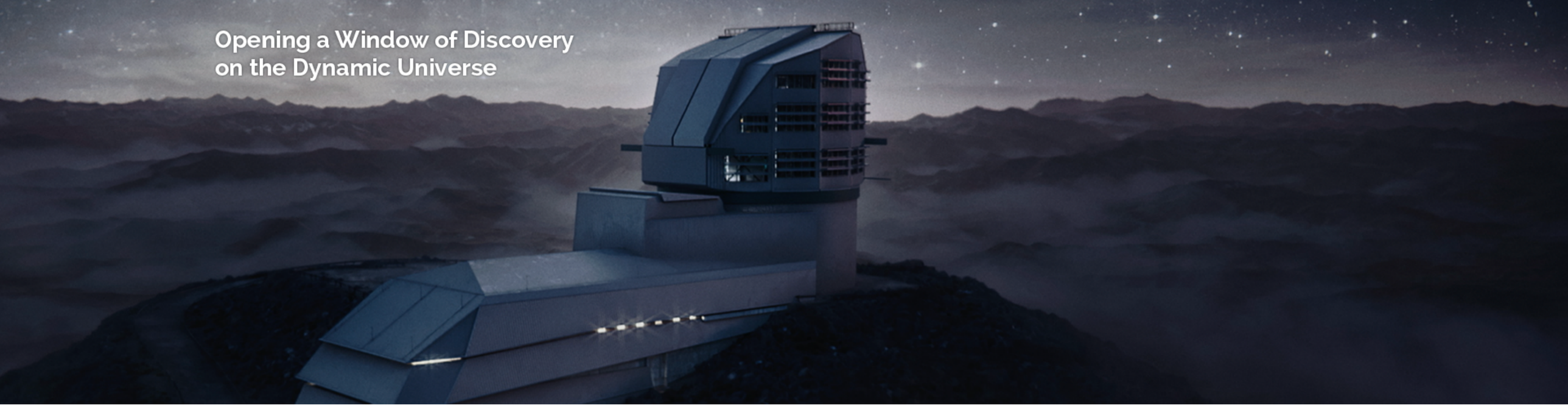

Gravitational lensing with the Vera Rubin's Legacy Survey of Space and Time (LSST) and LSST-MX

Alma X. González Morales
Universidad de Guanajuato

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ININ Cinvestav MCTP CONAHCYT

Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST)

- Cerro Pachón, Chile.
- Finalizing construction.
- 8.4-m mirror
- 3200 Gigapixel camera
- 6 optical filters (320-1050 nm)
- 9.6 deg2 of field-of-view (40 full Moons)

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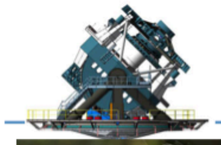
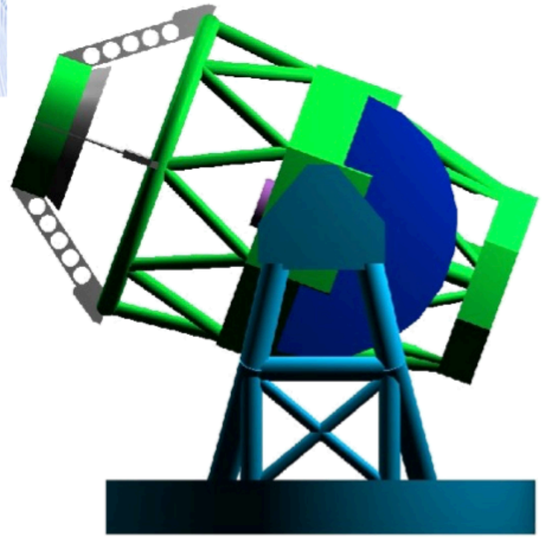
- Latest news (https://www.lsst.org/news/

Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST)

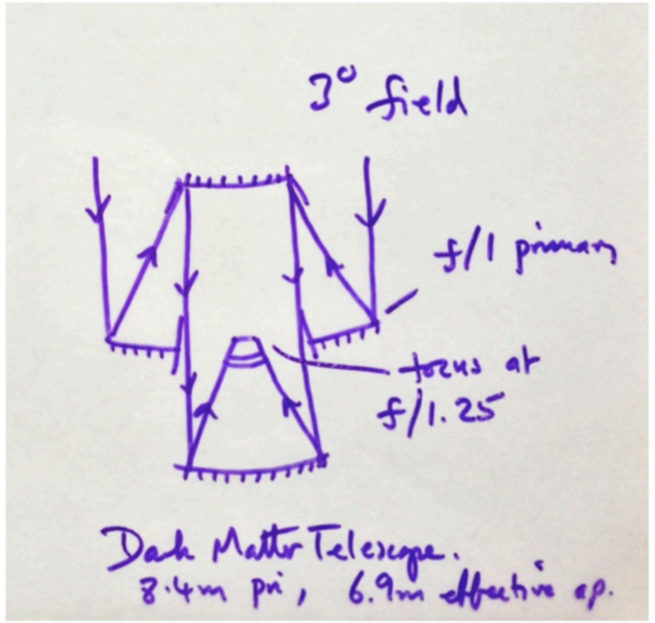


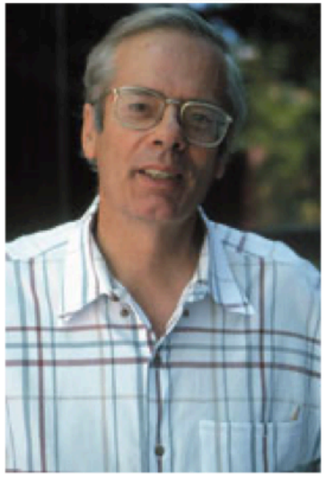
The LSST dream started in mid 90's

Tony Tyson – UC Davis:
Dreamed of an all sky survey to explore Dark Matter and the time domain



Roger Angel – U Arizona:
Dreamed of an optical design for large wide-field telescope





From Large Synoptic Survey Telescope (LSST) to the Vera C. Rubin Observatory in 2019

Slide from Construction Status
SPIE, Austin, 2018

The Vera C. Rubin Observatory (Since 2019)

Survey of lots of objects in the sky over time and timelapse. Streaks conceptually represent connection of NOIRLab and SLAC through this partnership.

Teal colors connect to the physical observatory.

This represents community, ideas, discovery, astronomy - different types of objects. Varying sizes and shapes conveys inclusivity.

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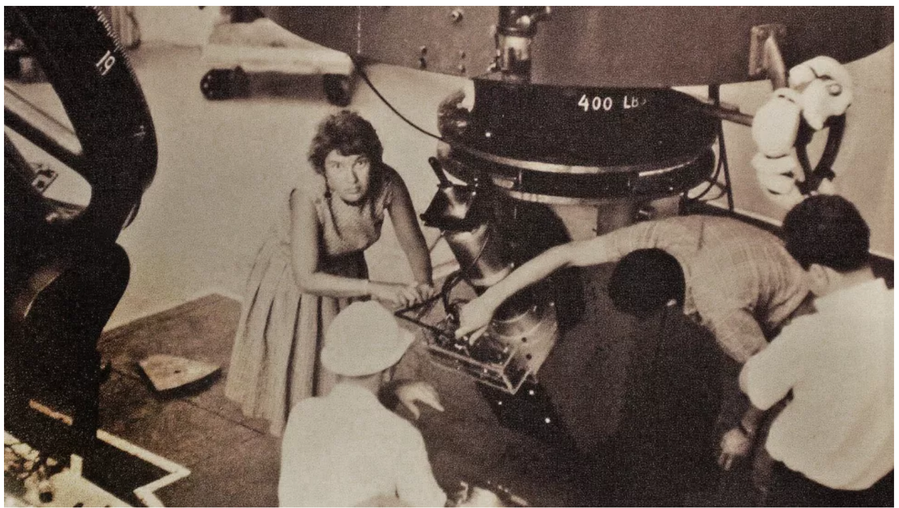
Big Data is an important part of Rubin Observatory. Straight lines with dots at the ends represent traces on digital electronic readout boards.



First national US Observatory to be named after a woman! The full name here celebrates this.

Teal colors connect to the physical observatory.

Observatory Construction Status

Rubin Observatory is nearing Completion!

(on sky data later this year)

Rubin Summit Facility shown with lift up and dome door open for Mirror install

Rubin is already taking images with the Commisioning Camera

Rubin is well into Observatory Commissioning!
(test data is streaming off the summit)

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2024

~~LSST Camera ships from SLAC in California to Chile~~

~~Primary/tertiary mirror (M1M3) coated and installed~~

~~Secondary mirror (M2) installed~~

~~ComCam on sky~~

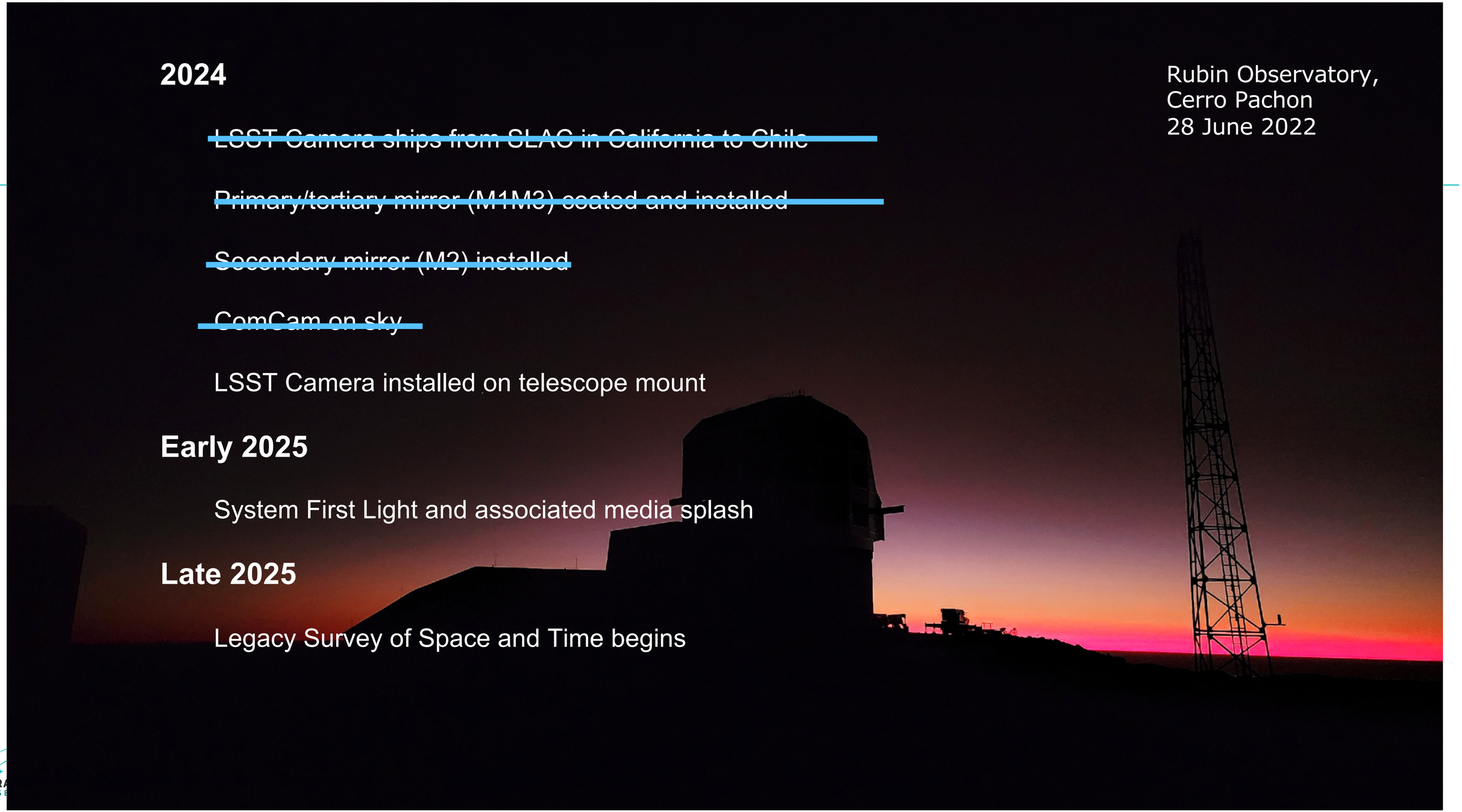
LSST Camera installed on telescope mount

Early 2025

System First Light and associated media splash

Late 2025

Legacy Survey of Space and Time begins

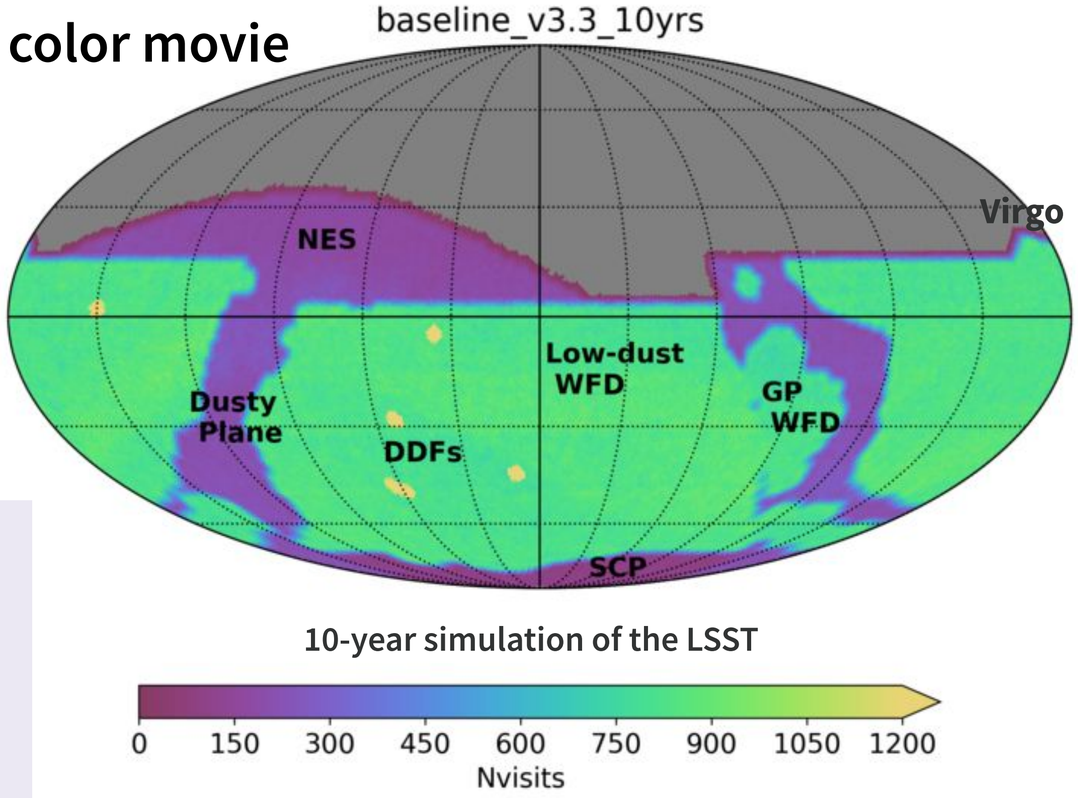


Legacy Survey of Space and Time

In the first 10 years of operation, the Vera C. Rubin Observatory will execute as its prime mission the Legacy Survey of Space and Time (LSST)

A "Wide-Fast-Deep" uniform optical/near-IR sky survey & color movie

- Entire visible sky, (18000 deg^2) every 3 nights
- ~825 visits / pointing, ugrizy bands, r~27.5 (36 nJy),
- 20 billion galaxies, 17 billion stars



10 million alerts/night, 11 data releases over 10 yrs

Raw Data

6.4 GB/exposure (compressed) | 20 TB/night | ~5 PB per year

Final 10-yr dataset

~6 million images | ~0.5 EB data products | 15 PB final catalog

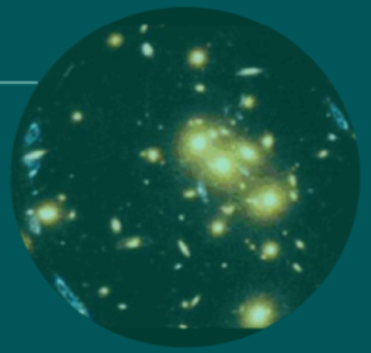
LSST

Main Science Drivers

Most relevant for this audience

Dark Matter, Dark Energy

- Weak Lensing
- Baryon acoustic oscillations
- Supernovae, Quasars



Cataloging the Solar System

- Potentially Hazardous Asteroids
- Near Earth Objects
- Object inventory of the Solar System

Milky Way Structure & Formation

- Structure and evolutionary history
- Spatial maps of stellar characteristics
- Reach well into the halo

Exploring the Transient sky

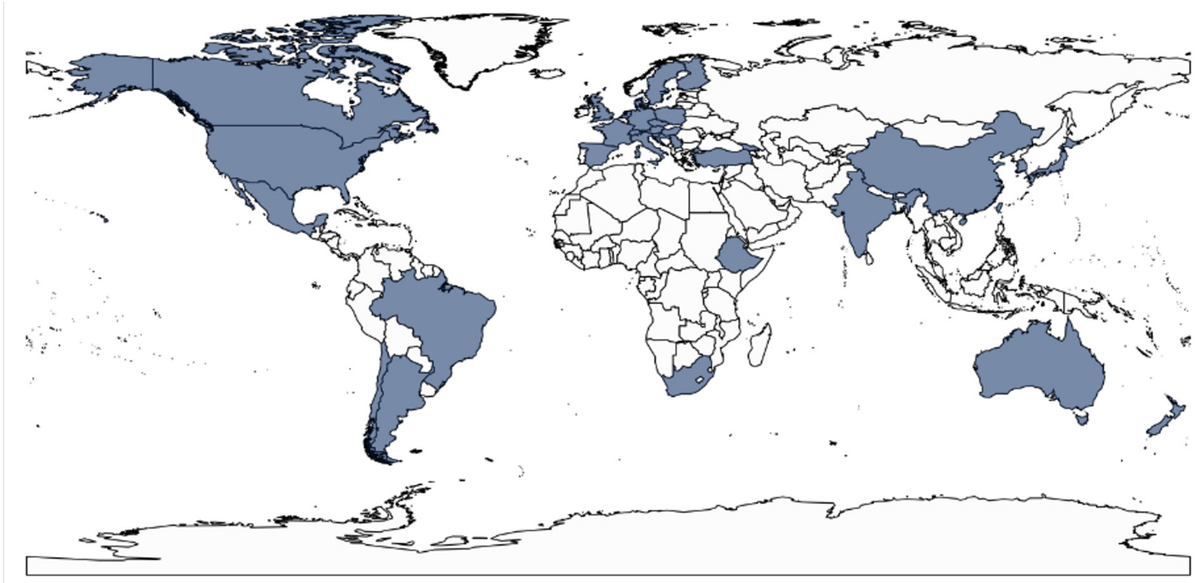
- Variable stars, Supernovae
- Fill in the variability phase-space
- Discovery of new classes of transients

Ivezić et al. (2008), V5(2018)

The Science Collaborations

The Rubin Observatory Science Collaborations (SCs) is a federation of independent, worldwide communities of scientists, self-organized into groups based on research interests & expertise.

>2000 people, 2500 affiliations, 6 continents, 33 countries, 8 teams.

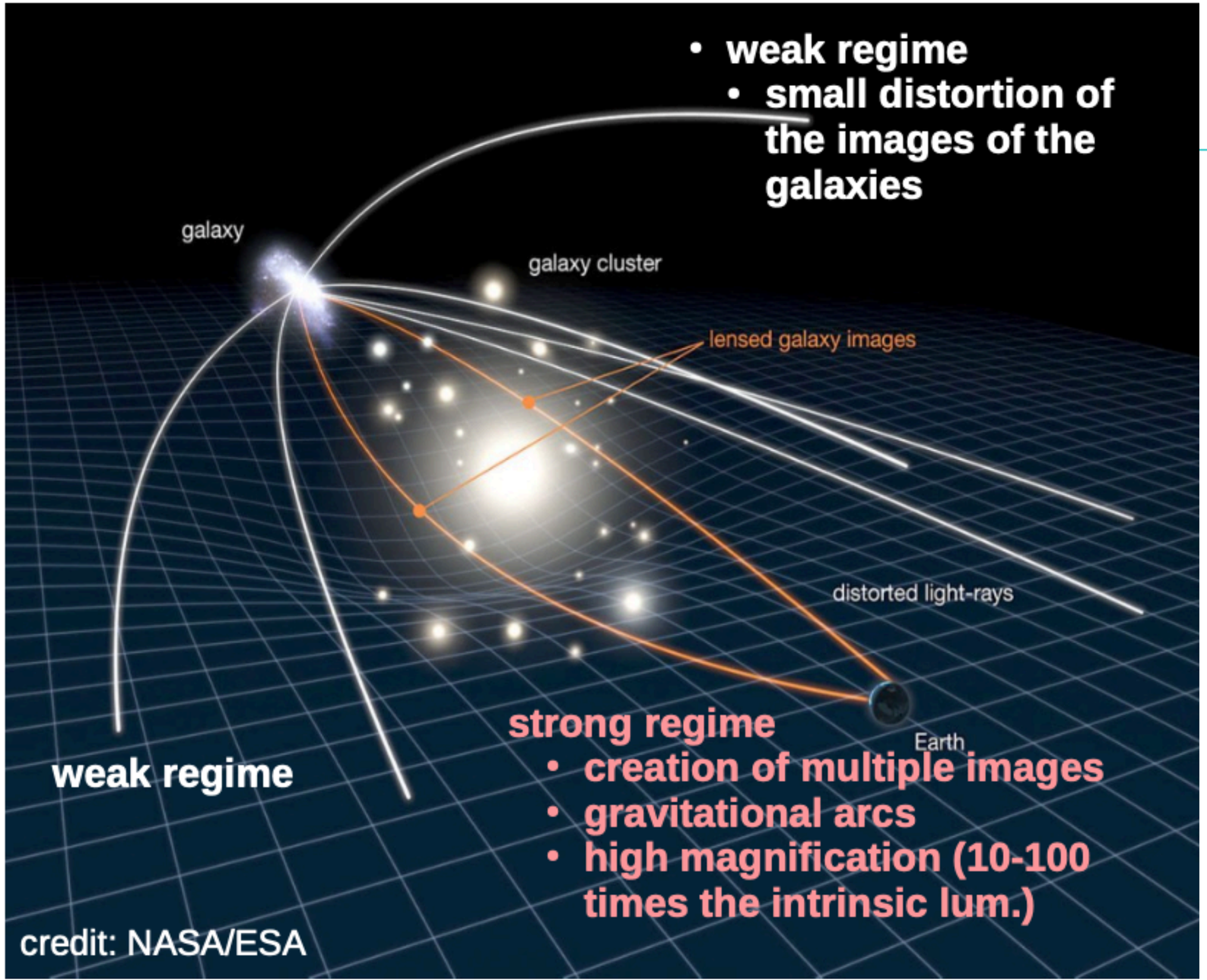


- **AGN**
- **Dark Energy**
- **Galaxies**
- **Informatics & Statistics**
- **Strong Lensing**
- **Stars, Milky Way & Local Volume**
- **Solar System**
- **Transients & Variable Stars**

Science Collaborations Coordinator Will Clarkson wiclarks@umich.edu
For more information, including how to join: https://lsstdiscoveryalliance.org/lsst-science-collaborations/

Gravitational Lensing

Gravitational Lensing



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Gravitational Lensing

Theory

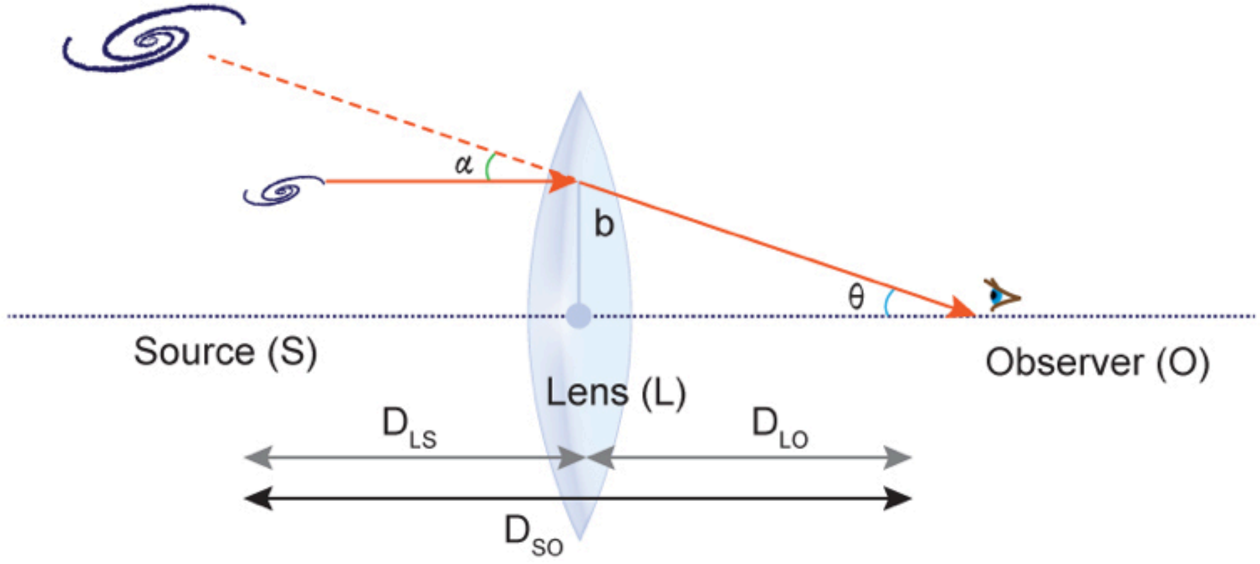
$$\vec{\beta} D_{OS} + \hat{\vec{\alpha}}(\vec{\theta}) D_{LS} = \vec{\theta} D_{OS}$$

$$\hat{\vec{\alpha}} = \frac{4GM}{c^2} \frac{\vec{\xi}}{|\vec{\xi}|^2}$$

For a point mass

$$\hat{\vec{\alpha}}(\vec{\xi}) = \frac{4G}{c^2} \int d^2\xi' \underbrace{\int dz \rho(\vec{\xi}', z)}_{\equiv \Sigma(\vec{\xi}')} \frac{\vec{\xi} - \vec{\xi}'}{|\vec{\xi} - \vec{\xi}'|^2}$$

For a mass distribution



Einstein Radius

$$\theta_E = \sqrt{\left(\frac{4GM}{c^2}\right)\left(\frac{D_{LS}}{D_{LO} D_{SO}}\right)}$$

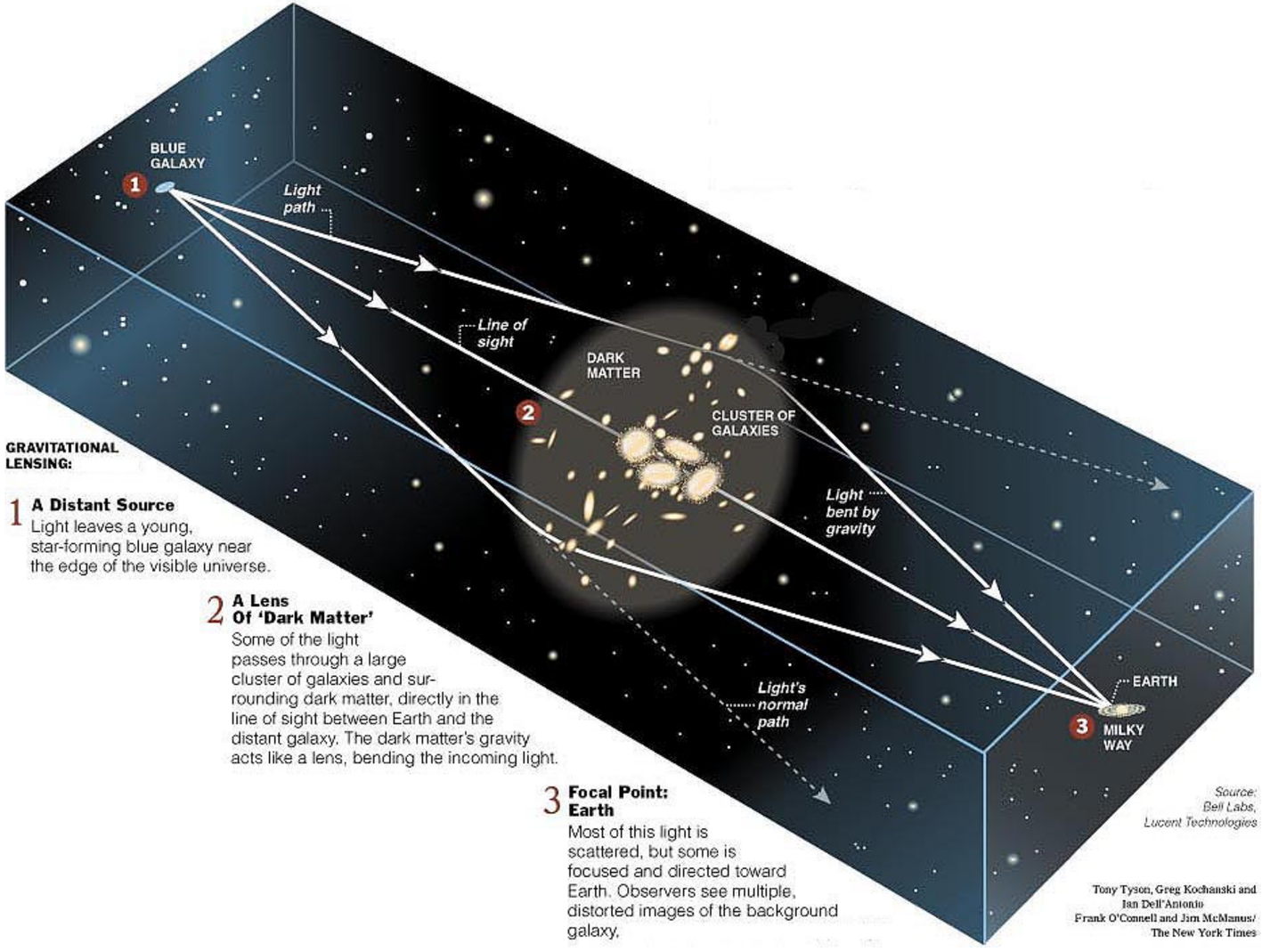
We can infer how much mass is present by measuring the Einstein Radius

For an extended mass distribution
$M = M(< \theta_E)$

$$M(< \theta_E) = 1.1 \times 10^{14} M_\odot \left(\frac{\theta_E}{30''}\right)^2 \frac{D_{OL} D_{OS}}{\mathrm{Gpc} D_{LS}}$$

Lensing

Cluster scales



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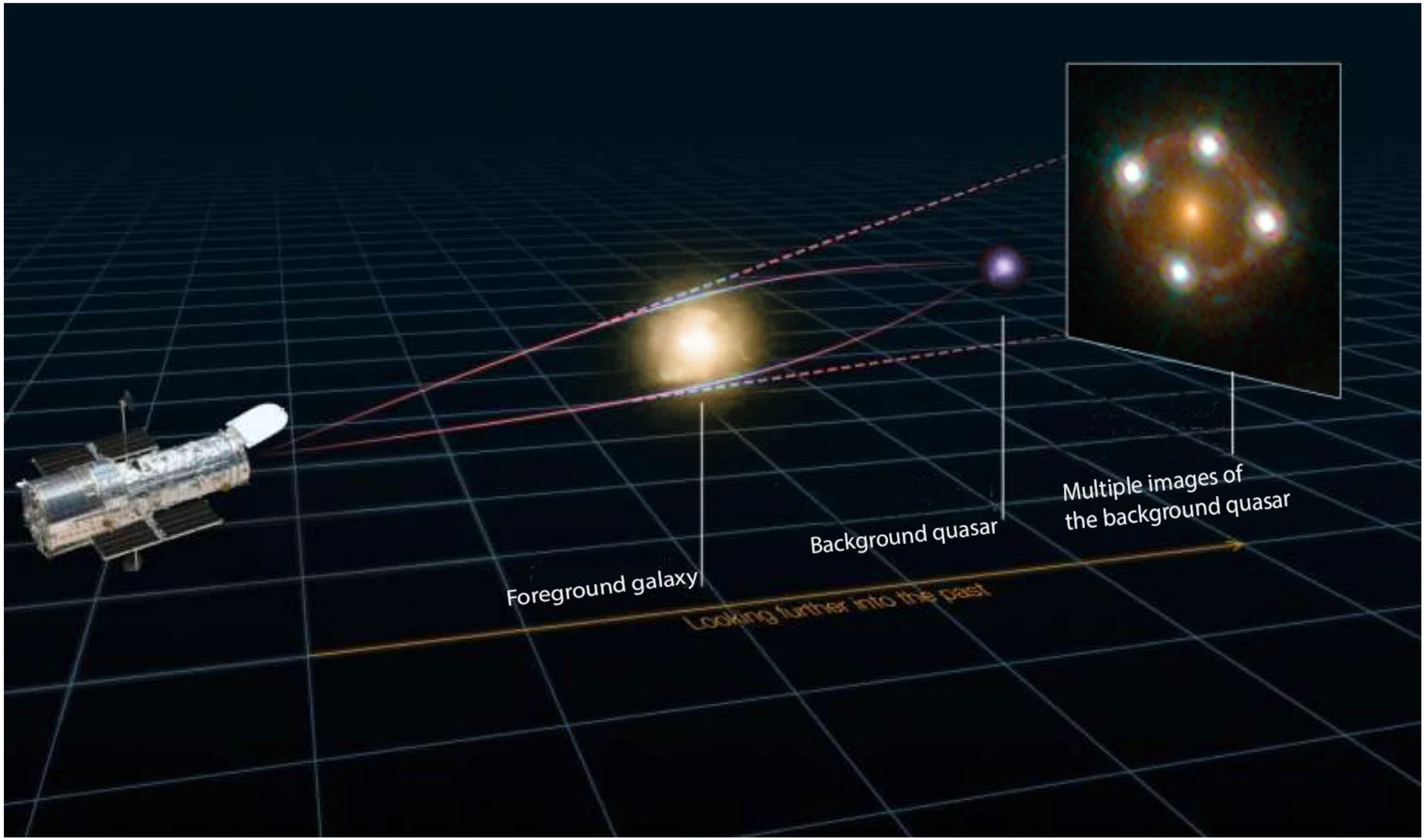
Strong Lensing
Galaxy Scales

Known lensed quasars ~10^2, we expect to find ~10^5 in the next decade with LSST.



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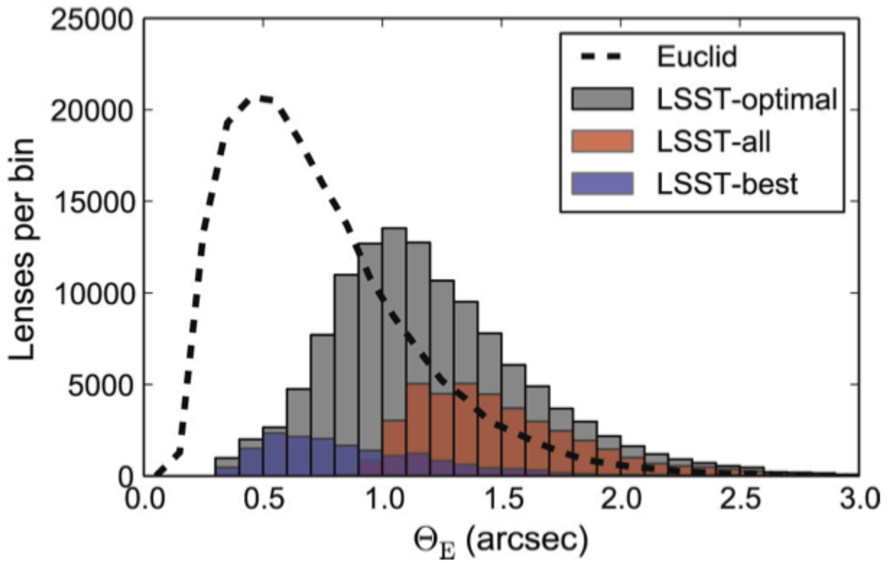
LSST Strong Lensing Detection

LSST will find more strong gravitational lensing events than any other survey before.



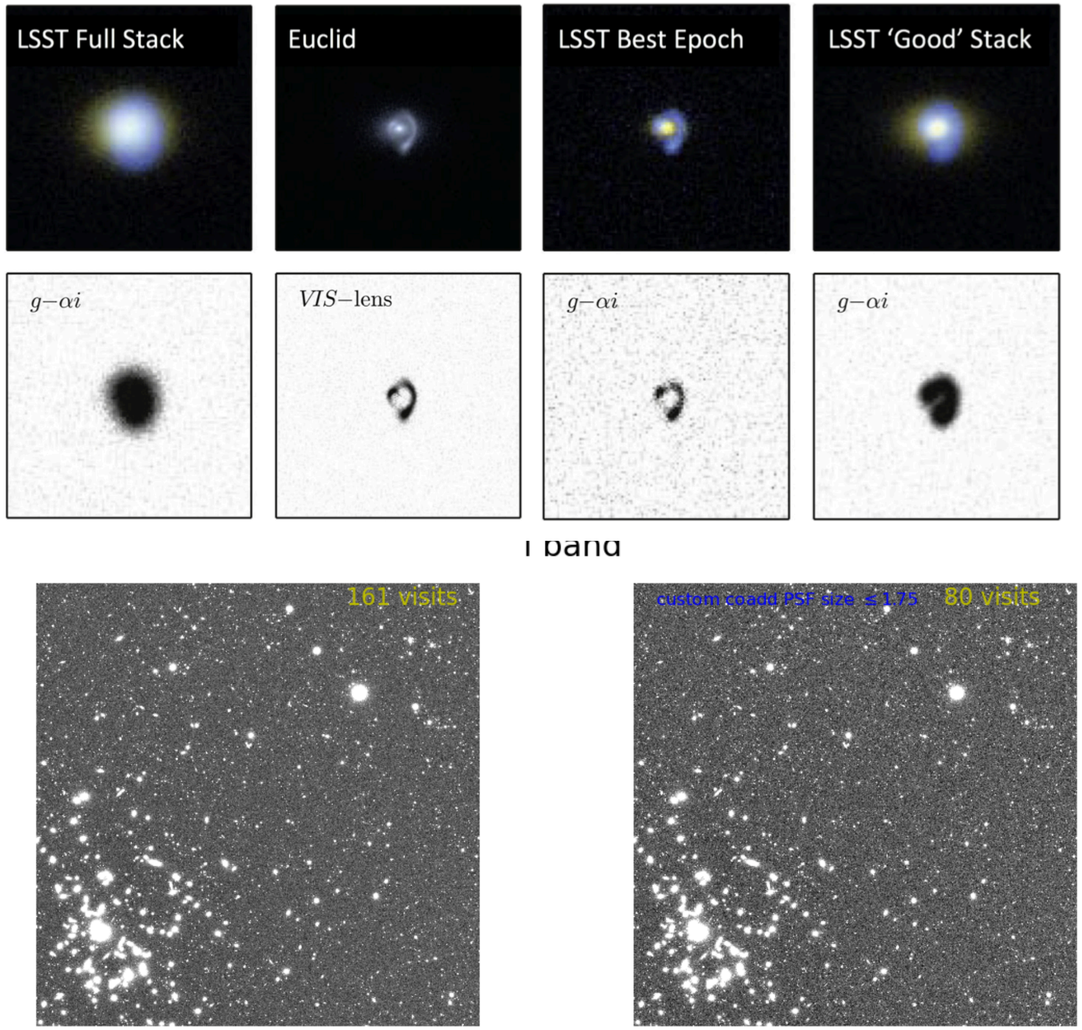
Strong Lensing phenomena can provide information about:

- The total mass distribution of galaxies, groups and galaxy clusters.
- Dark Matter structure on sub galactic scales
- Constrain cosmological parameters, constrain dark energy.
- High redshift transients and host galaxies
- Place constraints in stellar mass functions.
- And many more…

Current project

Optimal image quality for Lens Detection

- Understand how the PSF is constructed, PSF spatial variation, PSF behavior in the different filters.
- Create DP0 images (no lensing systems) with injected lens images, and custom coadds. i.e. different coadds based on quality selection.
- Test finding algorithms for different qualities of the images, Use simulated images to test how well we recover physical parameters (MsC and PhD students at UG)
- In summary: We are preparing for real data to come…

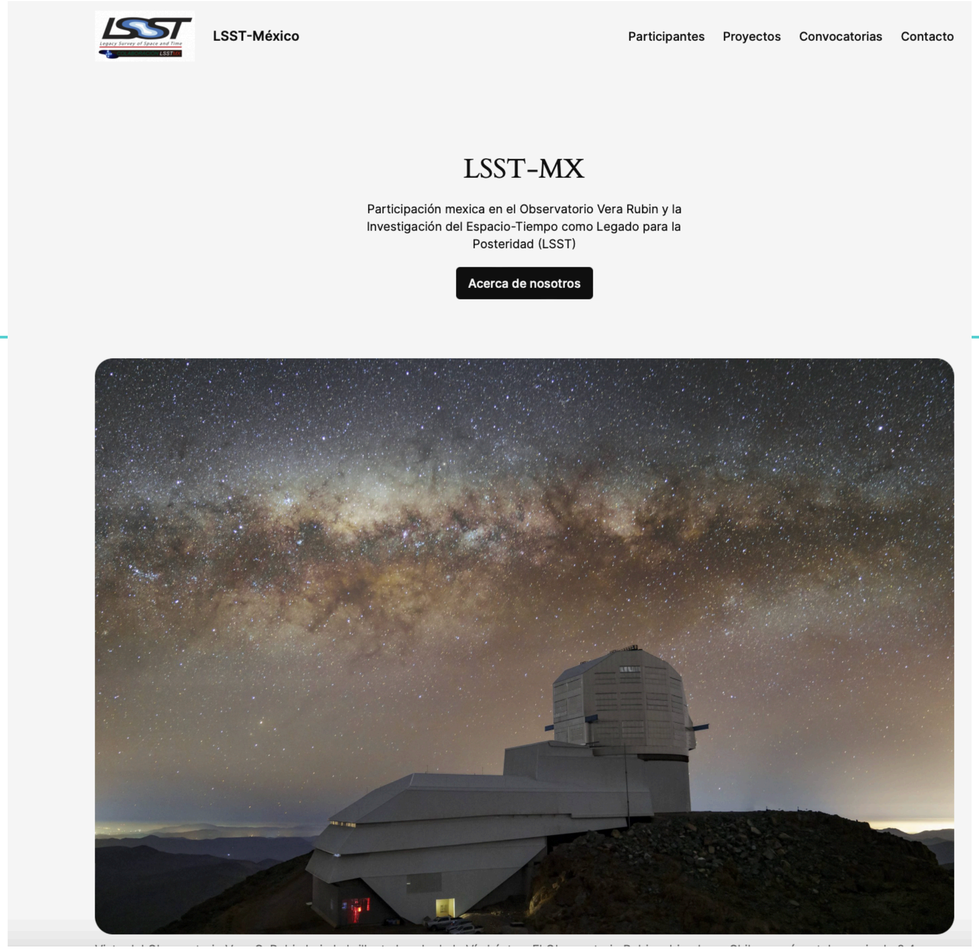


Mexican Participation

LSST-MX

A bumped road

- 2015-2016 Fronteras de la ciencia Call (unsuccessful)
  - $200, 000.00 USD per License (1PI, 4 JA)
- 2017 Internal call at UG (unsuccessful)
  - $400, 000.00 USD per License
- Fall 2019 Letter of intent for joint proposal by UG-UNAM for in-kind contributions.
- Fall 2020 Formal proposal lead by UG+UNAM for **in-kind** contributions. ~20 Researchers involved, 5 institutions. (**Plan for success!**)
- Spring 2021 Proposal accepted by LSST
- Fall 2021 Start of the contributions work plans and deliveries.
- Spring 2022 Almost all contributions started.
- 2024: +50 Researchers, including students from different levels and institutions, and contributions are ongoing.



Universidad de Guanajuato

ININ

Cinvestav

MCTP
Mesoamerican Centre for Theoretical Physics

Students and postdocs can join at any time.
Full Time researchers and lecturers can join through an annual call
https://fisica.ugto.mx/~lsstmx/

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LSST-MX

“in-kind” contribution

Lead institutions : UNAM and UG
Proposal leads:
Alma González (UG)
Octavio Valenzuela (IAUNAM)

Project Manager: Luis Ureña López (UG)

Project Leads
Directed software development to SLSC: **Alma González (UG)**
Directed software development to DESC: **Josue De Santiago (CINVESTAV) (See Josue’s talks next to mine)**
Non-Directed software development to DESC: **Alejandro Aviles Cervantes (ICF-UNAM)**
Directed software development to SMWLV: María de los **Angeles Pérez-Villegas (IA-Ensenada—UNAM)**
Non-Directed software development to SMWLV: **Jose Antonio Vázquez-Mata (IA-**

Full participant list in https://www.lsst.org/scientists/international-drh-list

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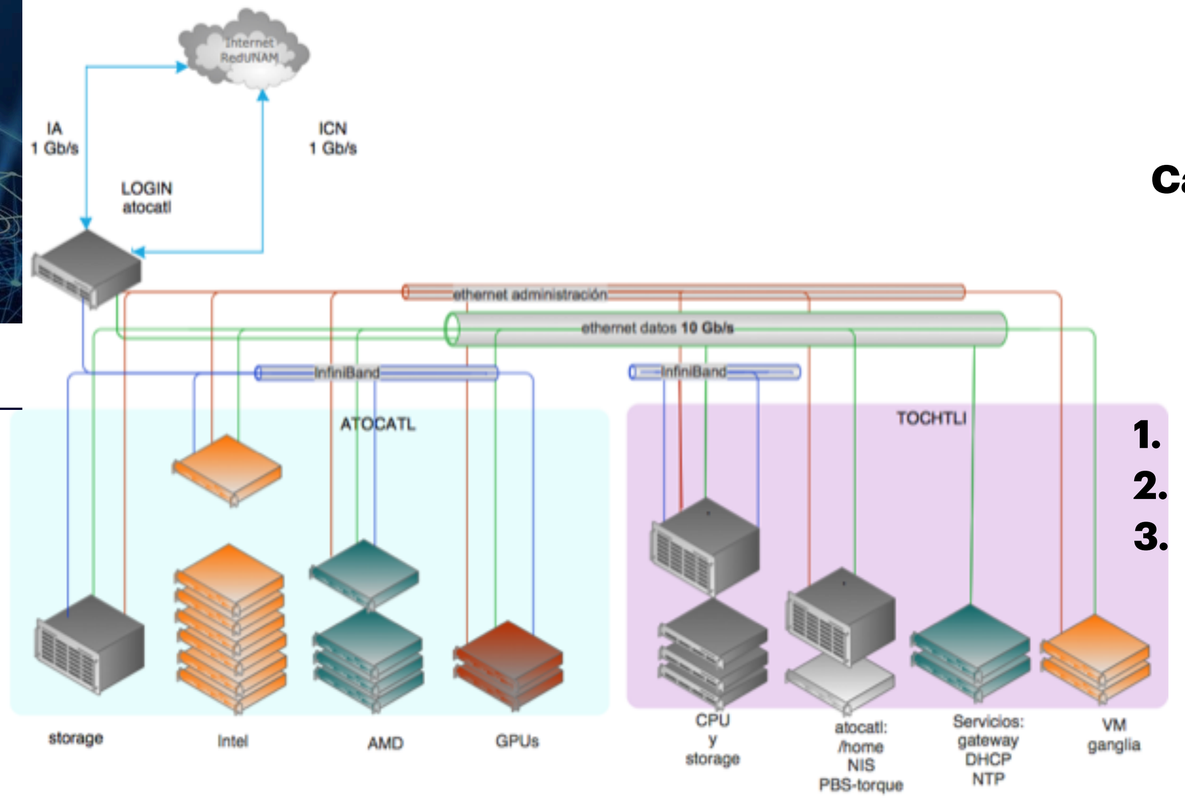
LITE IDAC LSS-TMX

Octavio Valenzuela (CL)
Institutions: IA, ICN, UNAM

LAMOD
LABORATORIO
DE MODELOS Y DATOS DE LA UNAM

www.lamod.unam.mx

2000 cores
6 Petabytes
10 Gbps connectivity



IDAC LSSTMX
1.6 Petabytes
200 cores

Catalogs/Tables 10^9
raws
200 Columns
PostgreSQL

1. **Object Catalogues**
2. **Derived Products**
3. **Coadded Images**

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LSST Science Collaborations

Mexican participation in 4 of them

+ service through the International Data Access Center

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If you are in Mexico City this November 9th

Visit our thematic tent at Noche de las estrellas

http://www2.astroscu.unam.mx/uc3/index.php/80-inicio/87-noche-de-las-estrellas

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More on LSST and data access

LSST data products

The LSST Data Products are organised into three main categories:

Prompt

A stream of ~10 million time-domain events per night, detected and transmitted to event distribution networks with 60 seconds of observation.

A catalog of orbits for ~6 million bodies in the Solar System

Previously "Level 1" data products

Data Release

A catalog of ~37 billion objects (20B galaxies, 17B stars), ~7 trillion observations ("sources"), and ~30 trillion measurements ("forced sources"), produced annually, accessible through online databases.

Reduced single-epoch, deep co-added images.

Previously "Level 2" data products

User Generated

User-produced added-value data products e.g deep KBO/NEO catalogs, variable star classifications, shear maps, etc …

Enabled by services and computing resources at the Data Access Centers and via the LSST Science Platform

Previously "Level 3" data products

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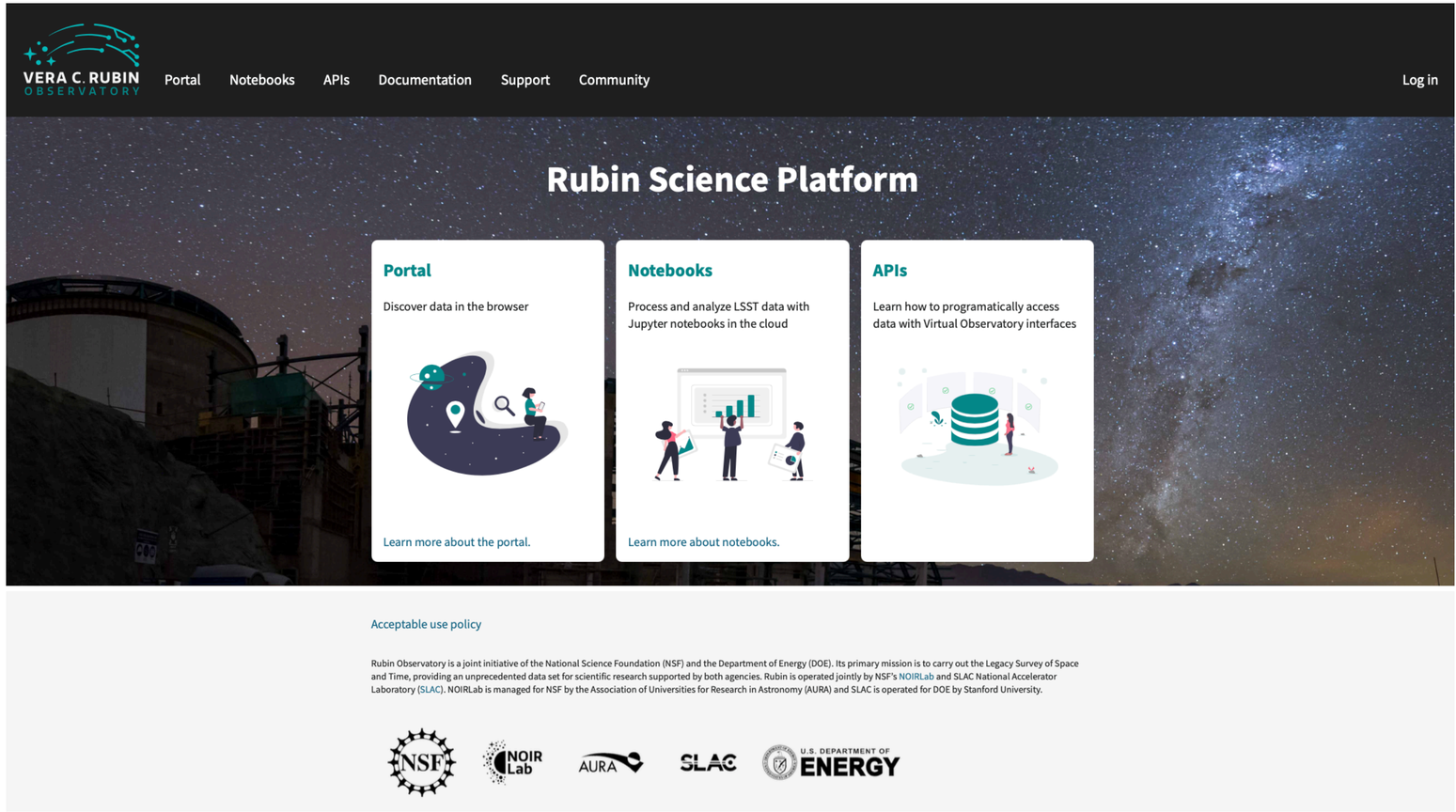
LSST Data Previews

- DP0: Simulated LSST-like data products available through the Rubin Science Platforms (RSP)
  - Data from the DESC Data Challenge 2. Contains extragalactic and galactic objects, and some time-domain objects such as Type Ia supernovae, AGN, and variable stars, but does not contain Solar System objects. See **The LSST DESC DC2 Simulated Sky Survey** (arXiv:2010.05926)
  - DP0.1 data processed with curren Rubin Pipeline
  - DP0.2 data processed with Rubin Pipeline by March 31 2022. 900 Delegates
  - DP0.3 is out: Solar System simulated object catalog.
- DP1: Subset of commissioning Images
- DP2: Full commissioning images
- DR1: Survey images from first year
- All data served in a format such as the future LSST data releases through the SRP



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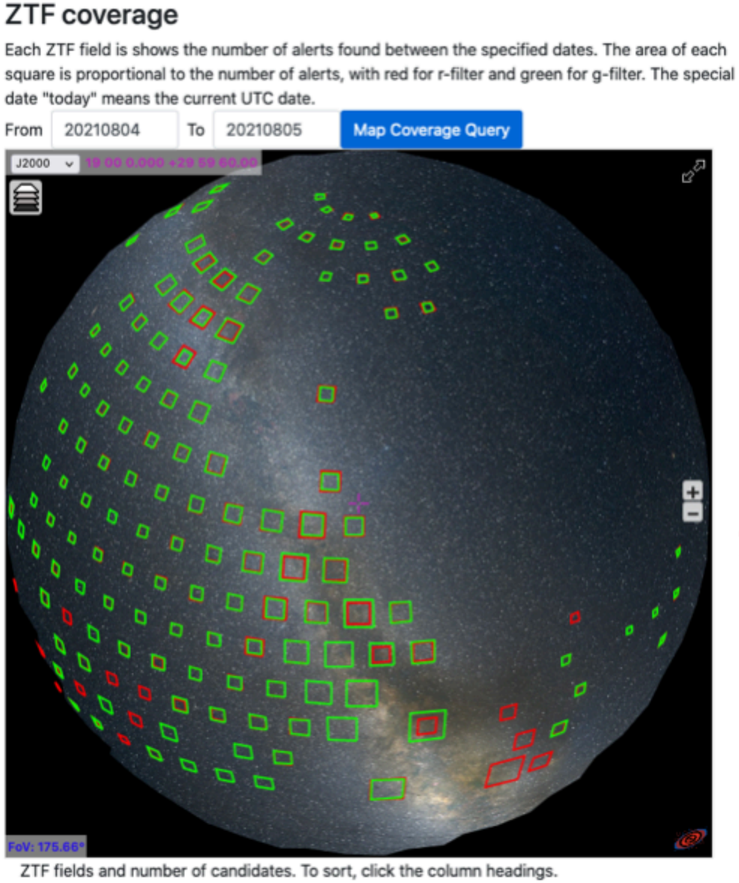
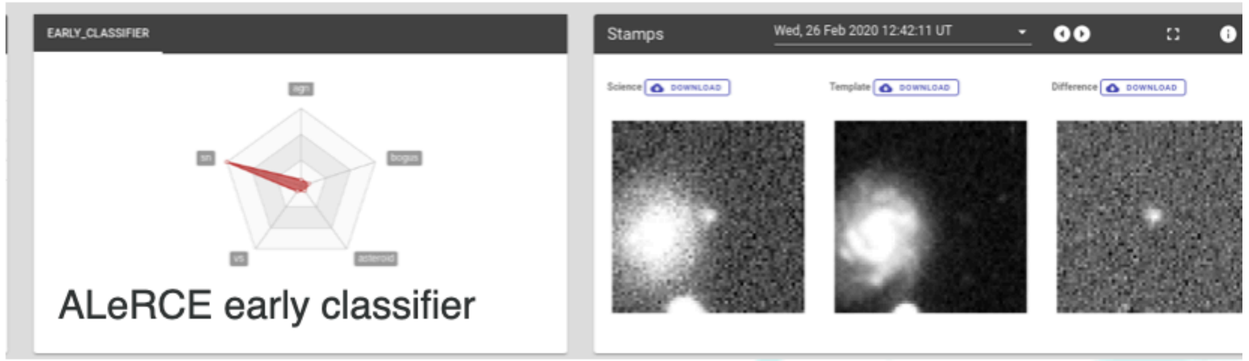
- Documentation and tutorials are publicity available, but most of such can only be run through the RSP.

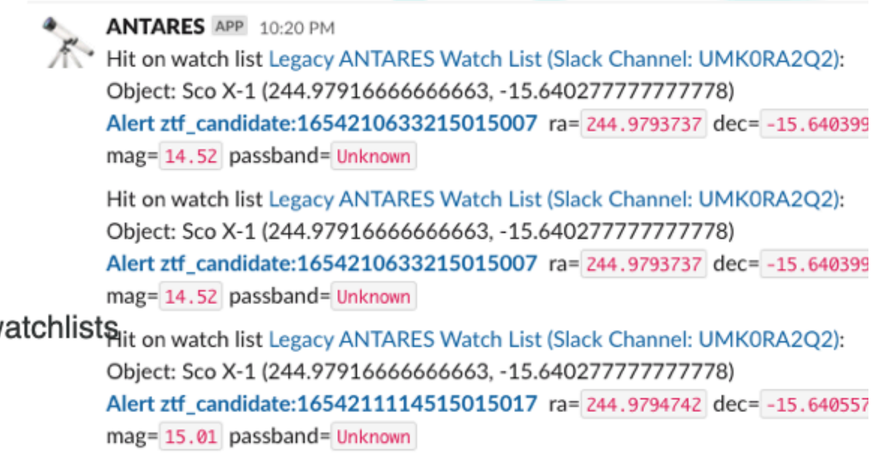
Get familiar with the brokers and prepare for LSST



Lasair coverage viewer

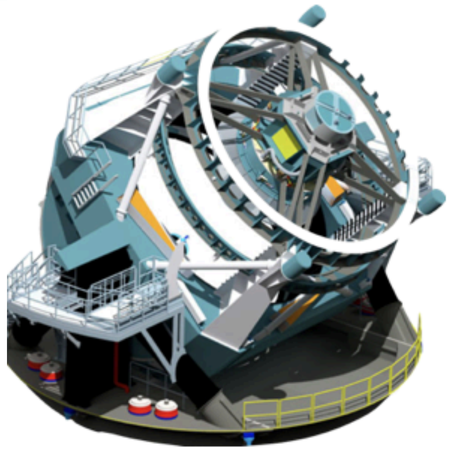


ANTARES Slack watchlists



Alert brokers

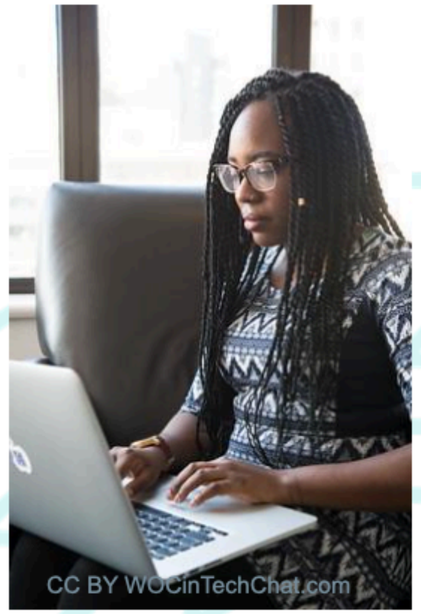
Rubin's real time science



Rubin

Alerts

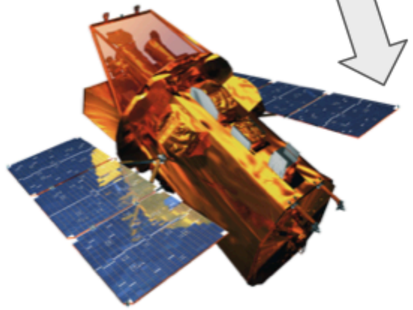
Brokers



Scientists

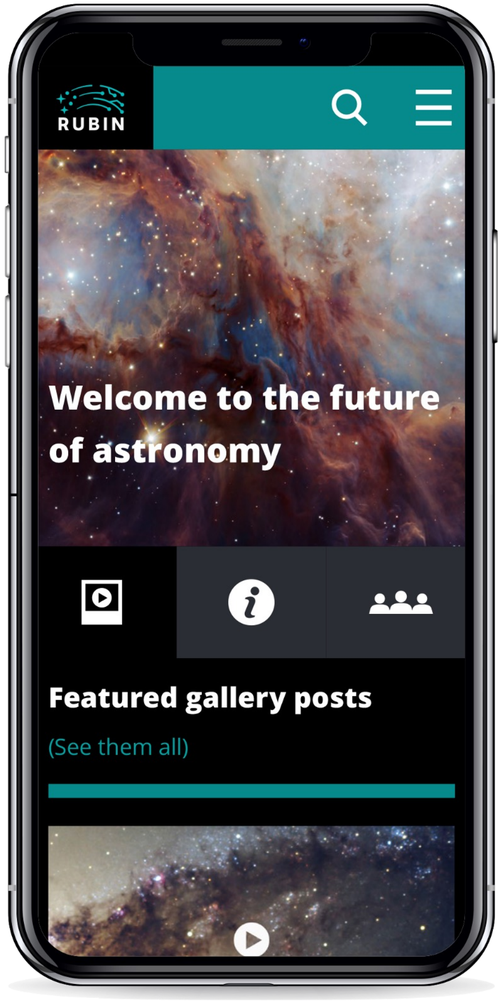
COMMUNITY SCIENCE AND DATA CENTER

Archives



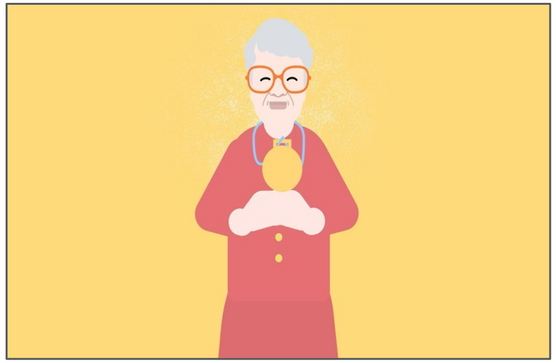
Other Facilities

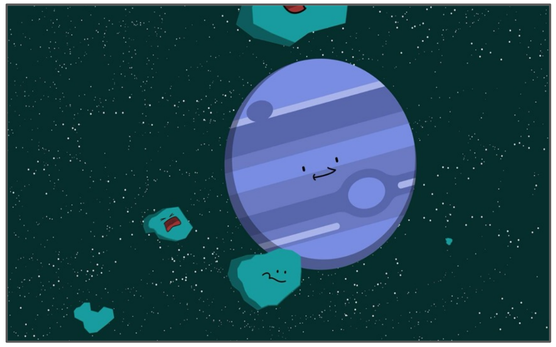
EPO Program is active in Operations!

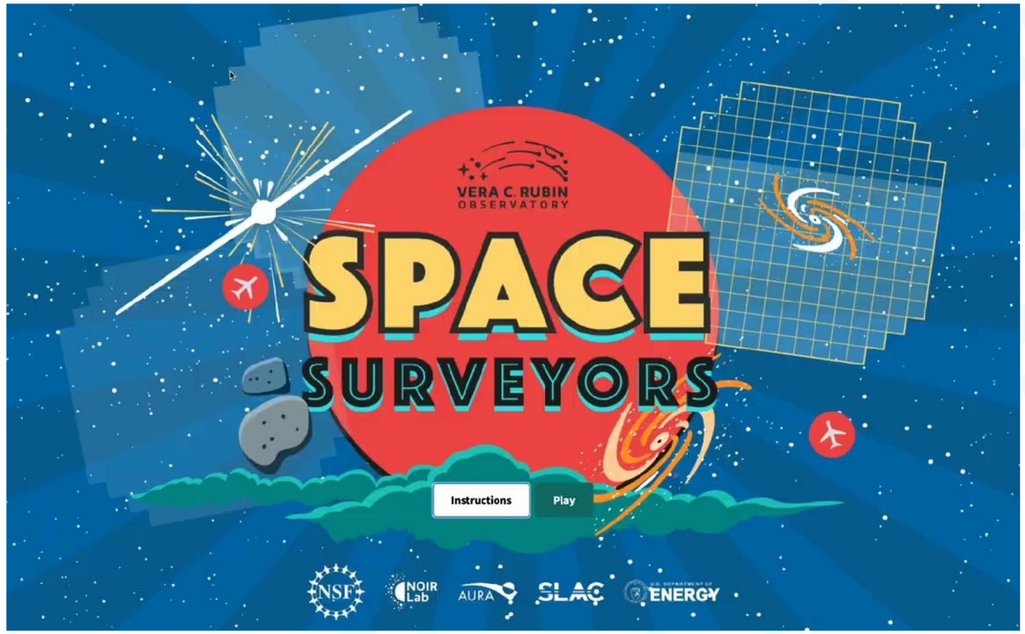


Website live: **rubinobservatory.org**

Animated videos on YouTube, available in English and Spanish



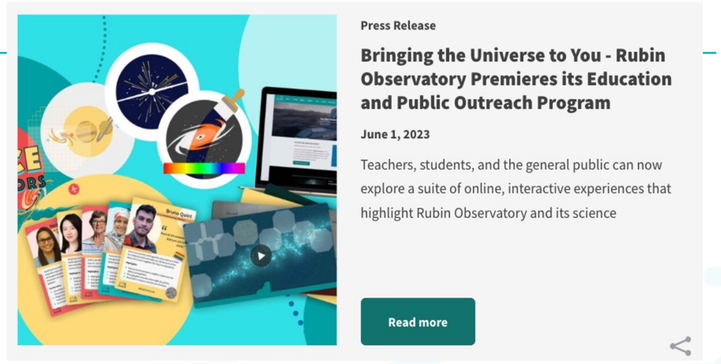


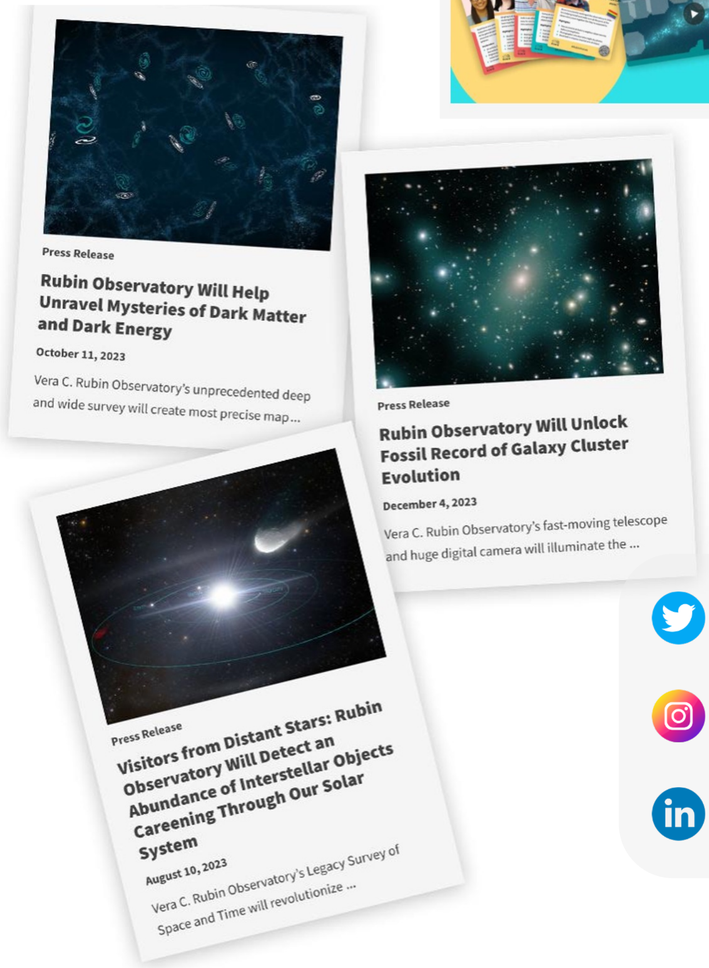


Try for a high score at spacesurveyors.app

Education & Public Outreach

- New content regularly posted to News, Events, Rubin Voices, and Education sections
- Final version of new Coloring the Universe formal education investigation released
- Ongoing external evaluation website/social media focus groups assessing reach/audience and measuring learning/engagement
- In 2023, social media accounts published over 1000 posts, reaching over half a million users and growing
- Increasing cadence of science releases to build momentum towards first light





@VRubinObs

@rubin_observatory

@RubinObservatory

Rubin and LSST: Perspectives and challenges

For UG and the other participant institutions

- Consolidate our current participation
- Continue to grow the initial seed group into a great Mexican community that gets the most out of LSST data.
- Transfer the *know how* to other non-participant institutions/researchers, so that LSST data continues to be deployed once its public (LSST has a 2 year proprietary data policy).
- Learn about DM and DE through Gravitational Lensing
- Take advantage of the LSST EPO (Education and Public Outreach) huge effort and make accessible in León, Guanajuato.
- If you are interested in joining talk to us (gonzalez.alma@fisica.ugto.mx)

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THANKS

VERA C. RUBIN
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