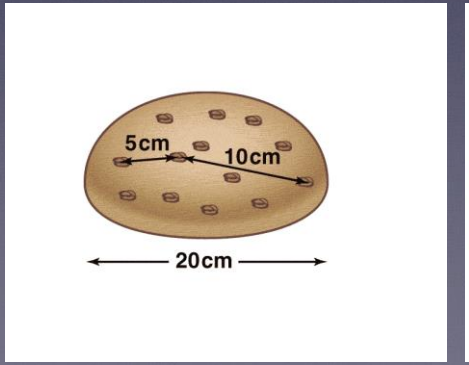


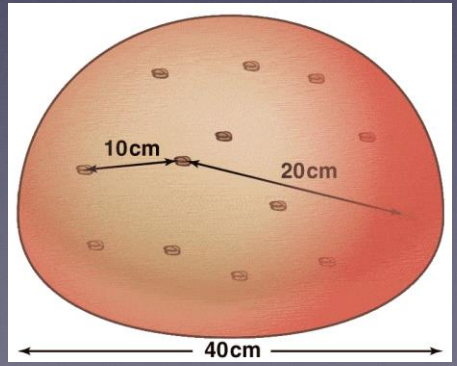
FIGURE 1

recession speed of a galaxy

distance


Edwin Hubble (1889-1953)





- What is modern astronomy about?
  - search for life elsewhere
  - understanding the Universe

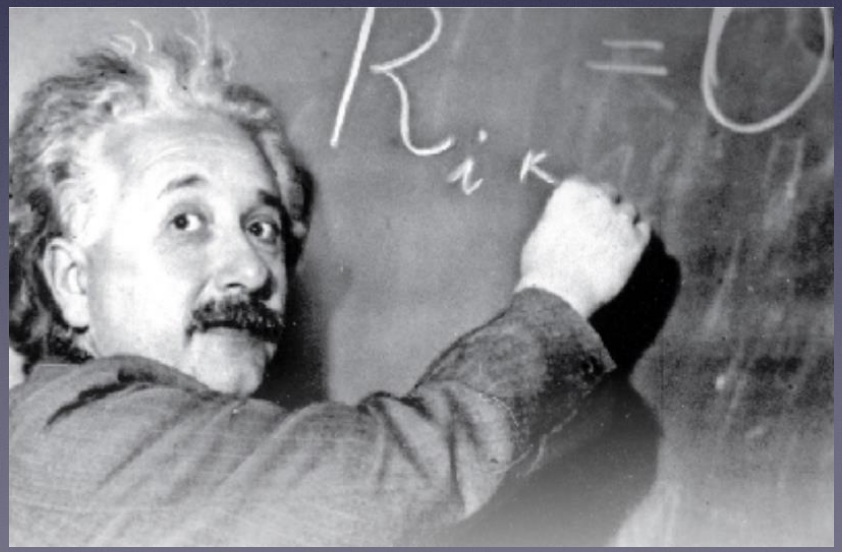
We have known for about 100 years that the Universe is expanding. About a decade ago, it was discovered that this expansion is accelerating. We are uncertain about what this acceleration means; the two most plausible explanations are
1) some mysterious and weird fluid called dark energy, or
2) perhaps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

- What is modern astronomy about?
  - search for life elsewhere
  - understanding the Universe

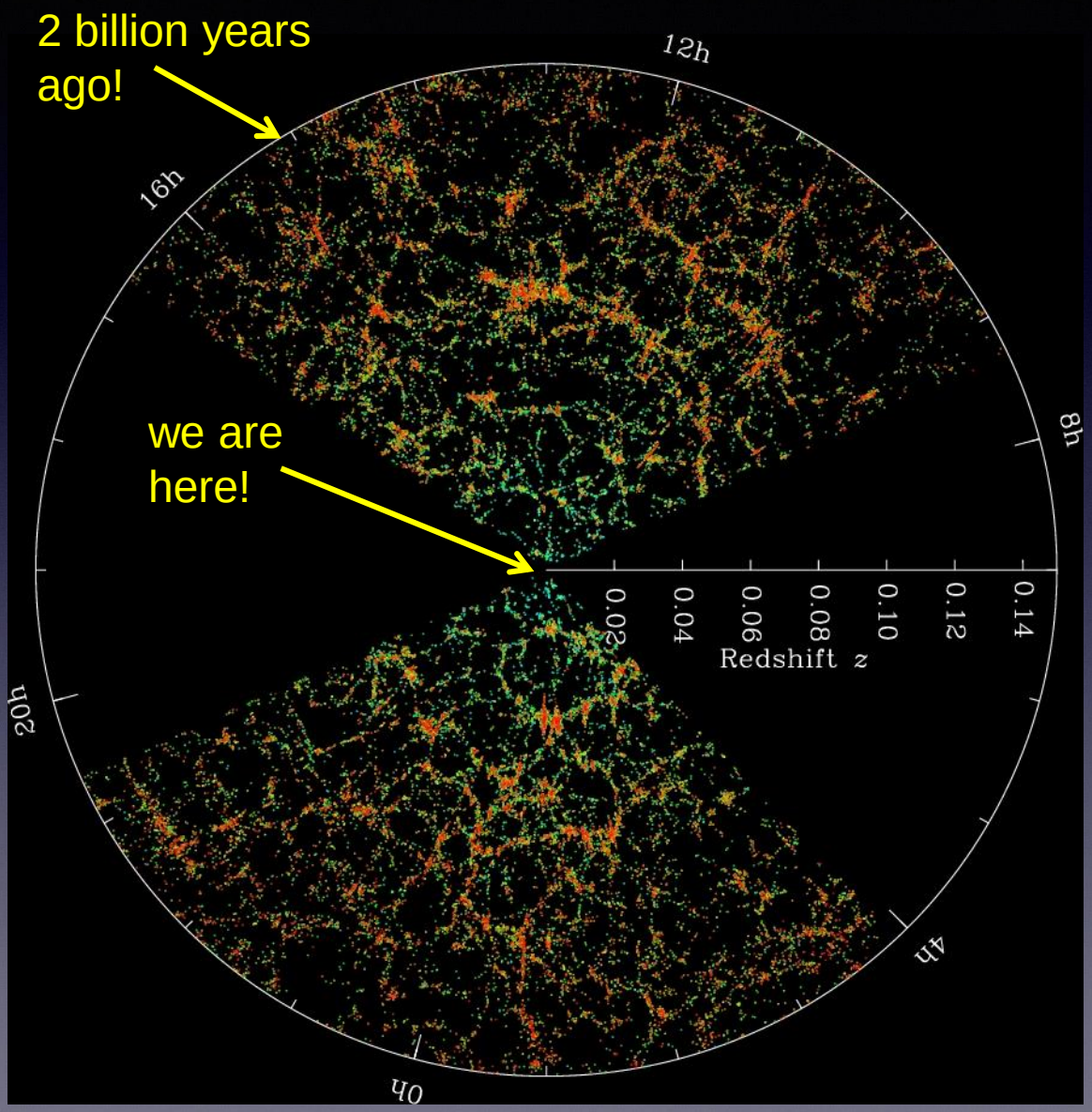
We have known for about 100 years that the Universe is expanding. About a decade ago, it was discovered that this expansion is accelerating. We are uncertain about what this acceleration means; the two most plausible explanations are
1) some mysterious and weird fluid called dark energy, or
2) perhaps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

Was Einstein wrong?

To distinguish between these two possibilities, we need much better astronomical data...



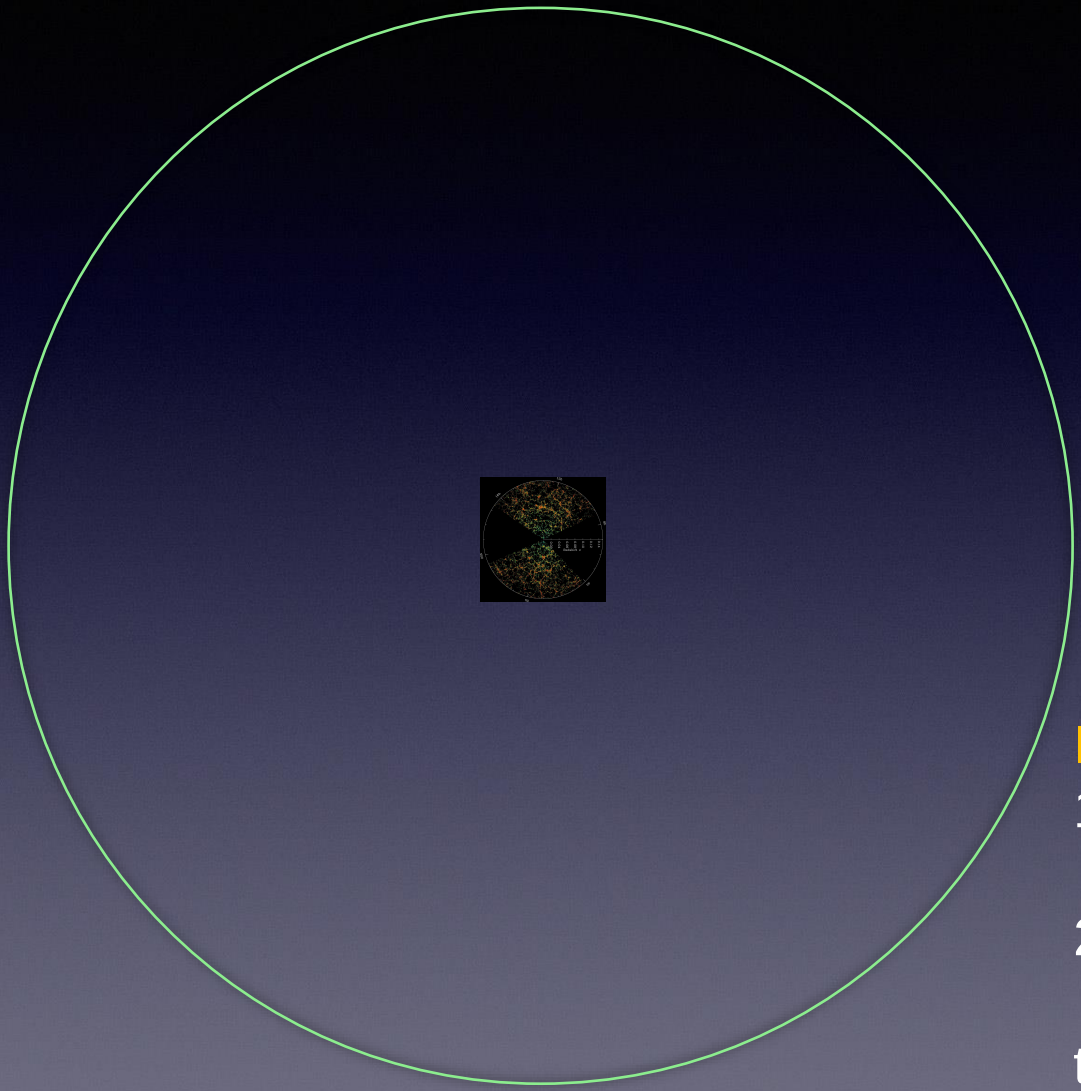
Spatial distribution of galaxies



Left: each dot is one galaxy from the Sloan Digital Sky Survey with 1 million galaxies

Note that the galaxy distribution is highly **inhomogeneous:** statistical details of that distribution contain rich cosmological information, that is, information about the evolution of the Universe since the Big Bang 14 billion years ago

Spatial distribution of galaxies



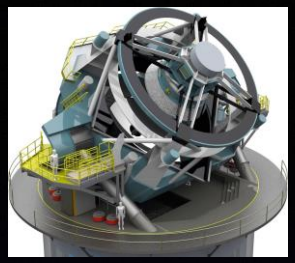
LSST goal: map 20 billion galaxies to a ten times larger distance limit than possible today!

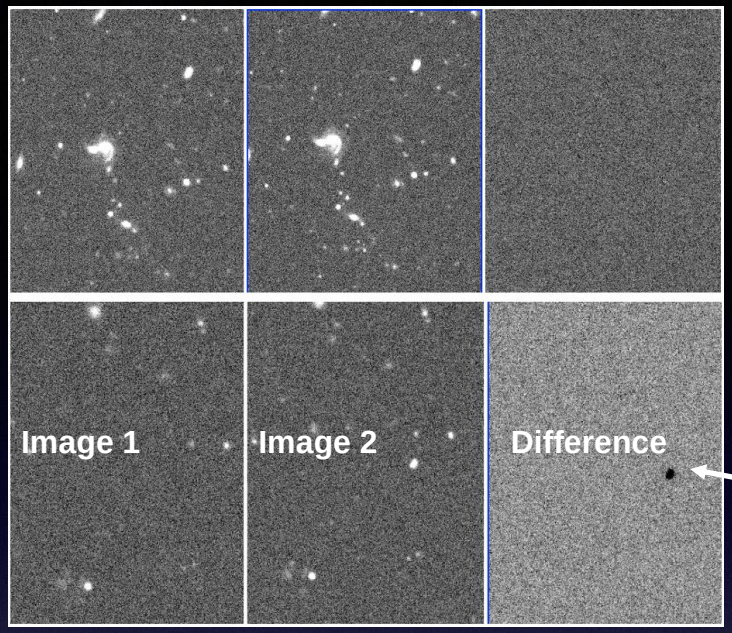
But how??

In a nutshell, we need:

1) a large telescope mirror to be sensitive, and
2) a large field-of-view for sky scanning speed,

to obtain the greatest sky survey of all time: LSST



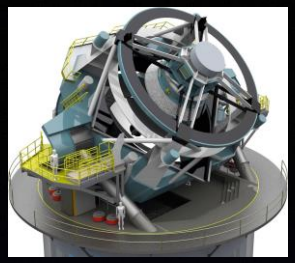


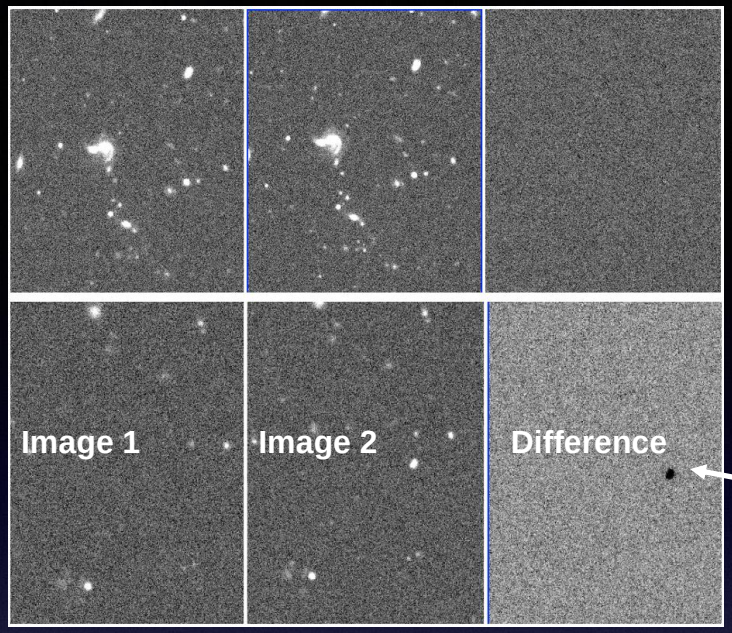
Transients with LSST

Additional "followup" data obtained to:
- confirmation and classification
- provide better temporal resolution
- use different filters/wavelengths
- obtain spectra (distance!)
- other measurements (e.g. polarimetry)

Alert!

Image 1 Image 2 Difference





Transients with LSST

Additional "followup" data obtained to:
- confirmation and classification
- provide better temporal resolution
- use different filters/wavelengths
- obtain spectra (distance!)
- other measurements (e.g. polarimetry)

Alert!

Image 1 Image 2 Difference

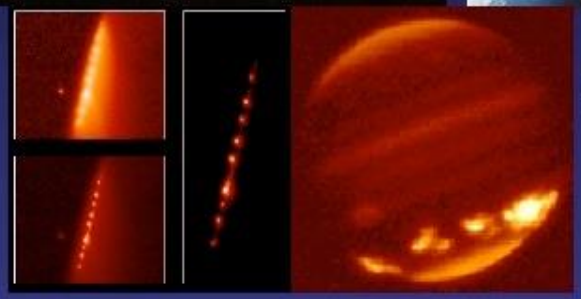
Alerts can trigger "Followup" observations:

~10 billion alerts

ANDREJA GOMBOC
CENTER FOR ASTROPHYSICS AND COSMOLOGY
UNIVERSITY OF NOVA GORICA
SLOVENIA

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)

photomontage!

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

Science motivation for undertaking the Legacy Survey of Space and Time

More details about science drivers and system design: Ivezic et al. (2019): ls.st/lop

Expansion and history of the Universe and the growth of structure
(dark matter, dark energy, cosmology, spatial distribution of galaxies, gravitational lensing, supernovae): "Was Einstein right?"

Time domain: what changes on the sky?
(cosmic explosions, variable stars, unknown unknowns)

The Solar System structure
(near-Earth hazardous asteroids, main-belt asteroids, trans-Neptunian objects, comets)

1

The Milky Way structure
(stars as tracers of the structure and evolution of our Galaxy, interstellar matter, the physics of stars)

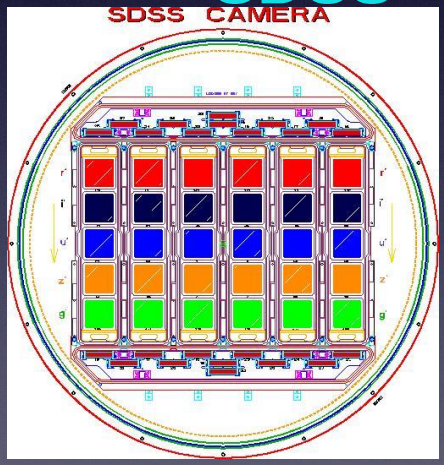
3

A key point: most of science programs will utilize the same dataset.

Modern observational methods in astronomy:

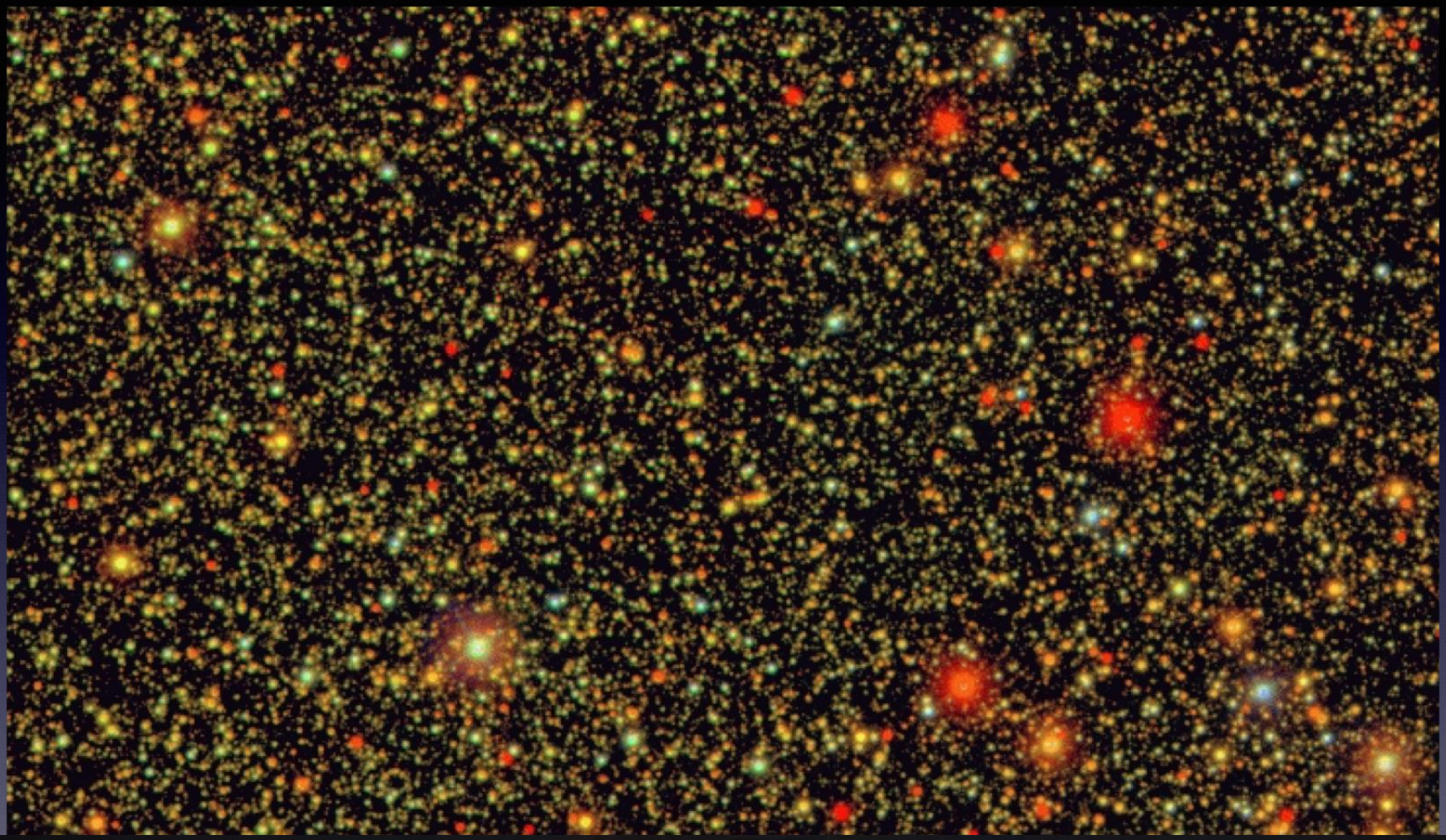
- Large telescopes on the ground
- Telescopes above the atmosphere (spacecrafts)
- Large sky surveys: digital sensor technology (CCD), information technology (data processing and data distribution), many objects observed at the same time

SDSS



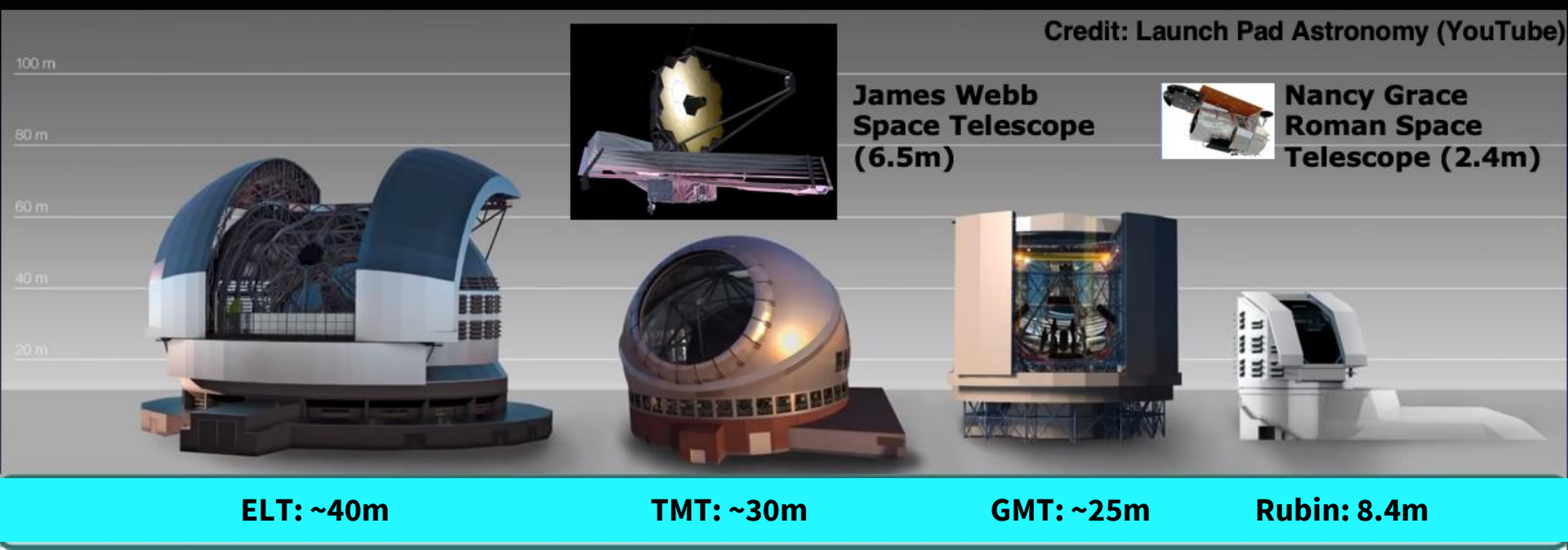
Modern astronomical surveys detect billions of objects: huge statistical power for studying the history and structure of the Universe

SDSS view along the Milky Way Disk



Moon for scale

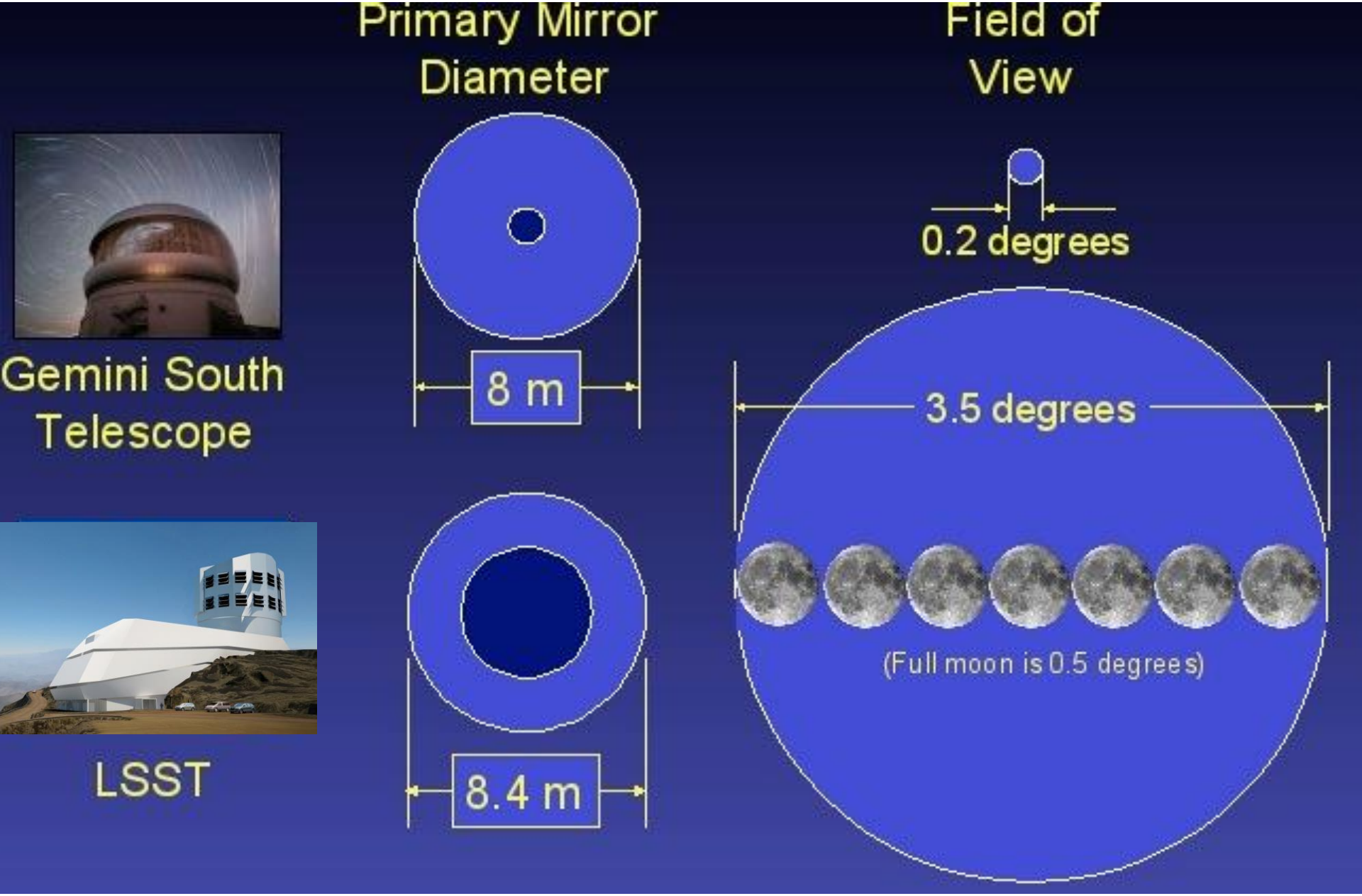
Naked eye: 1 star in 200x larger area



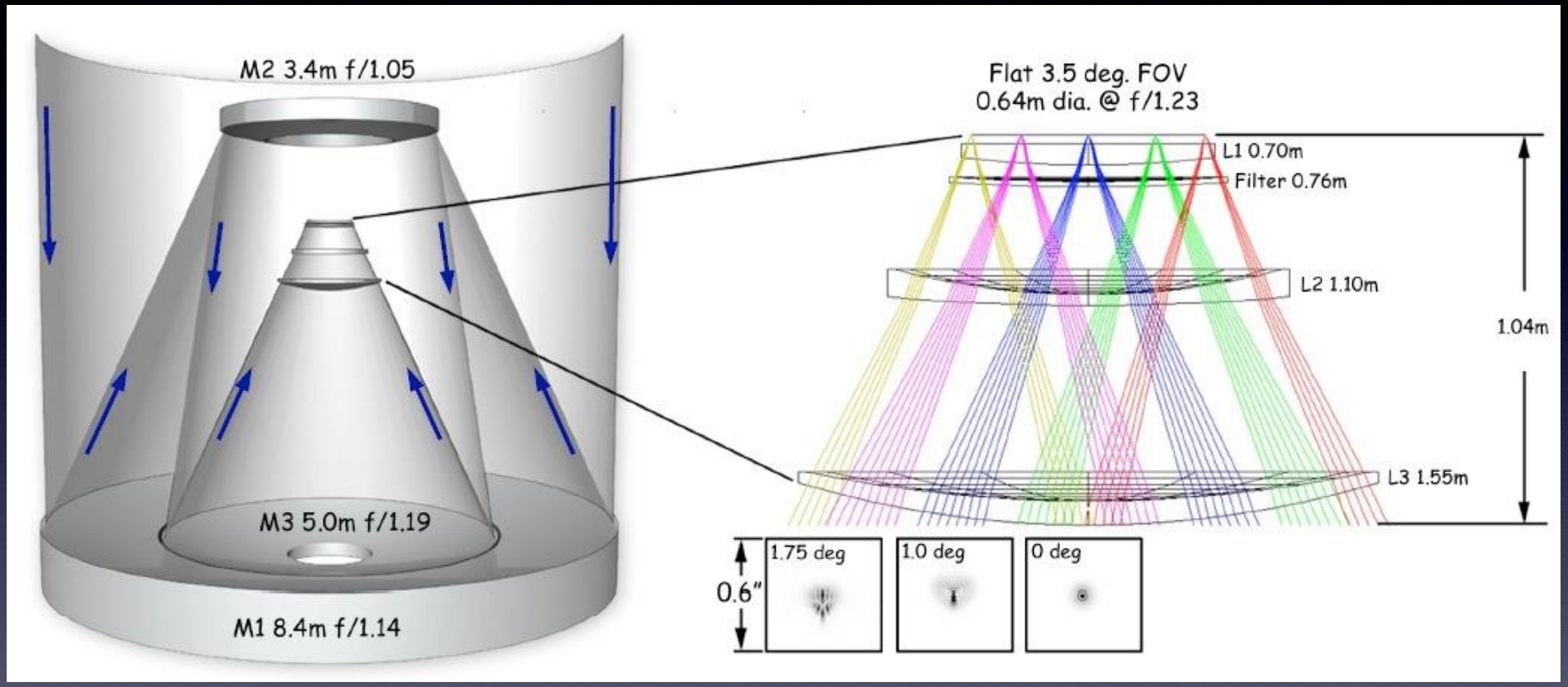
Rubin Obs. will not have the largest mirror but will have by far the largest product of the mirror area and the field-of-view size (etendue or throughput)

Vera C. Rubin (1928-2016)

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

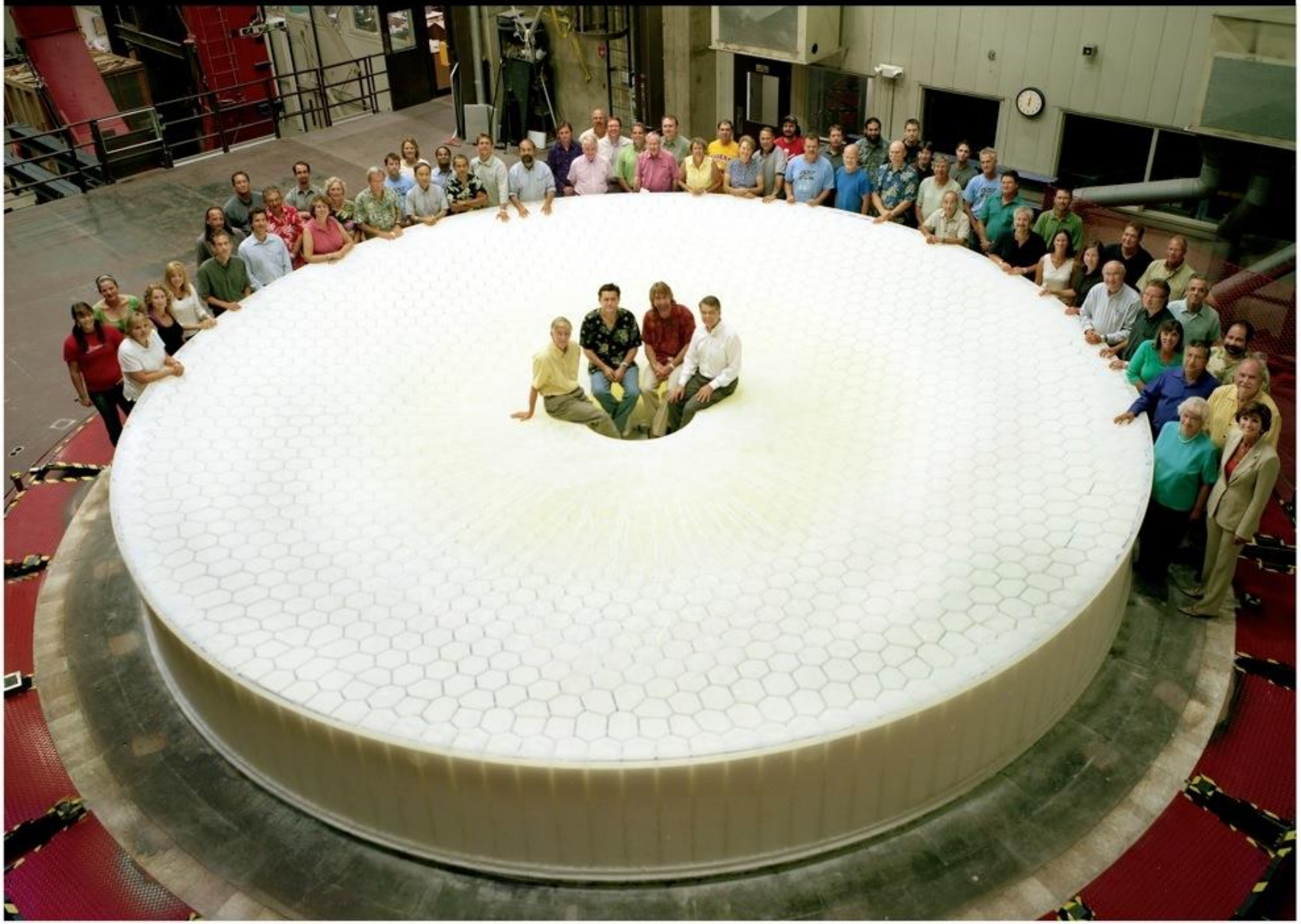


Optical Design for LSST



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



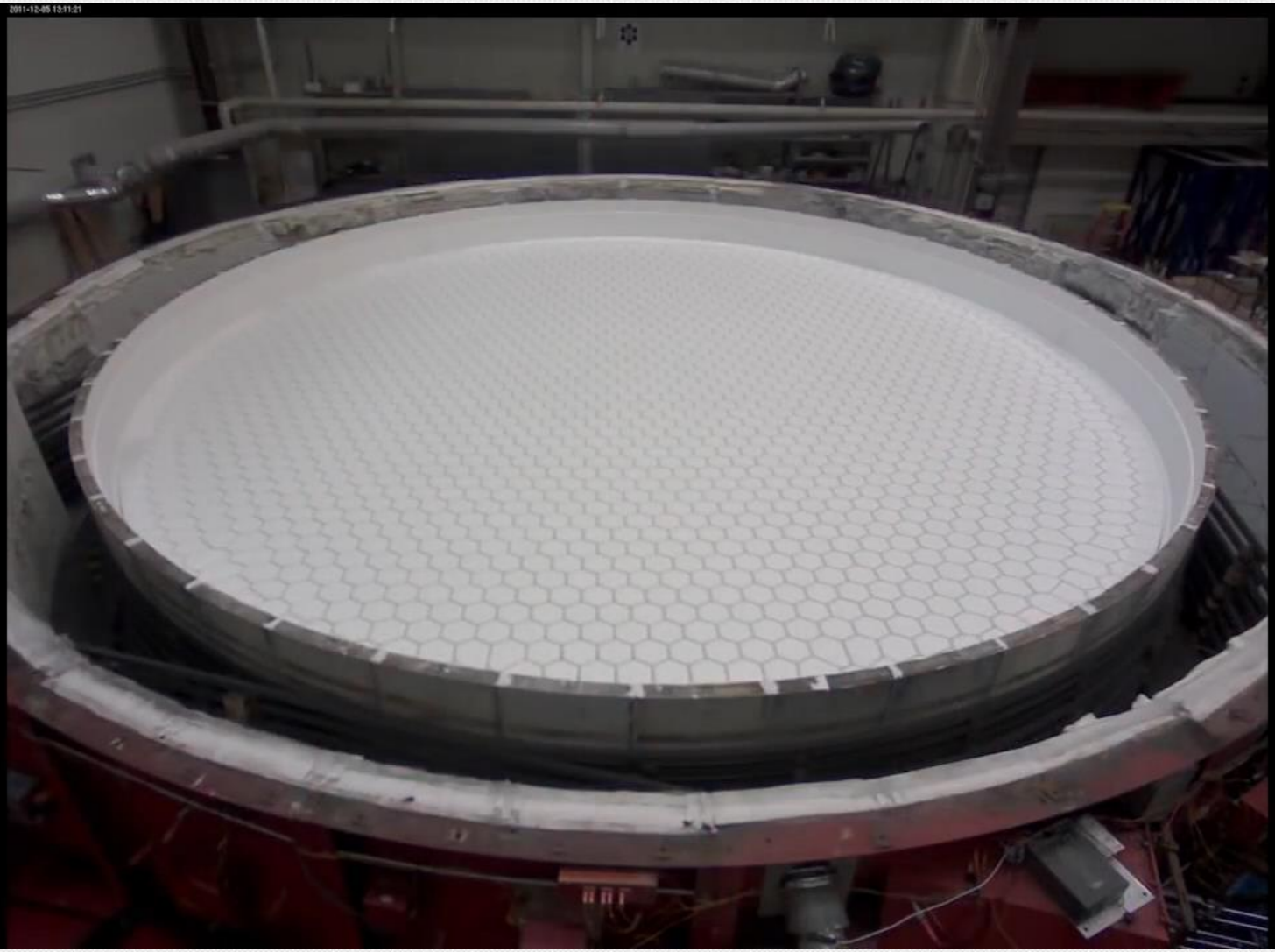
LSST Primary/Tertiary Mirror Blank

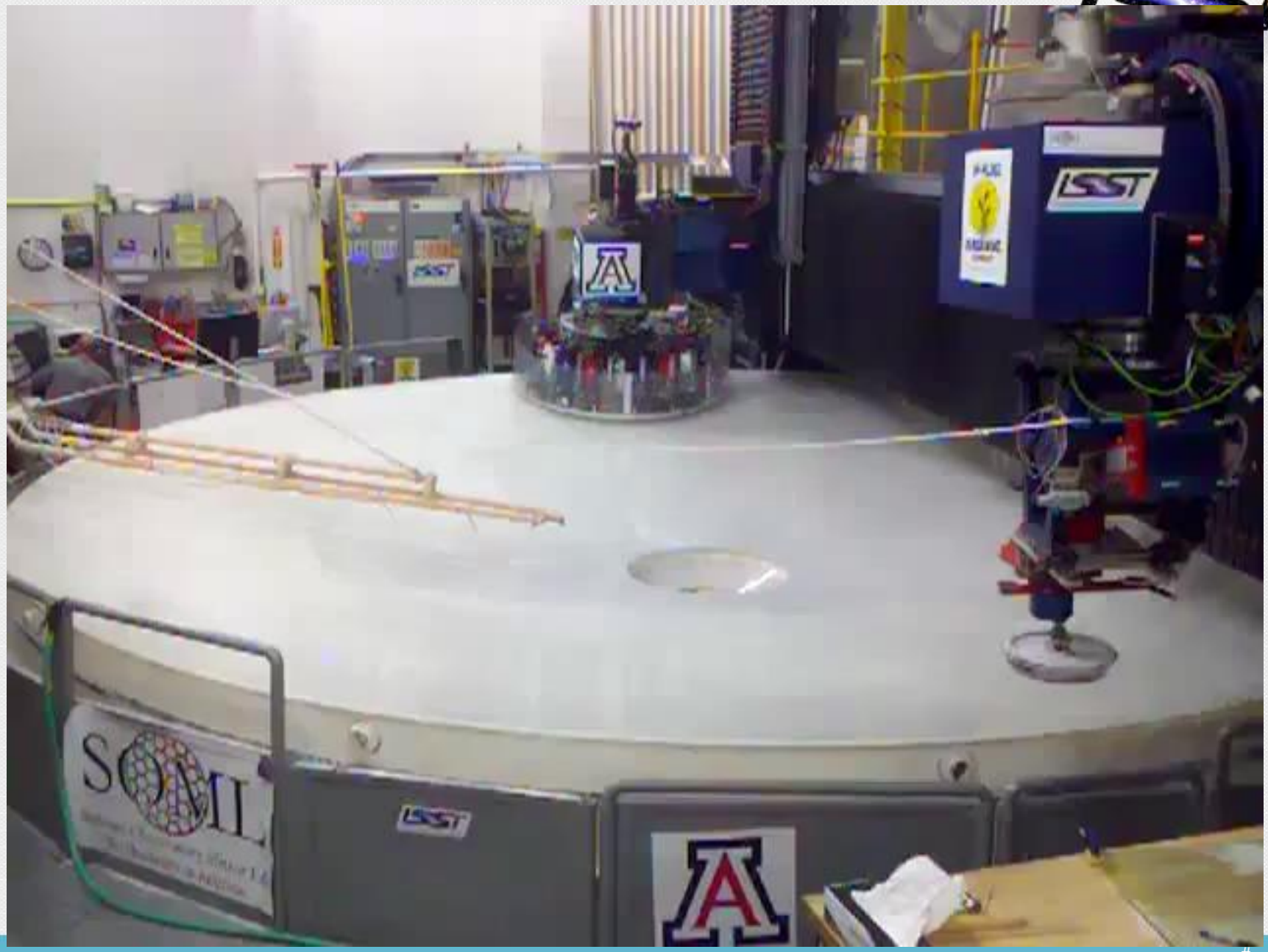
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

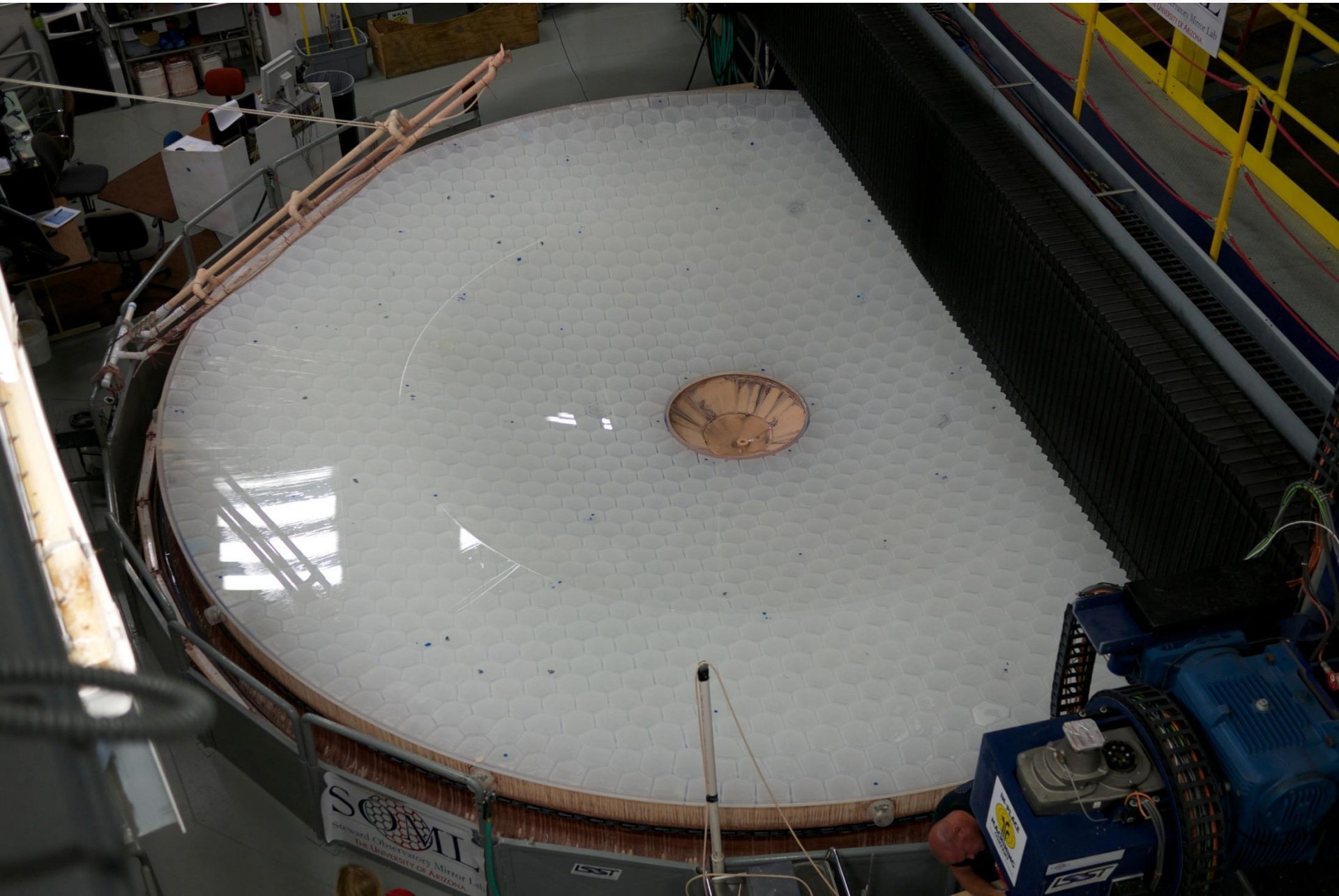
The University of Arizona, Tucson Arizona

SOML

Large Synoptic Survey Telescope

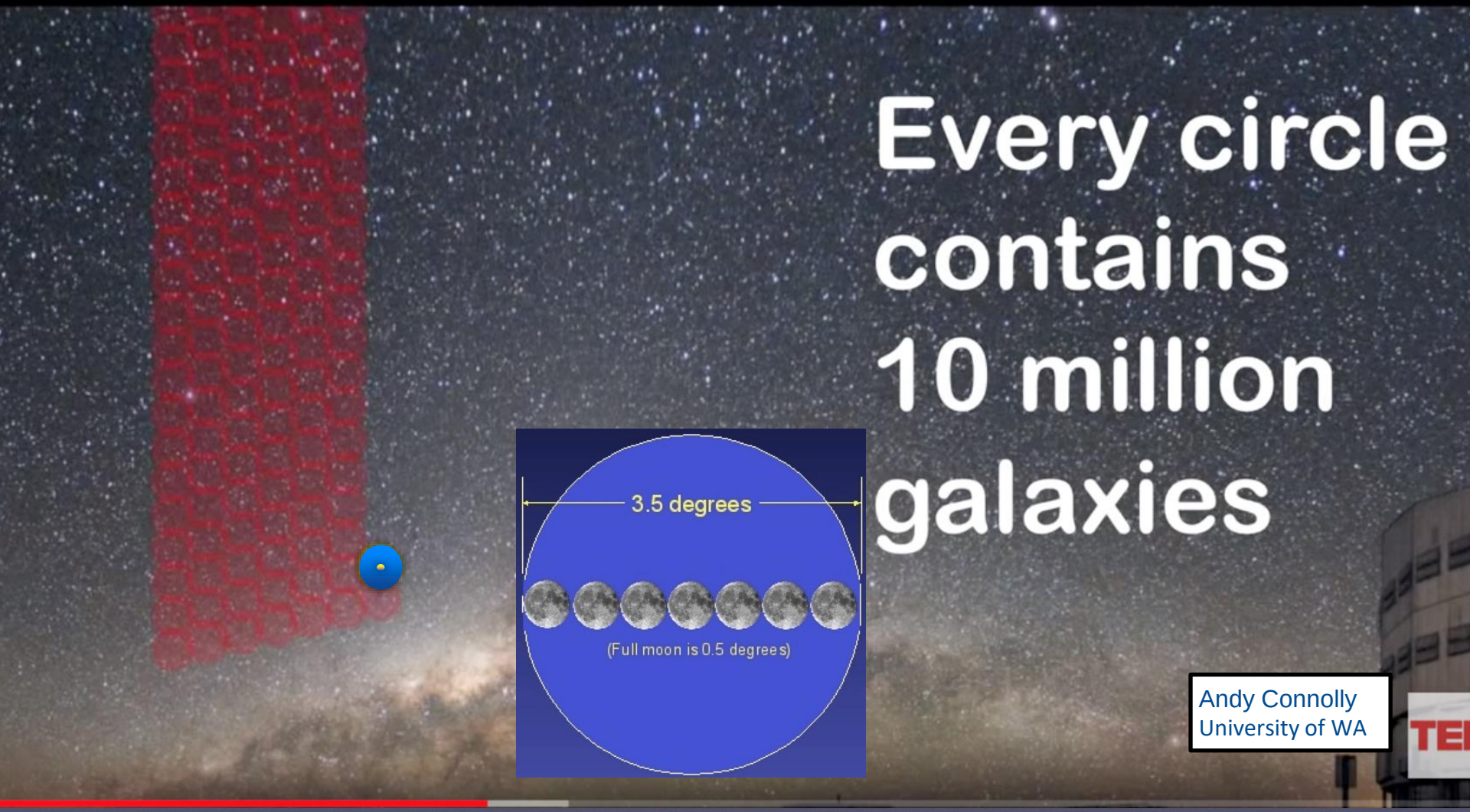

2011-12-05 13:11:21


SOML
LSST
LSST
LSST


SOML
Steward Observatory Mirror Lab
The University of Arizona

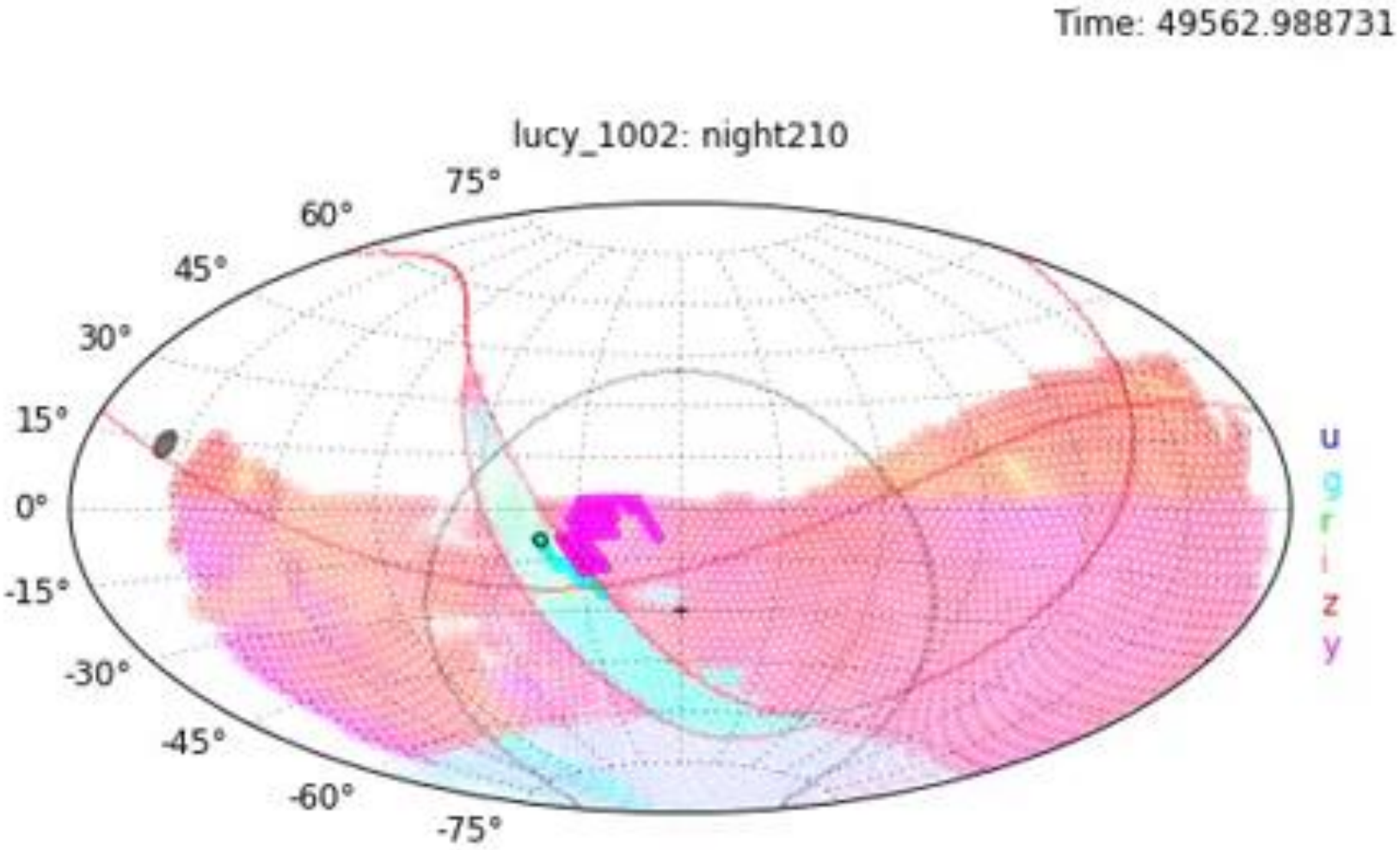
Basic idea behind LSST: **a uniform sky survey**

- 90% of time will be spent on a uniform survey:
  every 3-4 nights, the whole observable sky will be scanned twice per night
- in 10 years, half of the sky will be imaged about 1000 times:
  a digital color movie of the sky
- ~100 petabytes, or 100,000 terabytes, of data:
  about a billion 16 megapixel images, enabling **measurements for 40 billion objects**



Each red circle marks a previously obtained image as the small blue circle (the field of view, also shown magnified in the middle) moves across the sky. Each 3,200 megapixel image takes approximately 40 seconds so all these 120 or so red circles correspond to a bit more than an hour of data taking.

Automated scheduling of LSST observations (speed 1000x)



SDSS
gri
3.5’x3.5’
r~22.5

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

LSST’s field of view is 3000 times larger

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

Rubin Observatory Construction Status

Rubin Observatory Team, August 2022, Tucson, AZ

and a British site, too!

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)

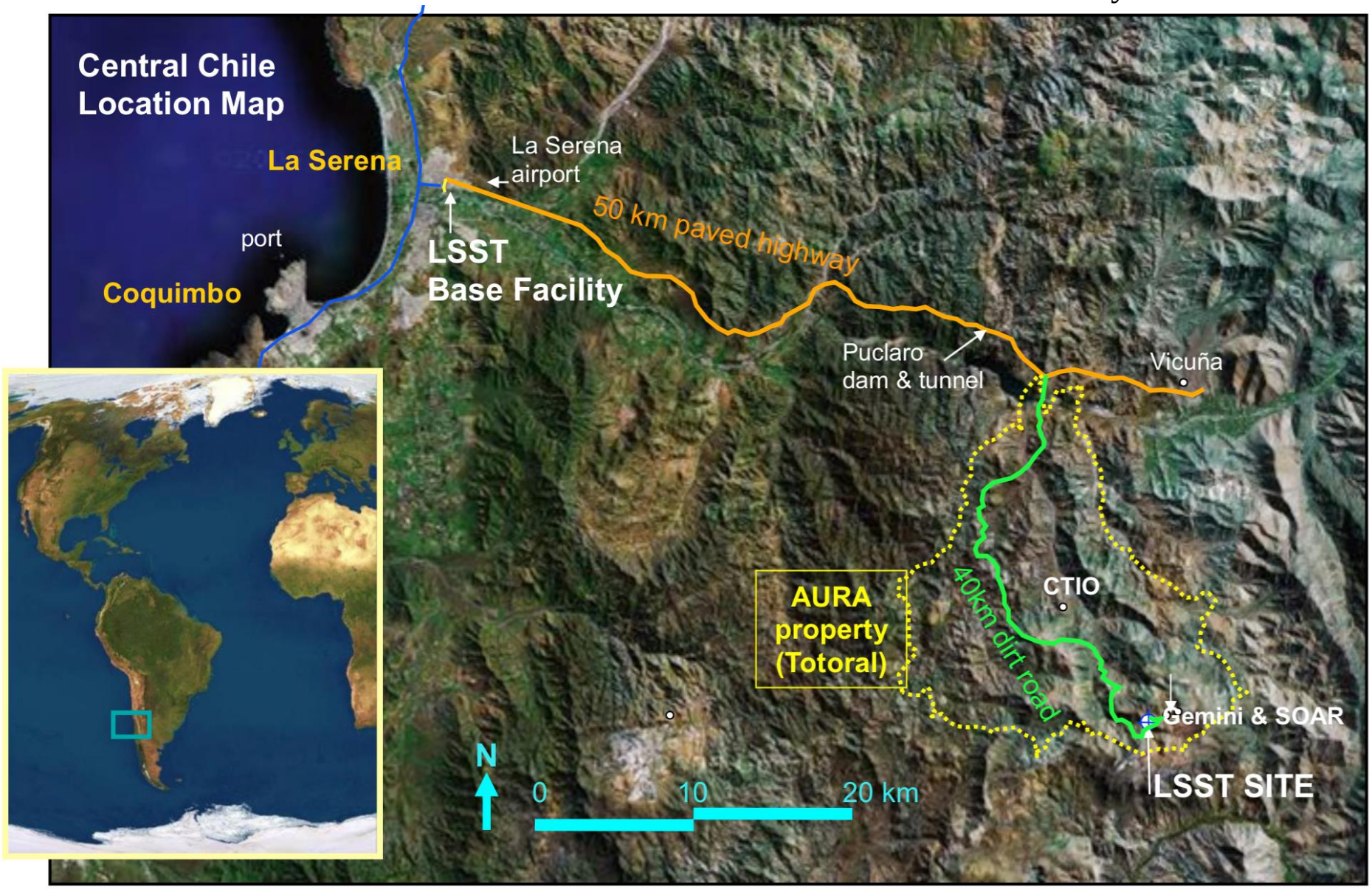
Data Access Center
Data Access and User Services

Summit Site

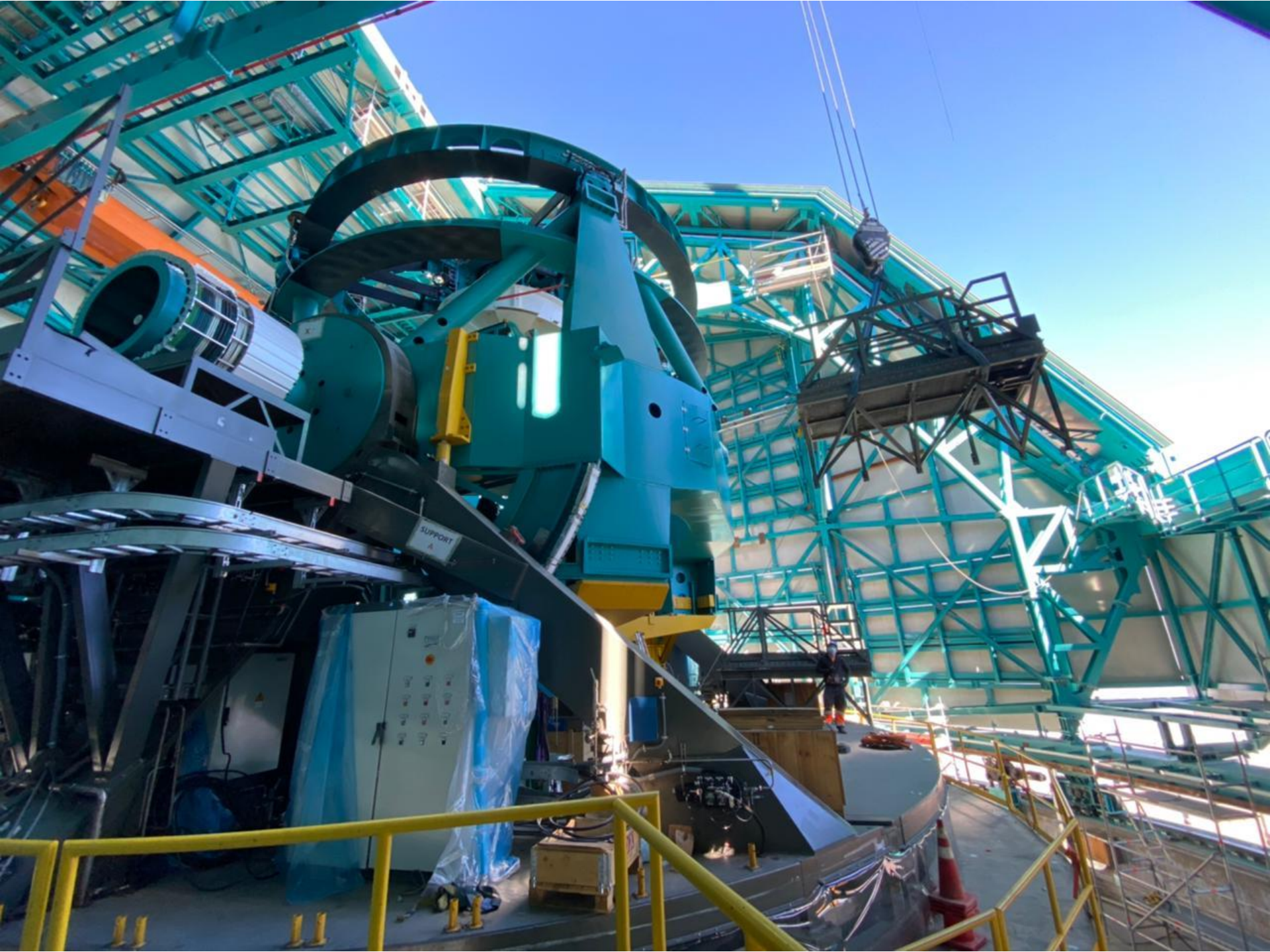
Telescope & Camera
Data Acquisition
Crosstalk Correction

Rubin Observatory is sited in Central Chile: Cerro Pachon

AURA: Association of Universities for Research in Astronomy

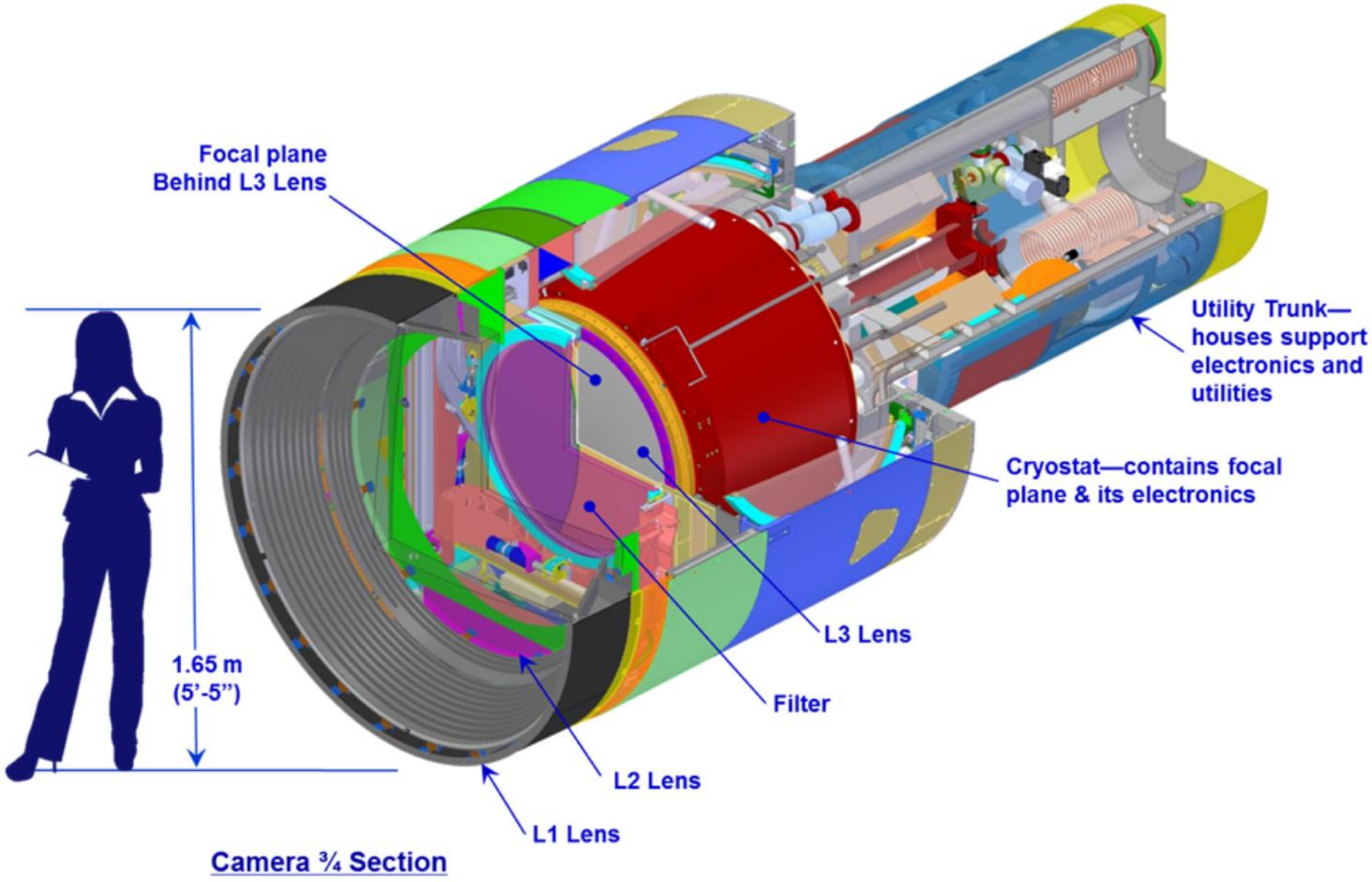


Telescope Mount Assembly before going from Spain to Chile

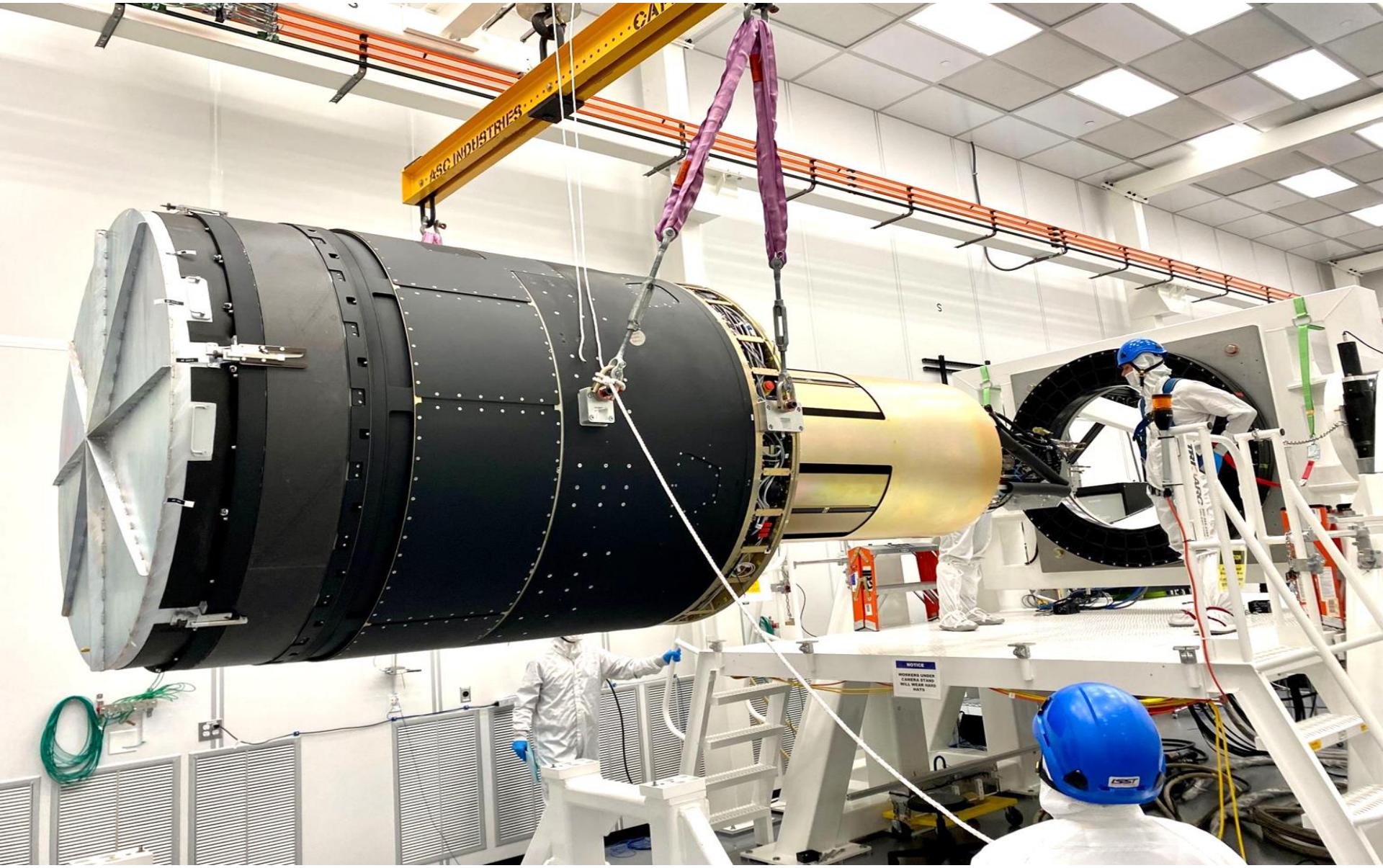

SUPPORT

TMA Moves

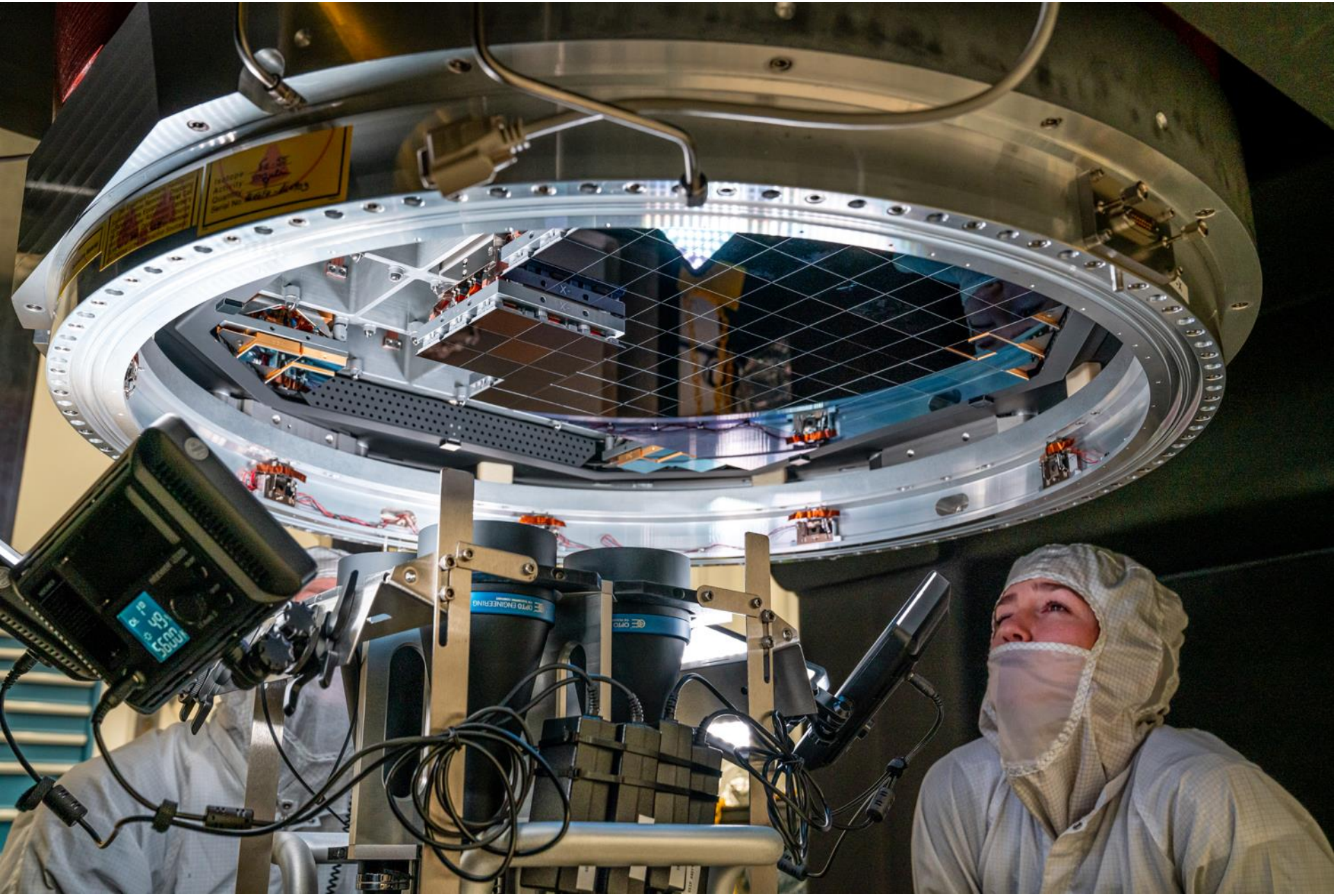
December 2022

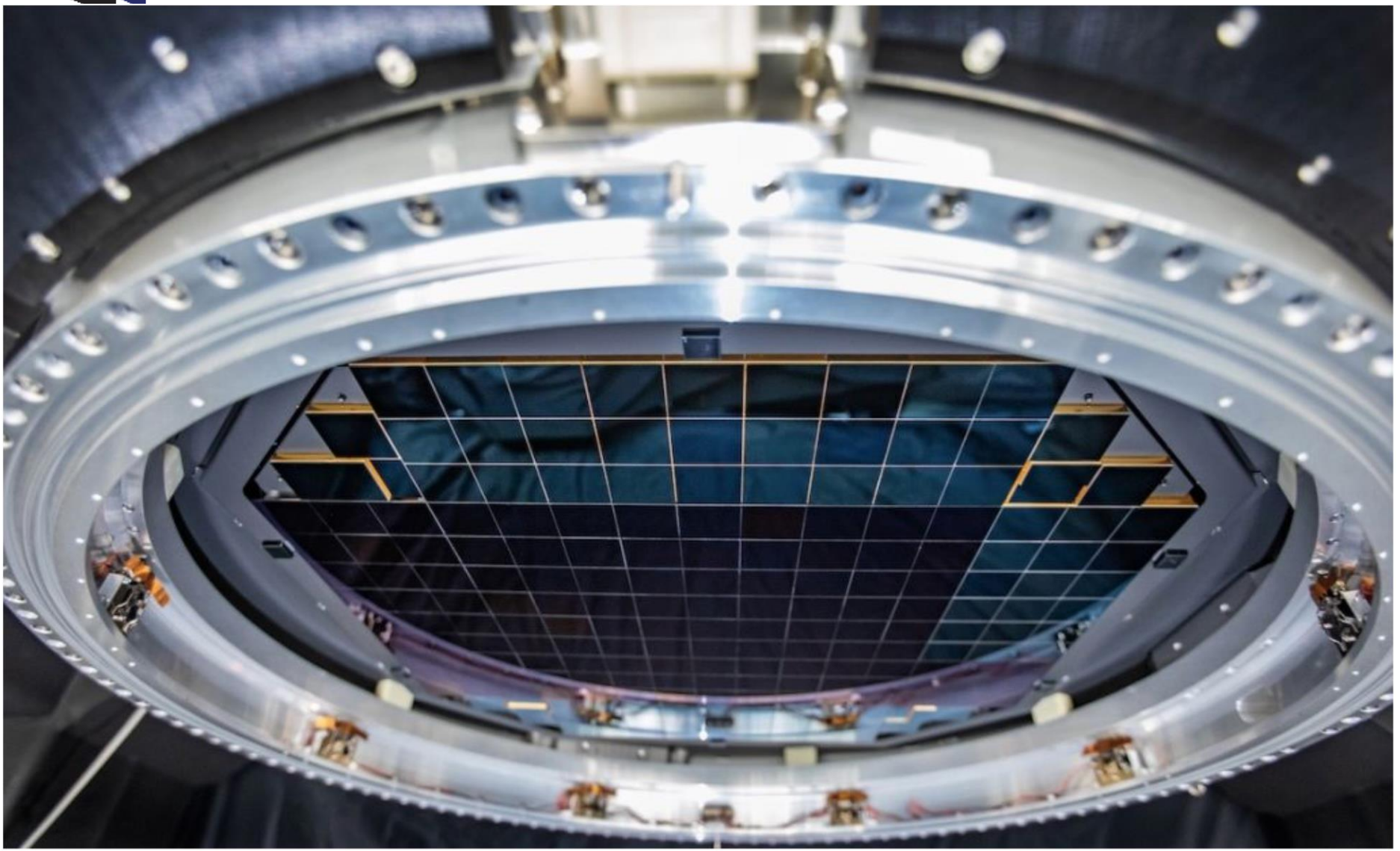


Camera ¾ Section

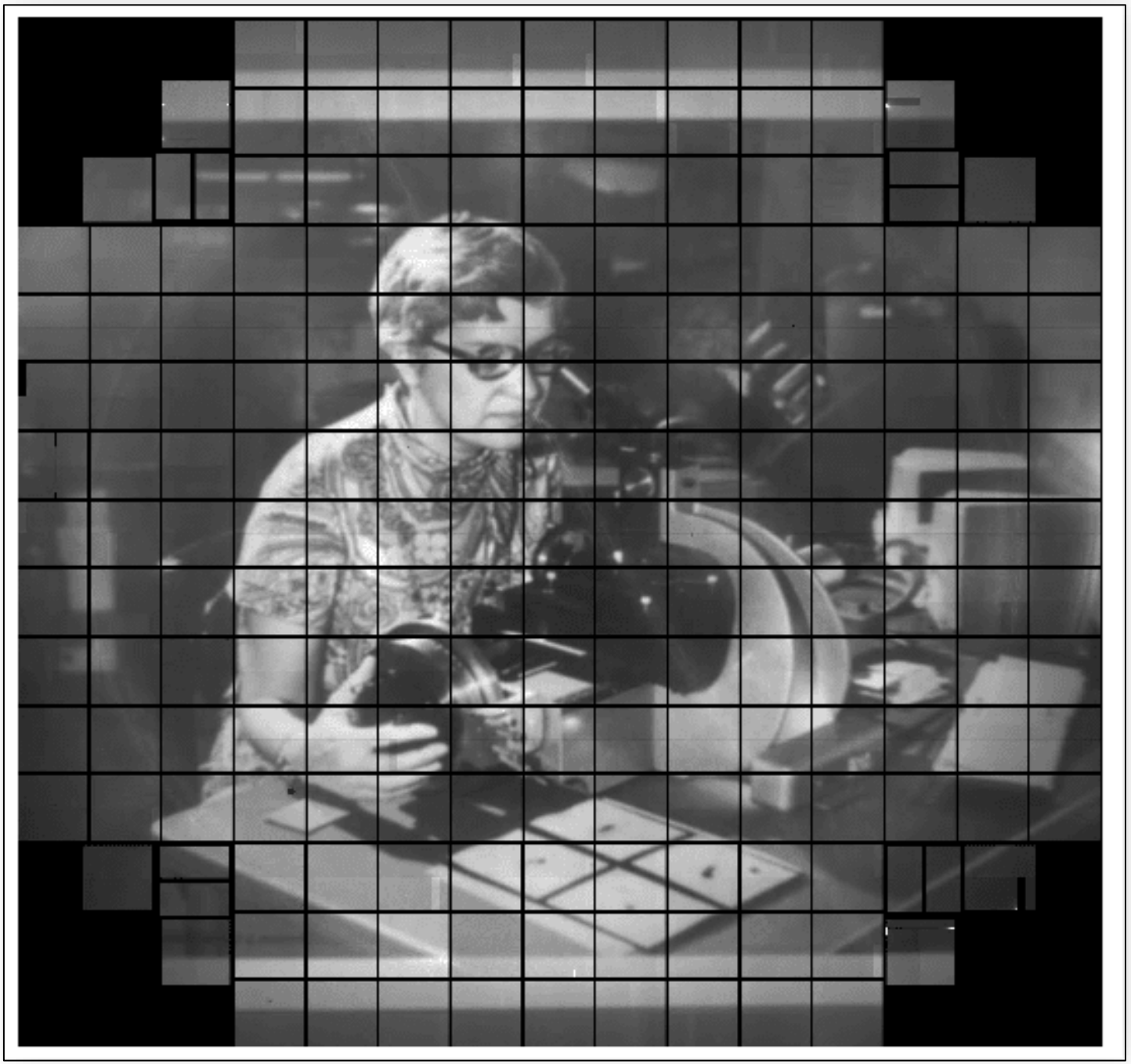

ASG INDUSTRIES
NOTICE
WORKERS UNDER
CAMERA STAND
WILL WEAR HARD
HATS

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…

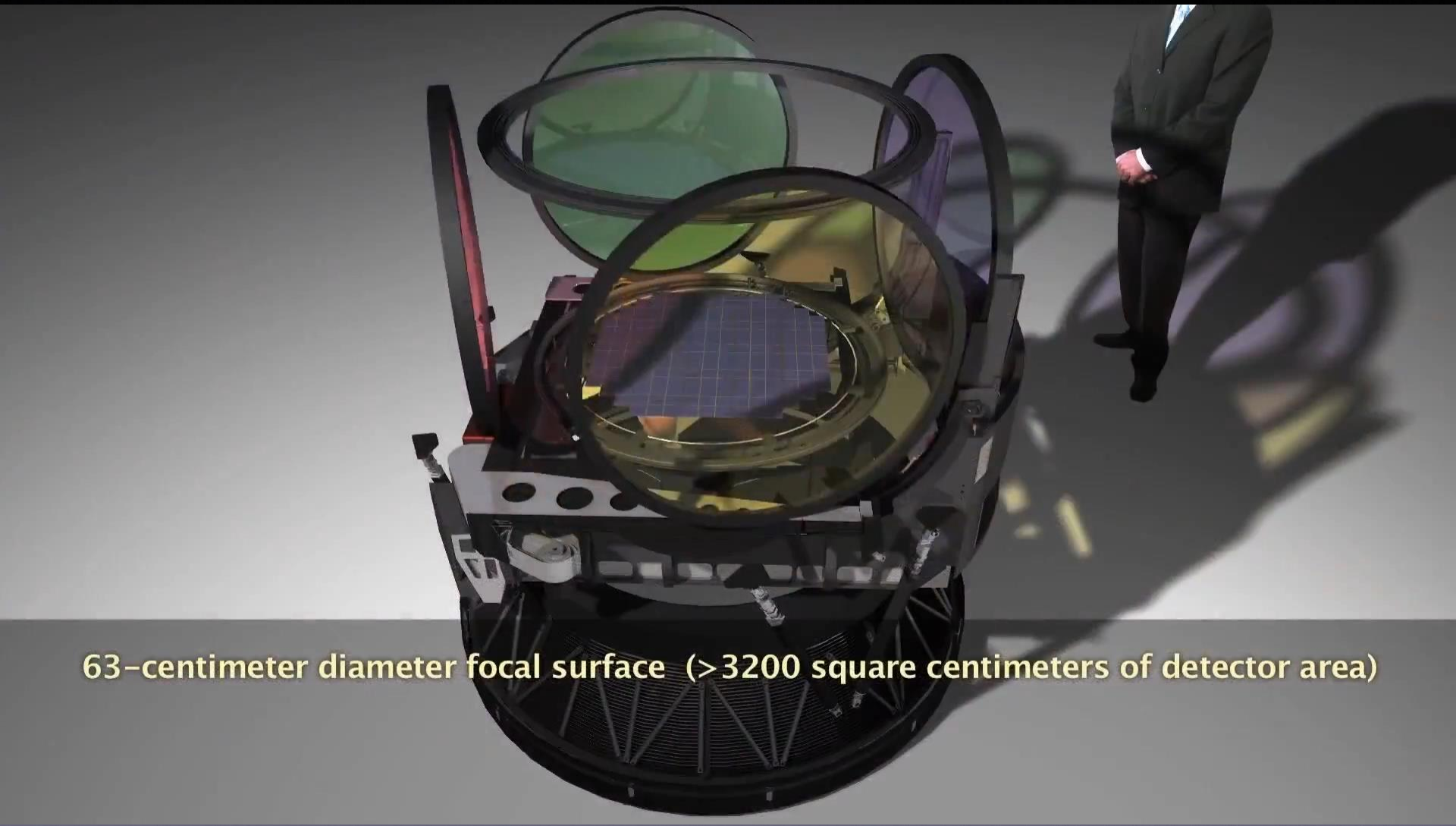
To view all images one a HDTV with 30 frames per second, it would take 11 months!
The greatest movie of all time!

Shutter operation

- The shutter nominally takes 1 second to open/close
- The standard exposure time is 15 second.

Shutter operation

- The shutter nominally takes 1 second to open/close
- The standard exposure time is 15 second.

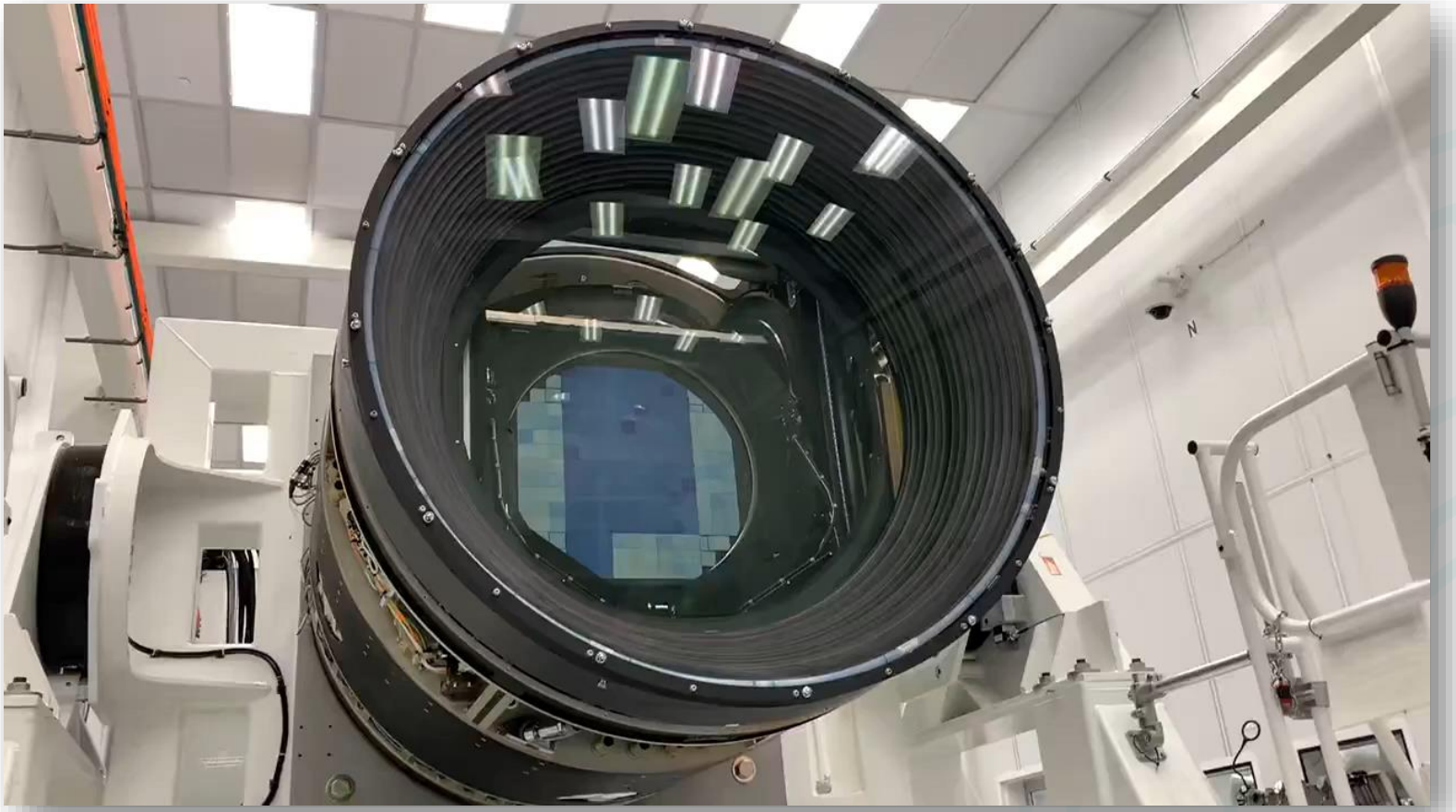

63-centimeter diameter focal surface (>3200 square centimeters of detector area)

Filter Exchange Operation

- It takes about 90 sec to change a filter for filters stored on the camera

Filter Exchange Operation

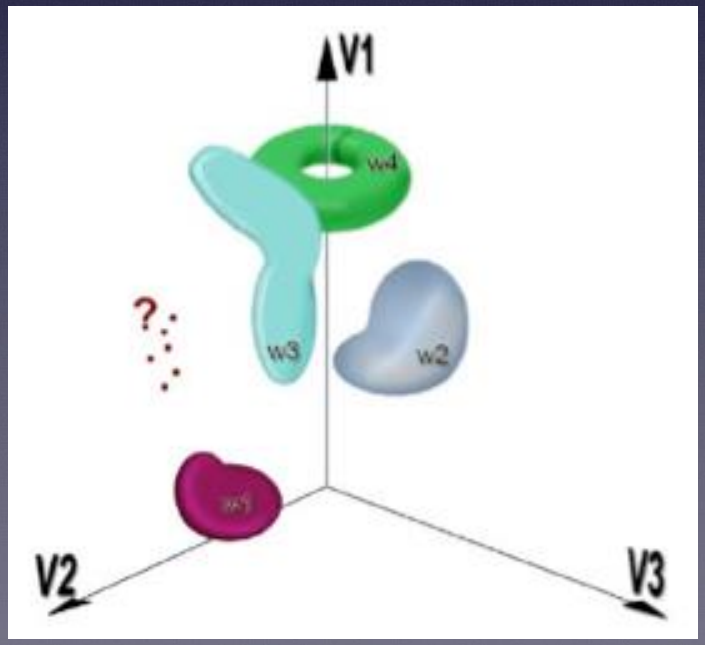
- It takes about 90 sec to change a filter for filters stored on the camera



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

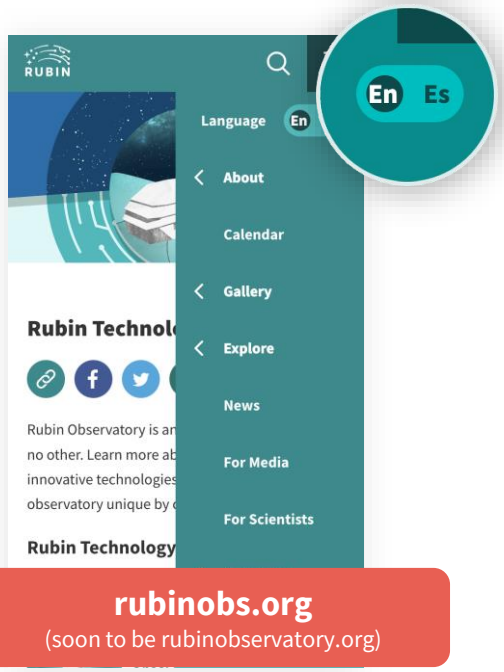


- 10,000-D space with 40 billion points
- Characterization of known objects
- Classification of new populations
- Discoveries of unusual objects

Clustering, classification, outliers

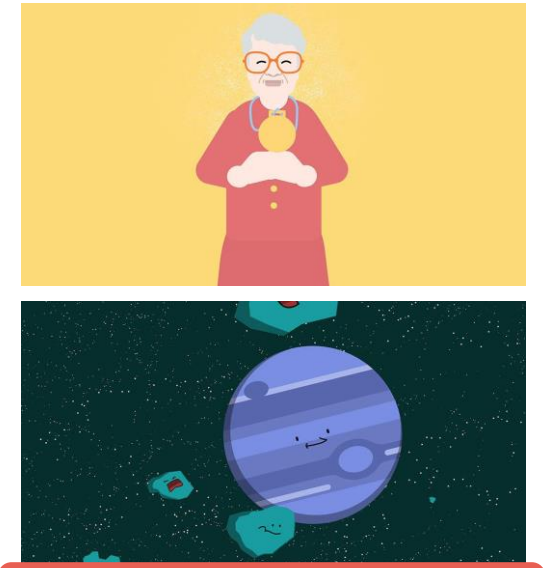
Rubin's Education and Public Outreach System is complete and ready to engage the public to explore the Universe with us!

A new mobile-first, accessible website with engaging, conversational content in English and Spanish



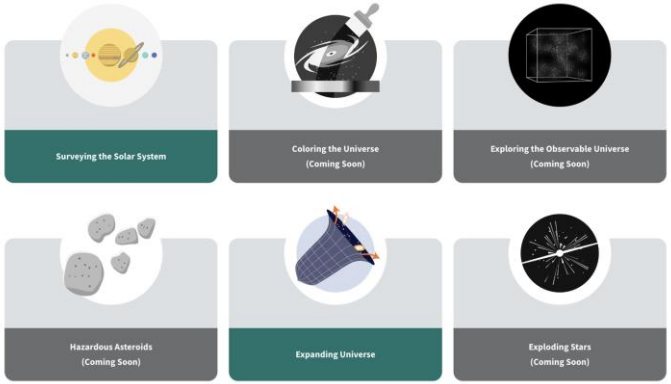
rubinobs.org
(soon to be rubinobservatory.org)

Animated videos about Rubin and its science, on Youtube in English and Spanish

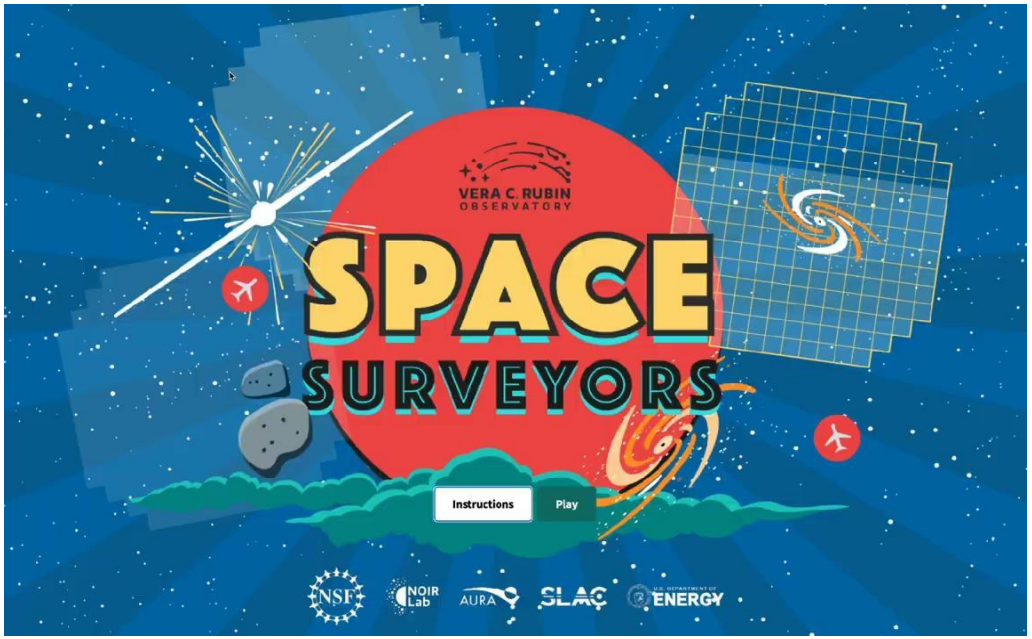


youtube.com/RubinObservatory

Formal education investigations with resources for teachers



Space Surveyors



spacesurveyors.app

What else we have in store

Coming soon

Skyviewer

Orbitviewer

Citizen Science with Zooniverse

Engage with us on social media!

/VRubinObs

/VRubinObs

/rubin_observatory

/RubinObservatory

/company/rubinobservatory

Rubin Construction Timeline

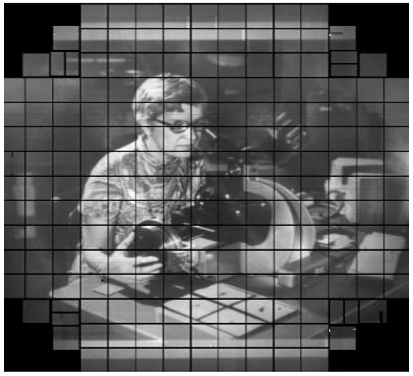
Starting a key year for full system integration and commissioning!

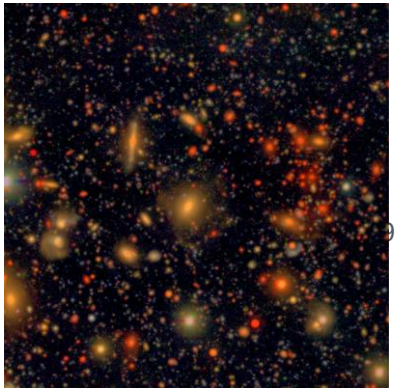
2023 — Analysis software ready for commissioning

2024 — **Oct 2023 : Arrival of LSSTCam on the summit**

2024 — **System First Light ~ October 2024.**

2025 — **Legacy Survey of Space and Time (LSST) starts 2025**





The COSMOS field seen by Hyper Suprime-Cam, courtesy of the HSC Collaboration, R. Lupton, and N. Lust.

Legacy Survey of Space and Time: a 10-year survey starting in 2024

More details: ls.st/lop

multi-color time-resolved faint sky map
- 20 billion galaxies
- 20 billion stars
- 10 billion alerts
- “millions and millions” of SNe, quasars, asteroids…

These slides: https://ls.st/ung

VERA C. RUBIN OBSERVATORY