Rubin Observatory's Legacy Survey of Space and Time: Challenges and Opportunities

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IFT-UNESP/ICTP-SAIFR/LIneA

On behalf of the Brazilian Participation Group

COSMO22 @ Rio– August 2022

A large amount of data indicates that we know that we don’t know what ~95% of the Universe is made of.

ΛCDM is the benchmark model that emerged to explain the data: Standard Cosmological Model

A cosmological model must be able to describe the full history of the Universe: from quantum fluctuations to galaxies.

Galaxy surveys are essential to study late-time history of the Universe:

how small perturbations grew to give rise to the observed large-scale structure.

History must be consistent: from early-time (BBN, CMB) to late-time (galaxies, etc).

From DES-Y3 webinar

Cosmology: from quantum fluctuations to galaxies

Late-time clustering should be compatible with the ΛCDM prediction assuming initial conditions from the CMB! To be tested!

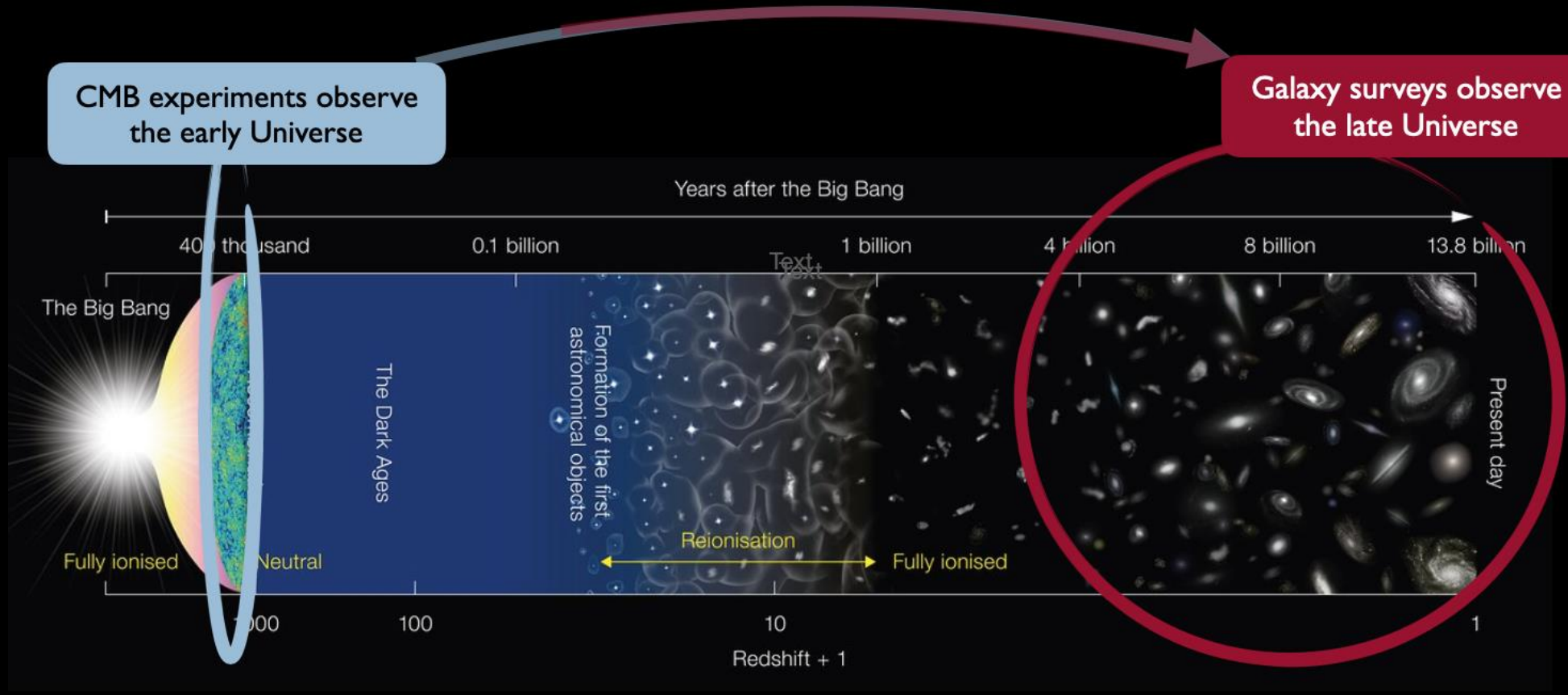


Image credit: NAOJ

Two main types of galaxy surveys:

- Spectroscopic: take spectra of galaxies

(good quality spectroscopic redshift vs smaller number of objects; no imaging)

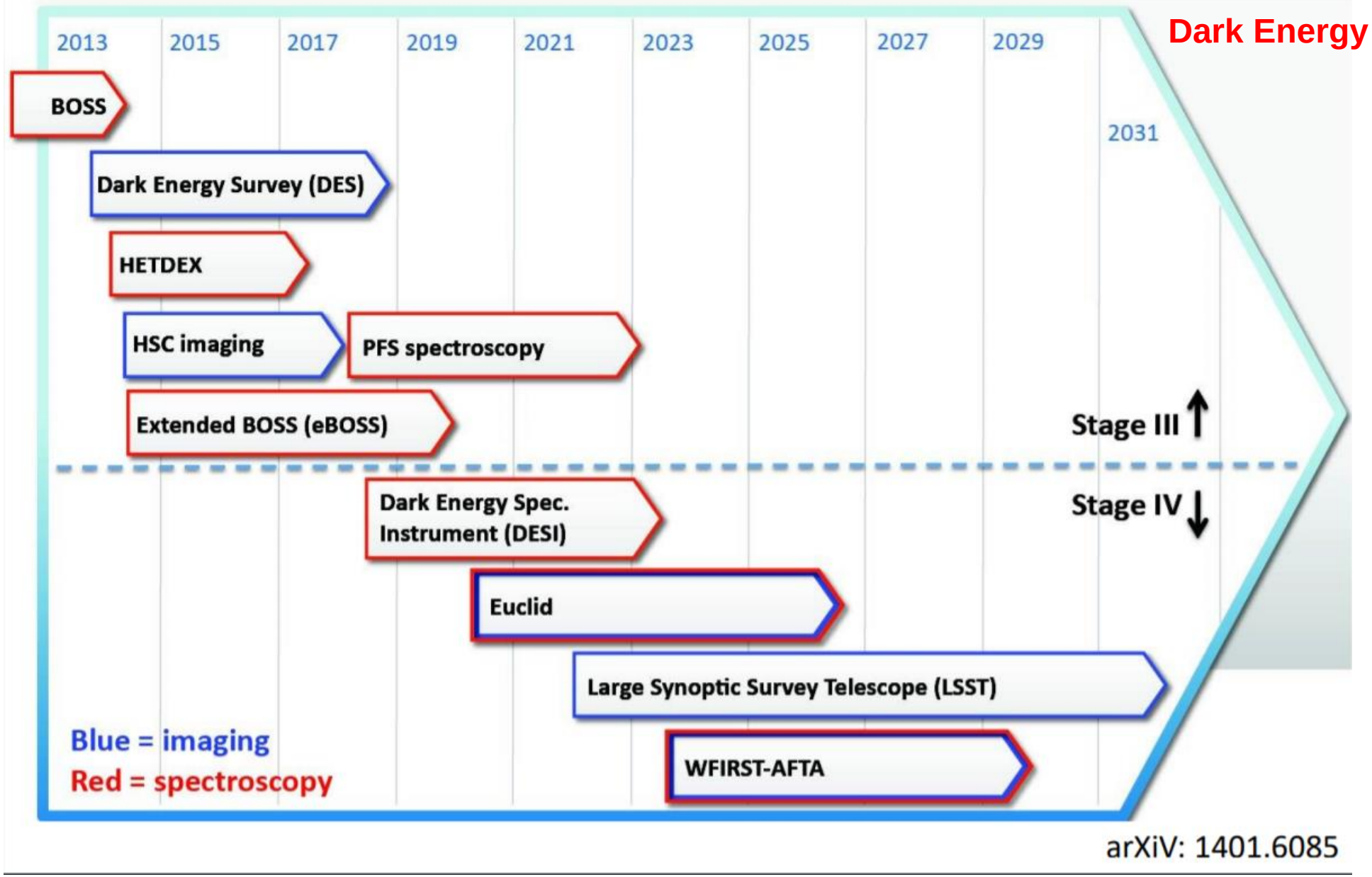
- Photometric: take pictures of fields of galaxies with different color filters using a digital camera

(fair quality photometric redshift vs larger number of objects; imaging)

Use tomographic redshift bins!

Dark Energy Survey (DES - Muir's talk) and LSST are photometric surveys

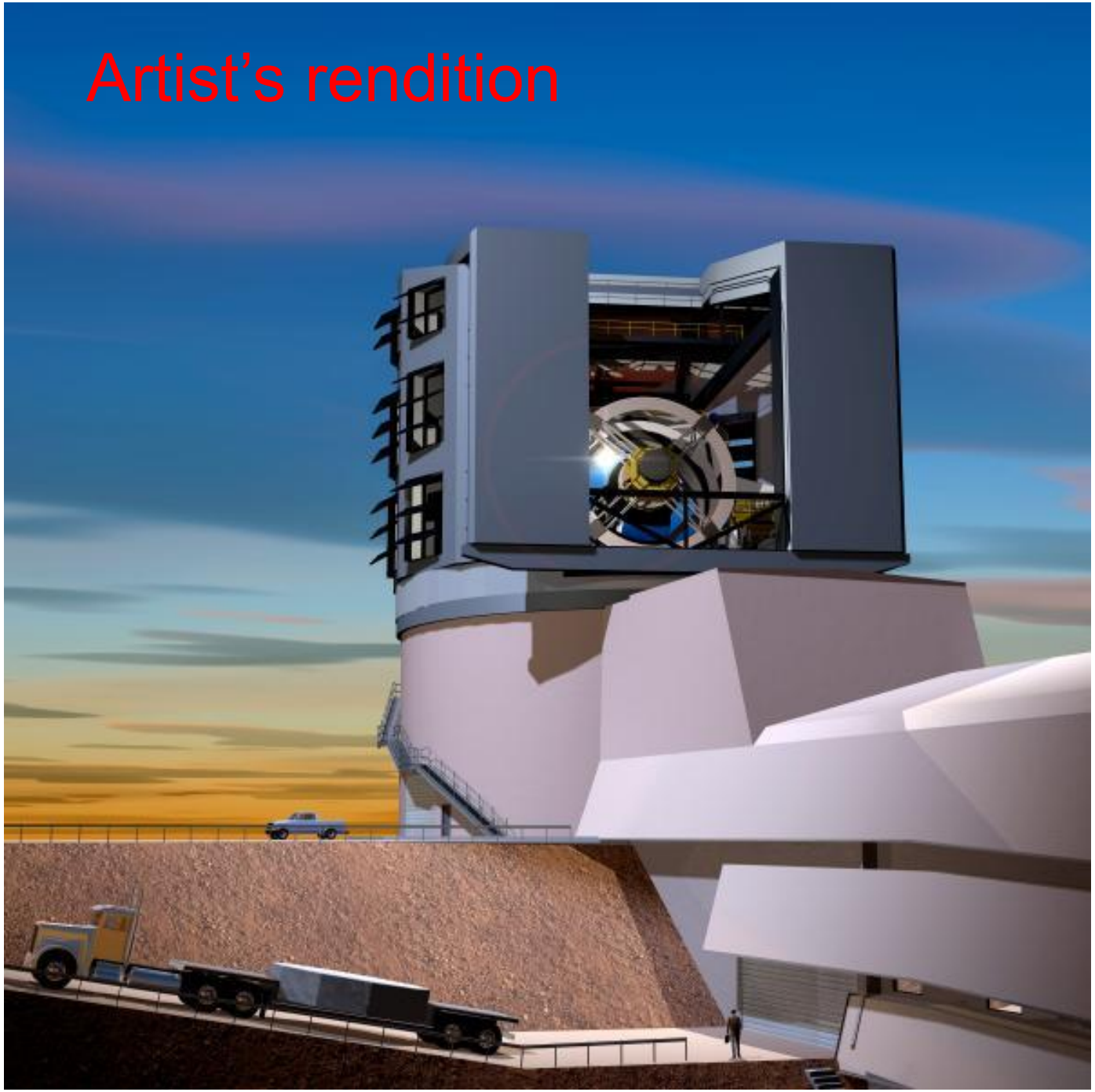
A somewhat outdated schedule of surveys



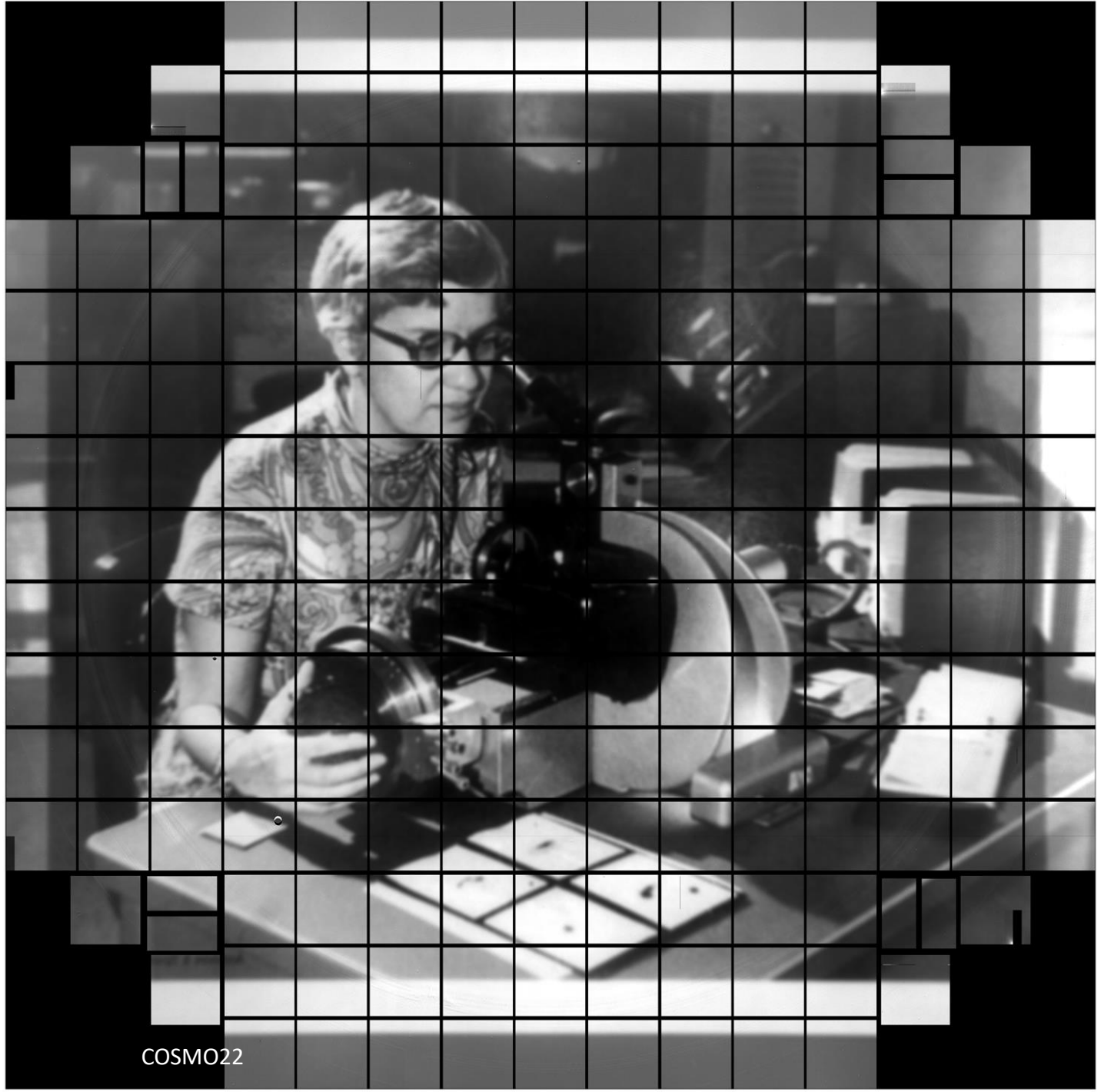
Legacy Survey of Space and Time

LSST is a 10-year survey to be conducted at the
Vera Rubin Observatory in Chile (CTIO)
using the
Simonyi Survey Telescope – 8.4 meters primary mirror
9.6 deg2 field of view

with the
LSSTCam
largest digital camera ever built (SLAC) – 3.2 Gigapixels
189 science CCDs
6 filters: ugrizy


Artist’s rendition

https://www.lsst.org/news/see-whats-happening-cerro-pachon



September 2020:

The Rubin Observatory LSST Camera team at SLAC National Accelerator Laboratory released the first 3200 megapixel digital photos taken using the array of imaging sensors that will be integrated into the LSST Camera.

www.lsst.org

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Vera C. Rubin Observatory

Rubin Observatory consists of an integrated system that combines an 8.4-meter primary mirror, the world's largest digital camera, a complex data processing system, and an online education platform. Rubin Observatory takes advantage of new technologies to provide a qualitatively new capability for astronomy.

About Rubin Observatory

Vera C. Rubin Observatory Project Mission Statement

Rubin Observatory's mission is to build a well-understood system that will produce an unprecedented astronomical data set for studies of the deep and dynamic universe, make the data widely accessible to a diverse community of scientists, and engage the public to explore the Universe with us.

Overview

The goal of the Vera C. Rubin Observatory project is to conduct the 10-year Legacy Survey of Space and Time (LSST). LSST will deliver a 500 petabyte set of images and data products that will address some of the most pressing questions about the structure and evolution of the universe and the objects in it. The Rubin Observatory LSST is designed to address four science areas:

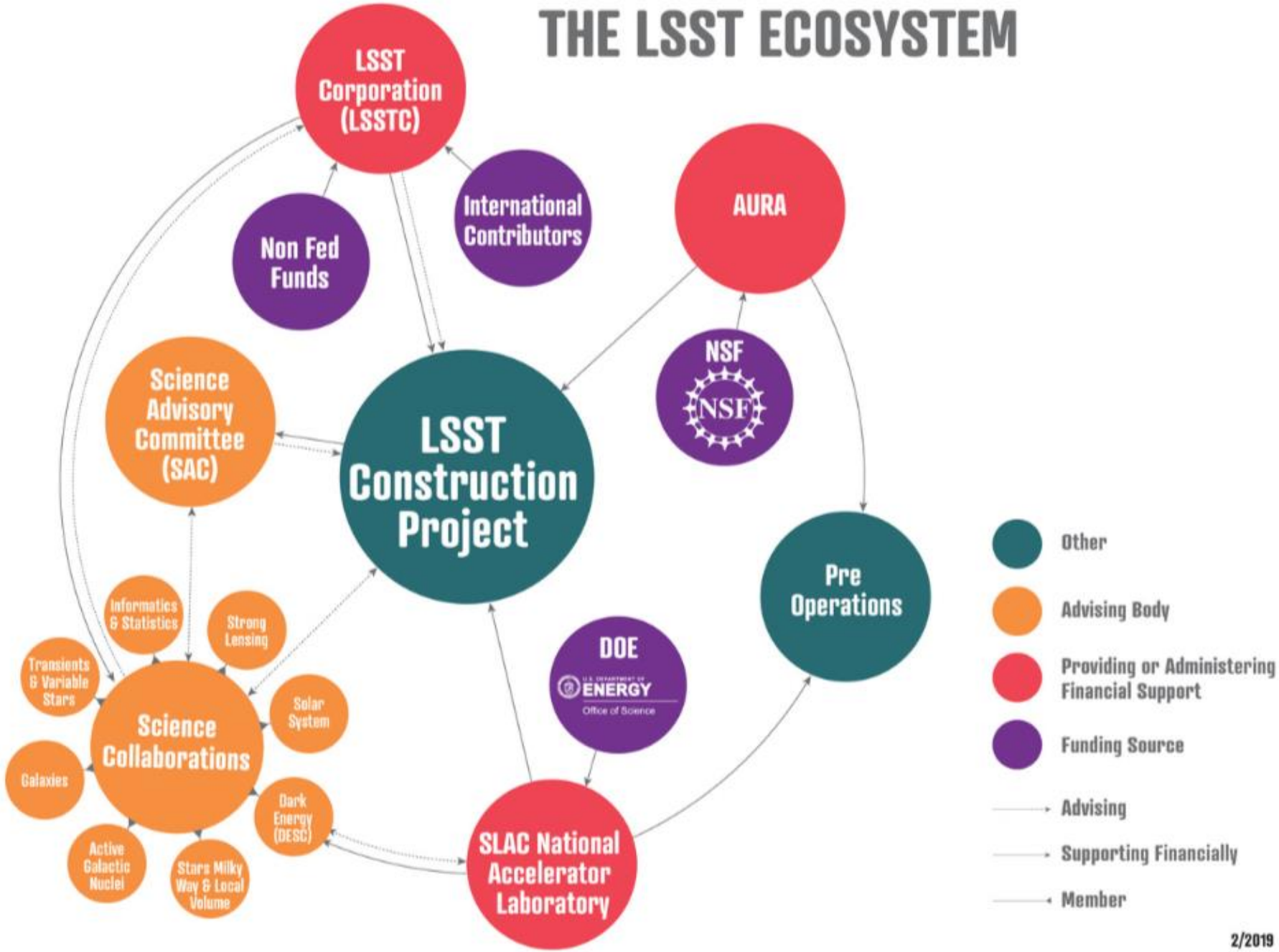
- Probing dark energy and dark matter.
- Taking an inventory of the solar system.
- Exploring the transient optical sky.
- Mapping the Milky Way.

In this artist's rendition, the Rubin Observatory primary mirror is seen through the slit of the dome at sunset.

The scientific questions that Rubin Observatory will address are profound, and yet the concept behind the design of Rubin Observatory is remarkably simple: conduct a deep survey over an enormous area of sky; do it with a frequency that enables images of every part of the visible sky to be obtained every few nights; and continue in this mode for ten years to achieve astronomical catalogs thousands of times larger than have ever previously been compiled.

The construction phase of the project will deliver the facilities needed to conduct the survey: a large-aperture, wide-field, optical imaging telescope; a gigapixel camera; and a data management system.

THE LSST ECOSYSTEM



2/2019

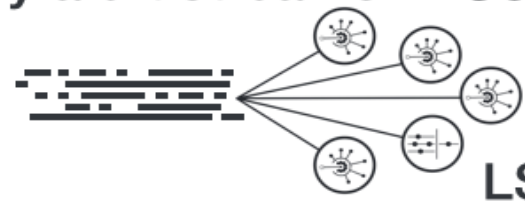
Raw Data: 20TB/night

Sequential 30s images that cover the entire visible sky every few days.

Prompt Data Products

Alerts: up to 10 million per night

60s via nightly alert streams



Community Brokers

LSST Alert Filtering Service

Results of Difference Image Analysis (DIA): transient and variable sources

Solar System Objects: ~6 million by year 10

24h via Prompt Products Database

LSST DACs (Chile & NCSA)

Independent DACs (iDACs)

Data Release Data Products

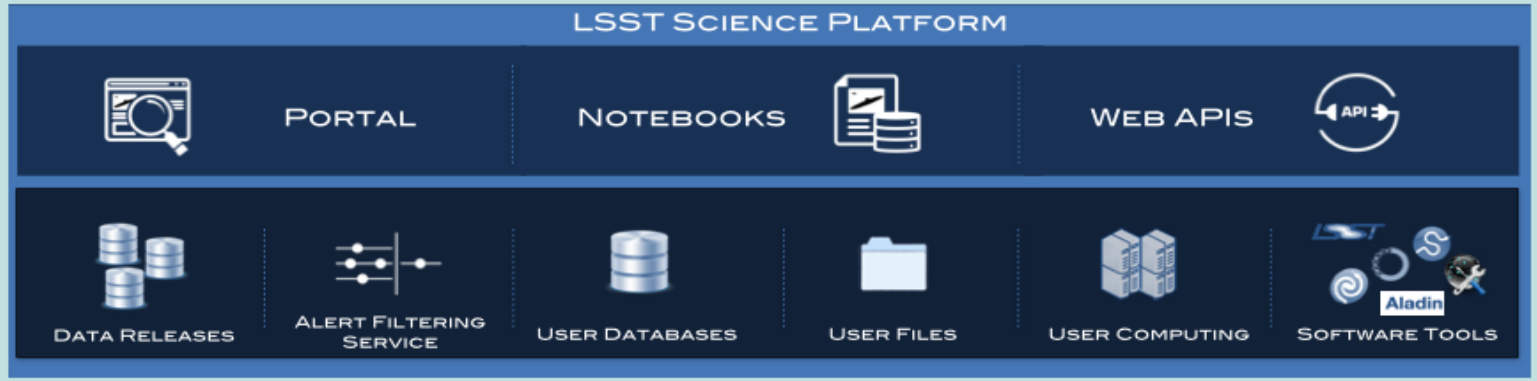
Final 10 year Data Release images: 5.5 million x 3.2 Gpx
catalogs: 37 billion objects, 15PB

via Data Releases

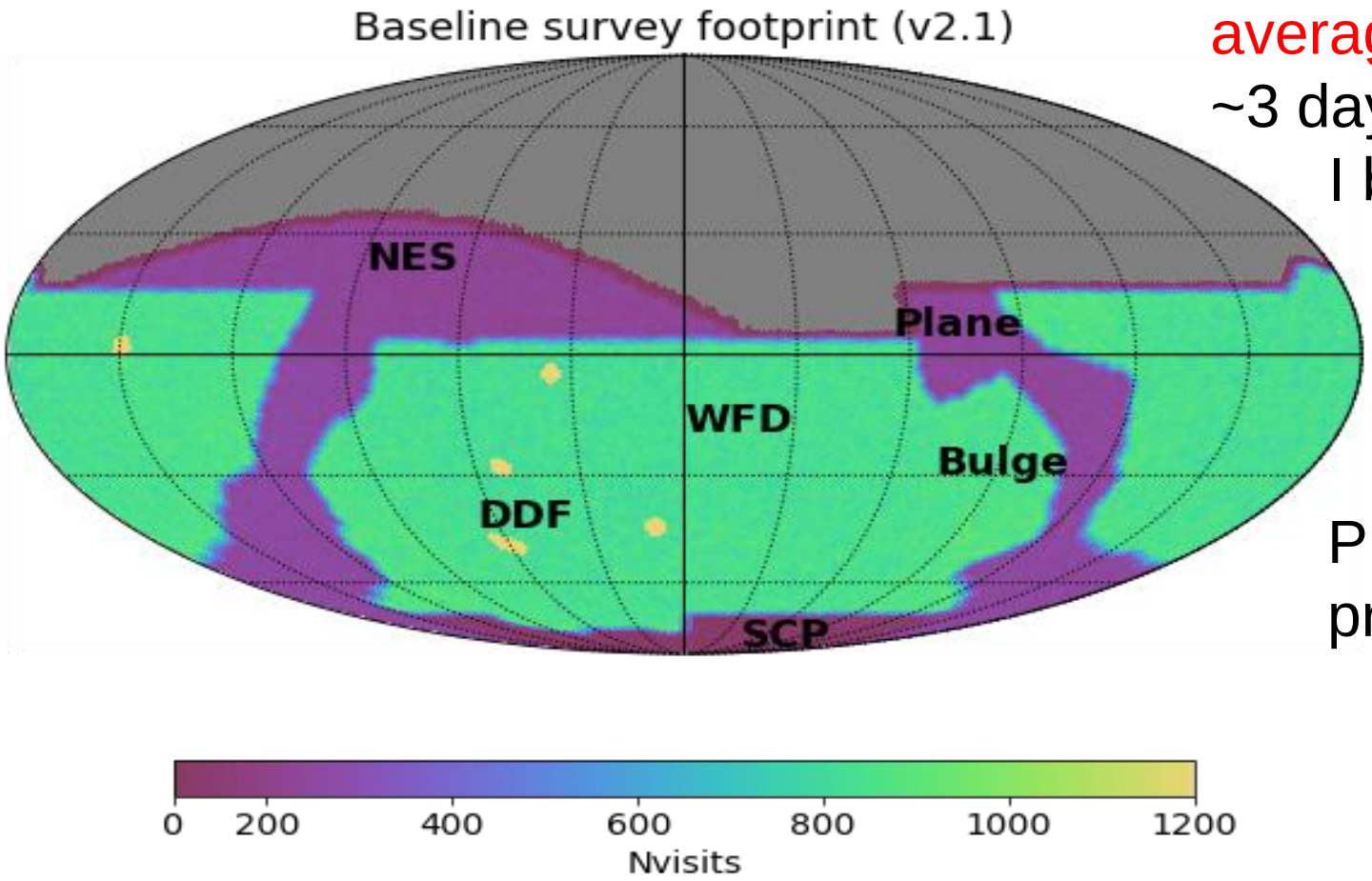
Slide from Melissa Graham's presentation at PCW22

LSST Science Platform

Provides access to LSST Data Products and services for all science users and project staff.



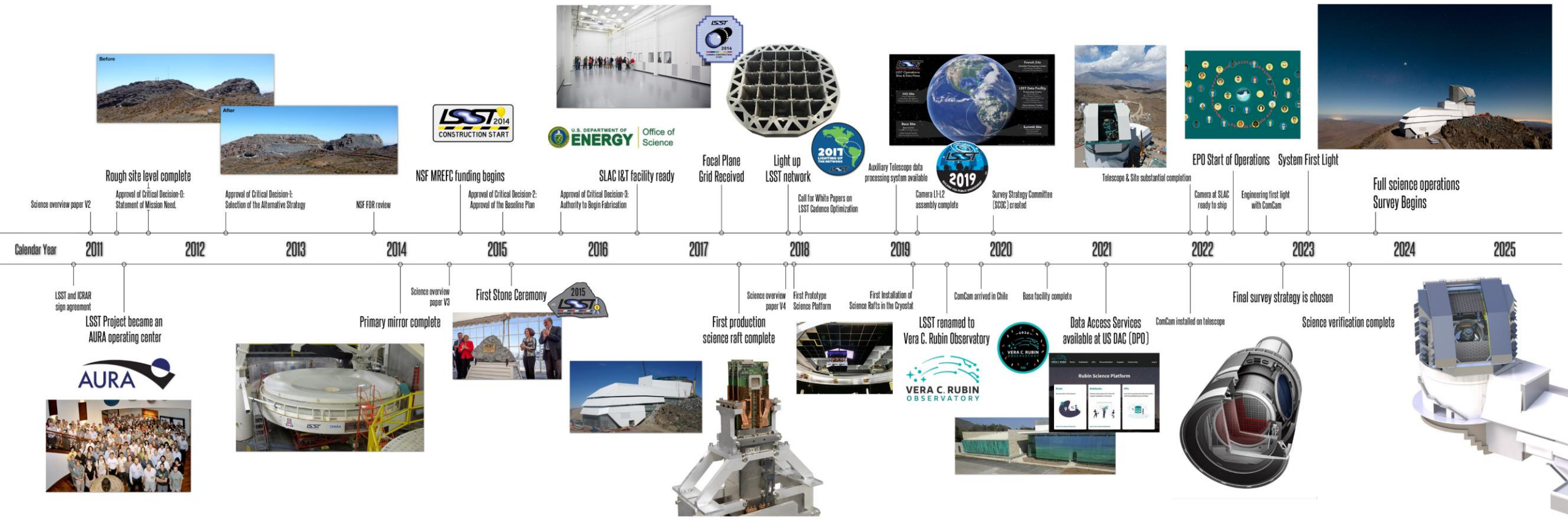
Survey footprint



The Wide-Fast-Deep (WFD) survey:
footprint should cover at least 18000 deg2
average of 825 visits per field over 10 years
~3 day cadence (time between visits)
I band : 24 (single exp.) – 26.8 (10 y)

Photometric redshift calibrated to a precision of ~0.002 (1+z)

LSST timeline



System First Light – March 2024

Key Project Documents

Link
LSST Data Policy

Link
Science Requirements Document

Link
Data Products Definition Document

Link
LSST Science Book

Link
LSST: From Science Drivers To Reference Design And Anticipated Data Products

Link
Summary of Data Management Principles

Link
LSST System Requirements

Link
Observatory System Specifications

Link
Data Management Subsystem Requirements

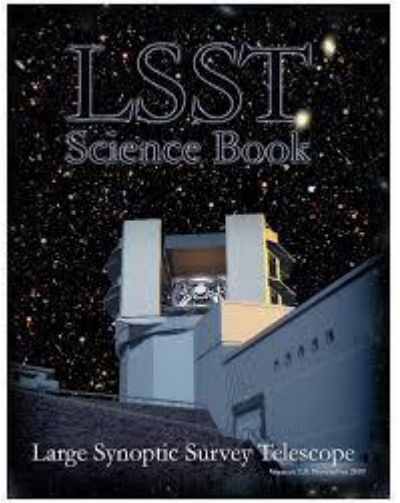
Link
Telescope and Site Subsystem Requirements

Link
Camera Subsystem Requirements

Link
Observatory Control System Requirements

www.lsst.org/scientists/publications/key-project-documents

LSST Science



www.lsst.org/scientists/scibook

LSST can do much more than study Dark Energy: unprecedent amount of data for multiple science goals

Science Topics are addressed within
LSST Science Collaborations
(autonomous, self-managed teams)

LSST Science Collaborations

8 Science Collaborations

Active Galactic Nuclei

Dark Energy

Informatics and Statistics

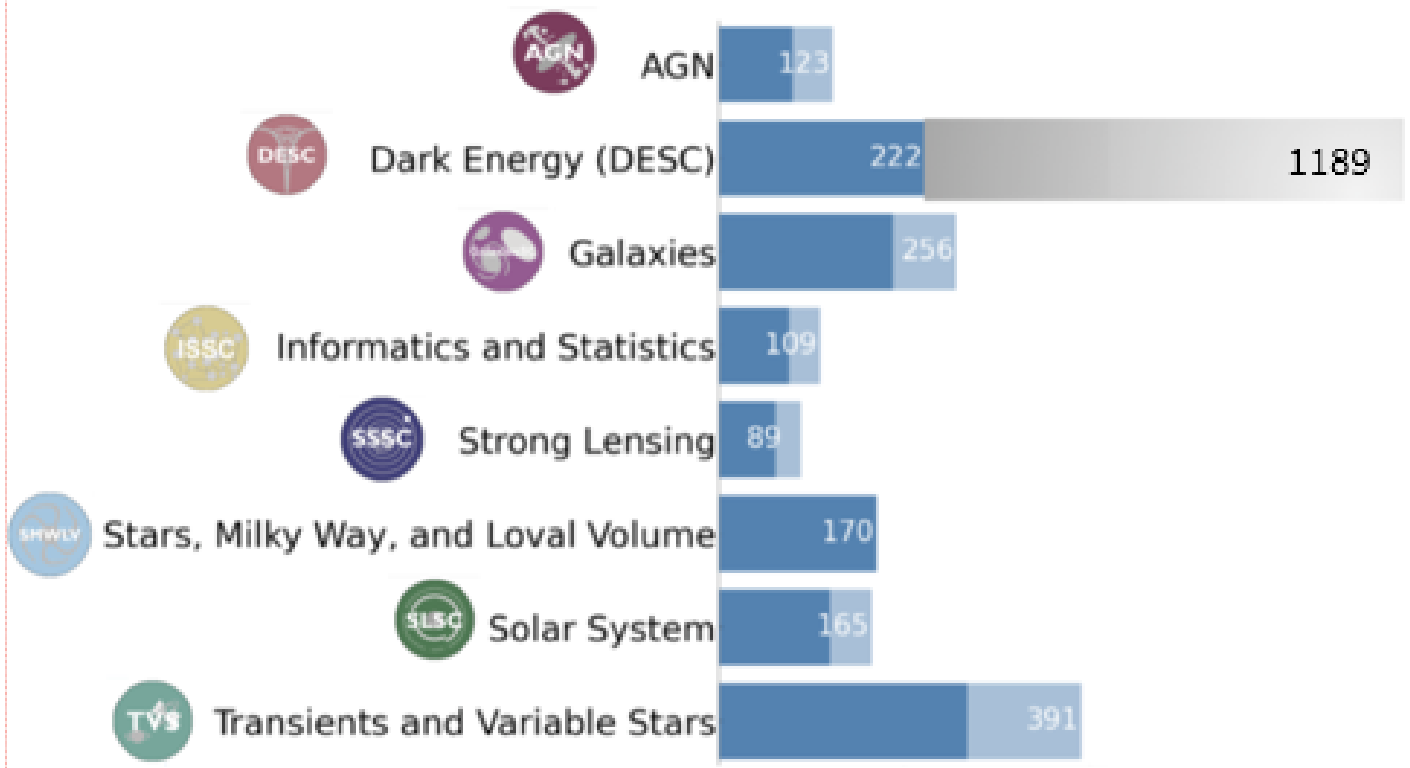
Transients and Variable Stars

Stars, Milky Way, and Local Volume

Strong Lensing

Galaxies

Solar System



Growth from 2018 (dark bars) to 2022 March (light)

2000+ members, physicists, astronomers, data scientists, software engineers

Credit: FBianco TLoredo

LSST - Brazilian Participation Group

I'm the current coordinator

Tassia Ferreira: spokesperson

MoA with Brazil signed in 2015 – 10 PIs (+40 juniors)

LIneA activities (including LSST) are supported by:

L. da Costa is the coordinator

LIneA is an Institutional Member of the LSST Corporation – LSSTC: L. da Costa is the representative.

LSST CORPORATION
INVESTING IN DISCOVERY

SEARCH

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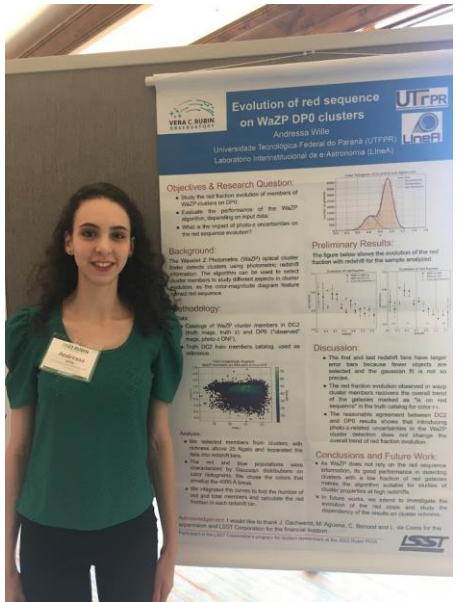
Enabling Science Program 2021 Award Recipients

Two undergraduate students selected. They presented their results in person at the LSST PCW 22 this month in Tucson.

Andressa



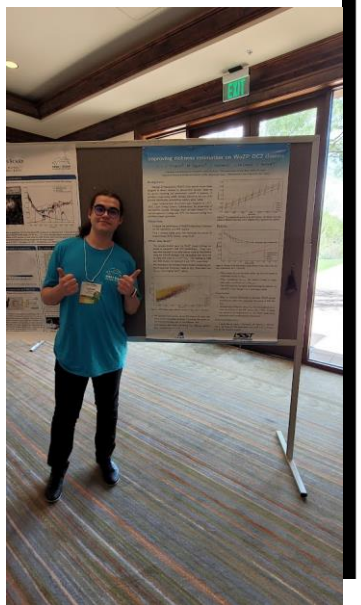
LIneA e LSST Corporation anunciam oportunidade de bolsa de estudo e pesquisa

17 de agosto de 2021 | LIneA

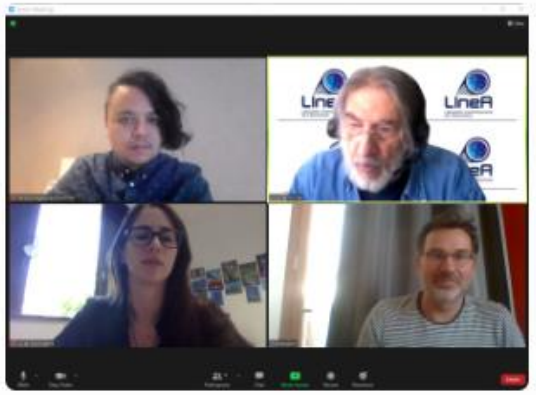
É com grande satisfação que o LIneA, em parceria com o LSST Corporation (LSSTC), anunciam duas bolsas de estudo e pesquisa destinadas para graduandos a partir do 3º período, sendo: uma para a área de Física/Astronomia e outra para a área da Ciência da Computação, durante um (1) ano. Os estudantes selecionados irão trabalhar com membros do Grupo de Participação Brasileiro do projeto Legacy Survey of Space and Time (BPG-LSST), desenvolvendo pesquisas na área de aglomerados de galáxias (leia aqui) como aprovado pelo LSSTC.

LSST CORPORATION

Gabriel



Award - $5,000



Identifying and Analyzing the Properties of Clusters of Galaxies in DPO (2021-05)

"LIneA has created a project to improve the performance of WaZP, a galaxy cluster finder and to study the evolution of the red-sequence of clusters, using an upgraded version of the portal infrastructure developed by LineA's team to host science workflows. The plan is to select two undergraduate students in physics and computer science to participate in our efforts to adapt and scale our infrastructure to the LSST data using DC2 as a test case."

An additional 15 PIs (+60 juniors) were secured by LIneA through in-kind contribution: an IDAC and contribution to the photometric redshift effort.

They were selected through a public call and results were announced in July 2022.

At the moment the BPG has 25 PIs and 61 young researchers.

BRA-LIN in-kind contribution program for LSST:

- Lite IDAC
- Software + Data Products for Photo-z
- Pipeline Scientist

BRA-LIN key-people:

- Program Lead: Luiz da Costa
- Program Manager: Julia Gschwend
- IDAC Contribution Lead: Carlos Adean
- PZ Contribution Lead: Julia Gschwend
- DESC Pipeline Scientist: Sandro Vitenti
- In-kind Program Coordinator (from Rubin): Aprajita Verma

Challenges and Opportunities
from the BPG’s perspective

LSST DESC

Dark Energy Science Collaboration

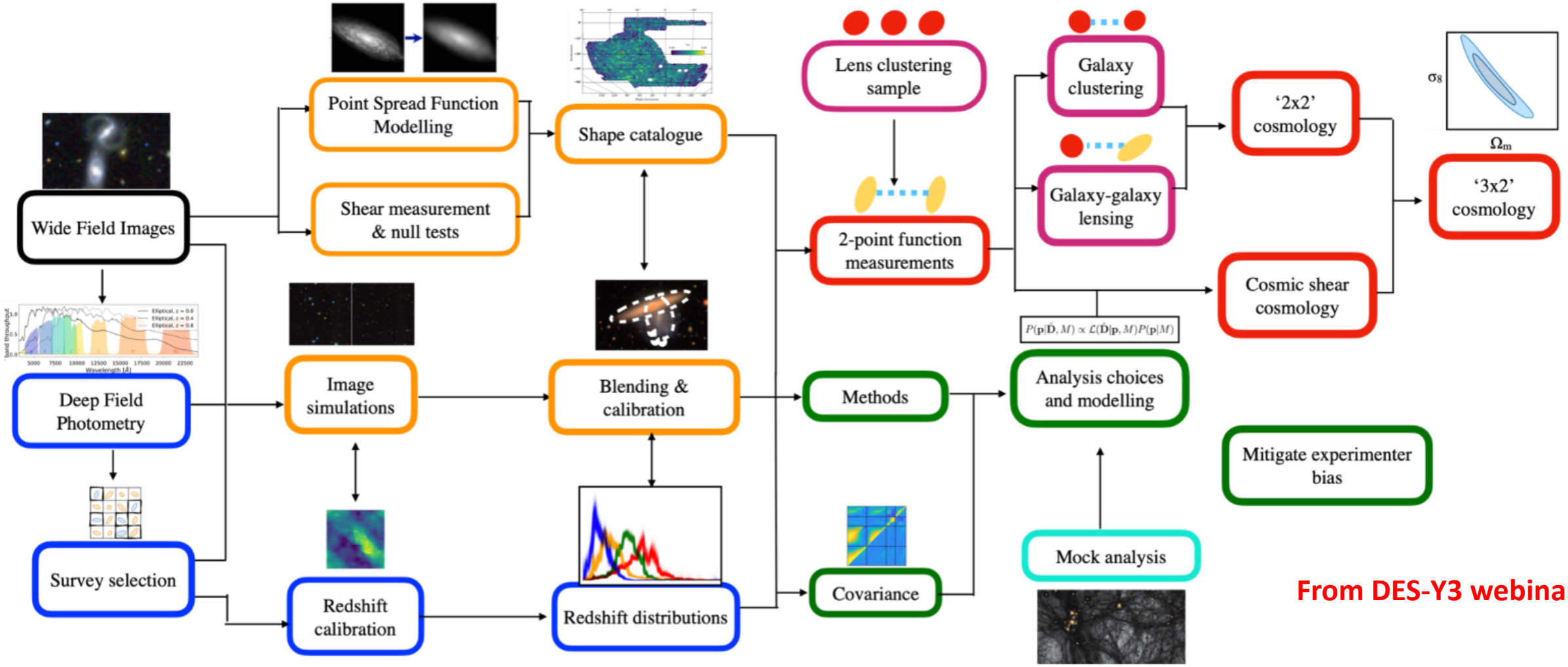
1100+ members in **20+** countries,

Lear about Dark Energy mainly from the (combination of) observables:

- Distribution of galaxies (including BAO)
- Distribution of the shapes of galaxies
- SNIa
- Cluster counts

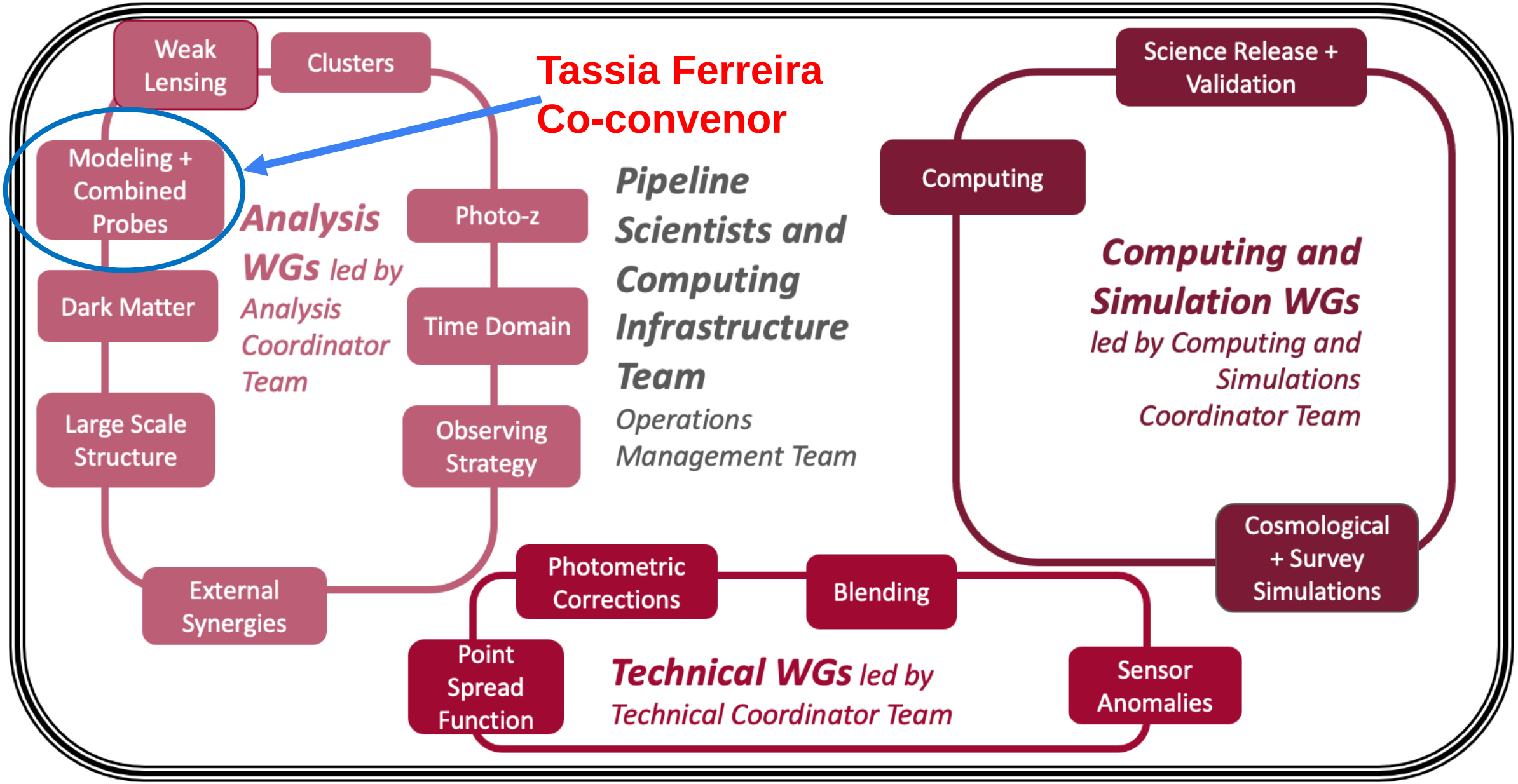
Lessons from the Dark Energy Survey (DES)

DES Year 3: from pixels to cosmology



From DES-Y3 webinar

DESC Management *led by*
Spokesperson Team



DESC challenges

- Large volume of data requires efficient modelling, codes and pipelines

Sandro Vitenti (LSST pipeline scientist): co-leading the development of the Firecrown pipeline for likelihood estimation.

Mariana Penna-Lima: participating in the development of the Cluster weak Lensing Mass Modeling (CLMM) library for cosmology. Non-Limber computations of cross-correlations. NumCosmo library for validation of LSST's Core Cosmology Library (CCL).

Felipe Andrade-Oliveira (LSST pipeline scientist): co-leading the development of the MCPCovariance pipeline.

- Cosmology with LSST Type Ia Supernovae

  Valerio Marra: Machine learning for SN classification, Strong Lensing of SN; tests of FLRW, isotropy of the universe, reconstruction of the metric from observations, cosmic variance from local structure,..

- Modelling challenges

  Tassia Ferreira, Rogerio Rosenfeld, Mariana Penna-Lima, Marcos Lima... : extensions of ΛCDM, non-Limber computations, mitigation of baryonic effects, non-linear power spectrum and galaxy bias (scale cuts, theoretical errors,...).

- New observables

  Valerio Marra: Dark sirens correlated with LSST catalogues.

- ## Parameter estimation challenges

Effficient samplers to be included in likelihood code Firecrown to find posterior distributions of the many parameters (cosmological + nuisance). At the moment testing extensions with the cocoa framework (UNESP collaboration with Vivian Miranda).

- ## Mock challenges

Fast mock generation beyond lognormal (for 3x2pt+clusters) in order to validate covariance matrices and pipelines.

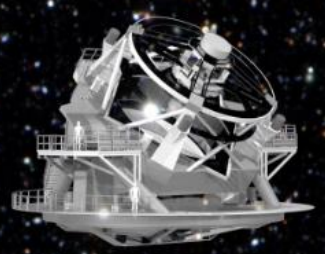
Stars, Milky Way, and Local Volume

- Mapping stellar populations

Basílio Santiago, Adriano Pieres,...: Stellar populations (indidual stars resolved up to ~10 Mpc), variable stars and transientes. Code MWFITTING to fit the stellar components of the Milky Way (used in DES already) and other codes.

- Finding new ultrafaint dwarf sattelite galaxies

Basílio Santiago, Adriano Pieres,...: Census of UFDW, stellar streams from tidal disruption.



Preparing for Astrophysics with LSST

Transients & Variable Stars *Stars, Milky Way & Local Volume* *Solar System Science Collaborations*

Community awards managed by LCO

With support from HEISING-SIMONS FOUNDATION

lsst-sci-prep.github.io/kickstarter_grants.html

Kickstarter Grants Program

Program Goals

- **Excellence in research:** Enable science collaboration members to dedicate time to LSST preparatory research
- **Supporting the research community:** Ensure that research opportunities and facilities are accessible on a fair and equitable basis to all science collaboration members, and overcome common barriers to entry

US$20,000 for 1 year

A. Pieres - Excellent Rubin Research

SMWLV

Brazil

KSI-10

The Lambda-CDM model states that galaxies are formed following the 'bottom-up' scenario, where the dwarf galaxies are firstly formed and then merged, building the giant galaxies as the Milky-Way (MW). In this way, a complete census of the dwarf galaxies in the surrounds of our Galaxy is an important tool to (1) provide strong constraints in the galaxy formation such as the reionization era and infall time, (2) probe the 'missing satellites problem' in the Local Volume, and (3) fix initial constraints about age and chemical abundances for this kind of objects. It is expected that Legacy Survey of Space and Time (LSST) will discover at least 4 times more dwarf galaxies/globular clusters than the Dark Energy Survey (DES), about 60 dwarf galaxies brighter than L>103 L(Sun) following [Hargis et al 2014], and accounting for real discoveries based on the DES data. The challenge now is to develop robust unsupervised methods to efficiently identify resolved stellar systems in a scale compatible to the LSST data volume. We are currently exploring a new method based on the wavelet algorithm, successfully used to identify clusters of galaxies [aka WaZP, Aguena et al. 2021], to detect dwarf galaxies / star clusters at different distance slices using the appropriate Hess-diagrams for stars of a given metallicy and age range as a filter. This project is designed to further explore the performance of the method using simulated models of the Galaxy and realistic mock stellar systems based on their observed properties. To this end we propose to fund one postdoc with background in astronomy and two undergraduate students with science/computer science interests to help further develop the codes and carry out tests using real data from DES, and simulated data from LSST/Data Preview Zero (DP0).

Solar System Science Collaboration

- Stellar occultation

Júlio Camargo, Rodrigo Boufler, Gustavo Rossi, Martin Banda, Flavia Rommel: A new era in stellar occultation predictions: combining precise orbits from LSST and precise star positions from GAIA. LIneA's Solar System Small Object Portal.
Development of Stellar Occultation Reduction and Analysis (SORA), an open-source python library to reduce and analyse stellar occultation data efficiently - arxiv.org/abs/2201.01799

G. Benedetti-Rossi - A web interface based on SORA - Stellar Occultation Reduction and Analysis

SSSC

Brazil

KSI-11

Stellar occultations are a powerful observational technique for the determination of sizes and shapes of small bodies in the Solar System with kilometric accuracy. In addition, an investigation of the neighbourhoods of the occulting body is also possible and may lead to the discovery and analysis of rings, jets, satellites and atmospheres as tenous as a few nanobars. One of the interesting features of a stellar occultation is that it does not matter how faint the target object is, it is enough to record the flux variation from the star it occults as its light is temporarily blocked by the small body. Therefore, high angular resolution information can be obtained for the faintest objects if the occultation event involves a bright enough (V~16.0) star. A crucial step in this process is the prediction of such an event. With the LSST, tens of thousands of TNOs will be observed and have their positions given with respect to the Gaia astrometry so that the number of reliable predictions for a variety of interesting objects will experience an unprecedented increase. In this context, the python-based library SORA has been developed. It provides a rigorous python-based library for the analysis of light curves from stellar occultations. A graphical interface for SORA would make it more accessible not only to the occultation community but to those - amateurs hopefully - who wish to contribute to and better understand the analysis of an occultation light curve. Software specialists are required to develop the user interface (front-end) and the necessary tools for the communication between this front-end and the scientific code.

15 new PIs for the BPG nominated this August!

Active Galactic Nuclei +5

Dark Energy +1

Informatics and Statistics +3

Transients and Variable Stars

Stars, Milky Way, and Local Volume +3

Strong Lensing

Galaxies

Solar System +3

New PIs possible through LIneA in-kind contributions which are essential for doing science with LSST:

- Photometric redshift

Julia Gschwend et al:

- Photo-z Server – data and metadata photo-z related repository
- Training Set Maker – pipeline to generate training and validation sets for photo-z estimation from public spectroscopic data
- Complementary data products – photo-z measurements for all objects in public data releases.

- Independent Data Access Center (IDAC)

LIneA IT team:

- Access of proprietary LSST data to members
- Access of public data using the Science Server
- 5 PB storage, 500 TB database, 500 cores
- Process photo-z measurements
- Accquisition of equipment has started

Conclusions

Rubin Observatory's LSST will provide an unprecedent amount of data.

An extremely rich Science Program with LSST data ahead – see LSST Science Book.

Amazing opportunities that comes together with challenges.

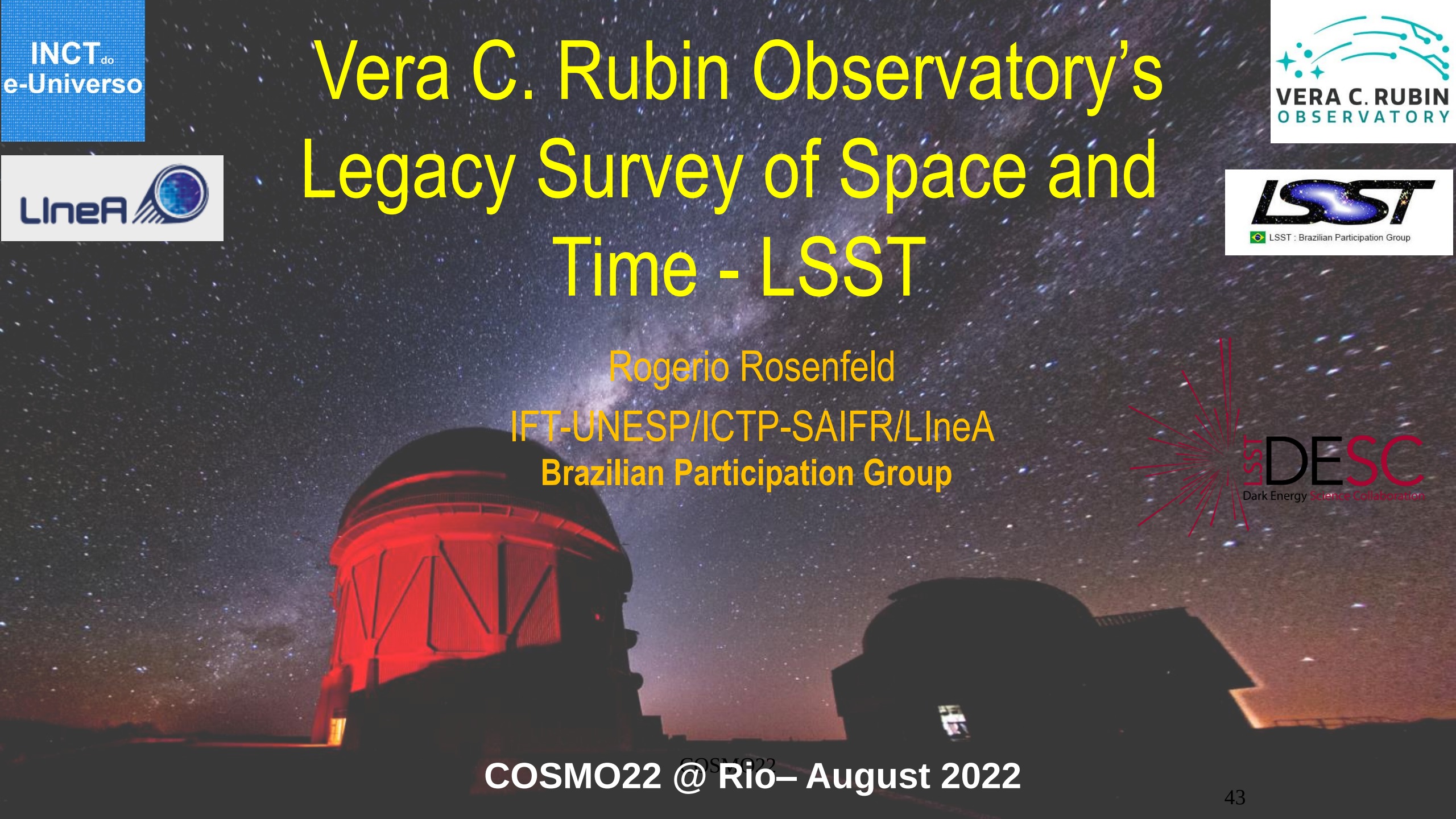
LSST's eight Science Collaborations already in full action with Data Challenges and Data Previews catalogues to test modelling, pipelines, etc. Getting ready for real data!

Brazilian Participation Group already engaged in some Science Collaborations.

Many of us have experience from working in DES.

Recent expansion of the BPG with LIneA in-kind contribution. Need to get new member up-to-speed.

Exciting times ahead. Eagerly waiting for first light in 2024!



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Rogerio Rosenfeld

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