The Vera C. Rubin Observatory and the LSST Dark Energy Science Collaboration (DESC):

Promise for Fundamental Physics with the LSST Survey and Beyond

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VERA C. RUBIN OBSERVATORY

LSST DESC Dark Energy Science Collaboration

Talk Outline

Rubin Observatory and DESC: structure and relationship

Fundamental physics goals

A look ahead to operations and analysis phase

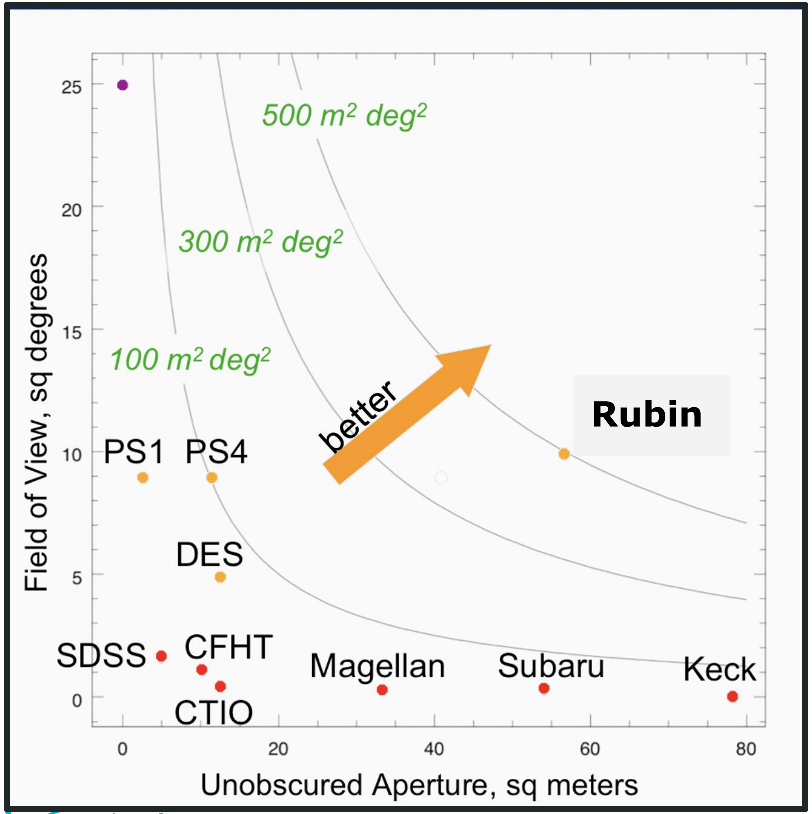
Some early thoughts about evolution and extensions

What we need in order to succeed

The Vera C. Rubin Observatory

- Largest new US investment in ground-based optical/IR facility
- System comprises an 8.4 meter telescope, the largest digital camera ever constructed, and an analysis and information distribution pipeline
- Jointly supported by NSF & DOE
- Strong international participation
- No proprietary data period- levels the playing field across partners
- Construction now nearing completion
- Operations phase expected to begin late 2024

Unprecedented Aperture X Field of View



Etendue = AΩ product is figure of merit for surveys

Rubin (aka LSST) combines those features

Baseline plan is 10-year time-lapse imaging of entire Southern sky

Images are co-added to detect faint objects

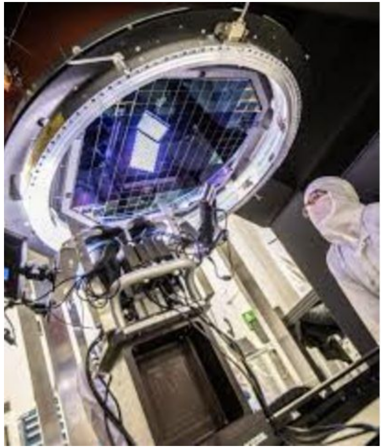
- 3-d mass map from weak lensing of galaxies
- evolution of large scale structure: DM vs DE
- streams of stars in MW and external galaxies

Images are subtracted in real time to detect transients, allowing dark energy and dark matter probes through

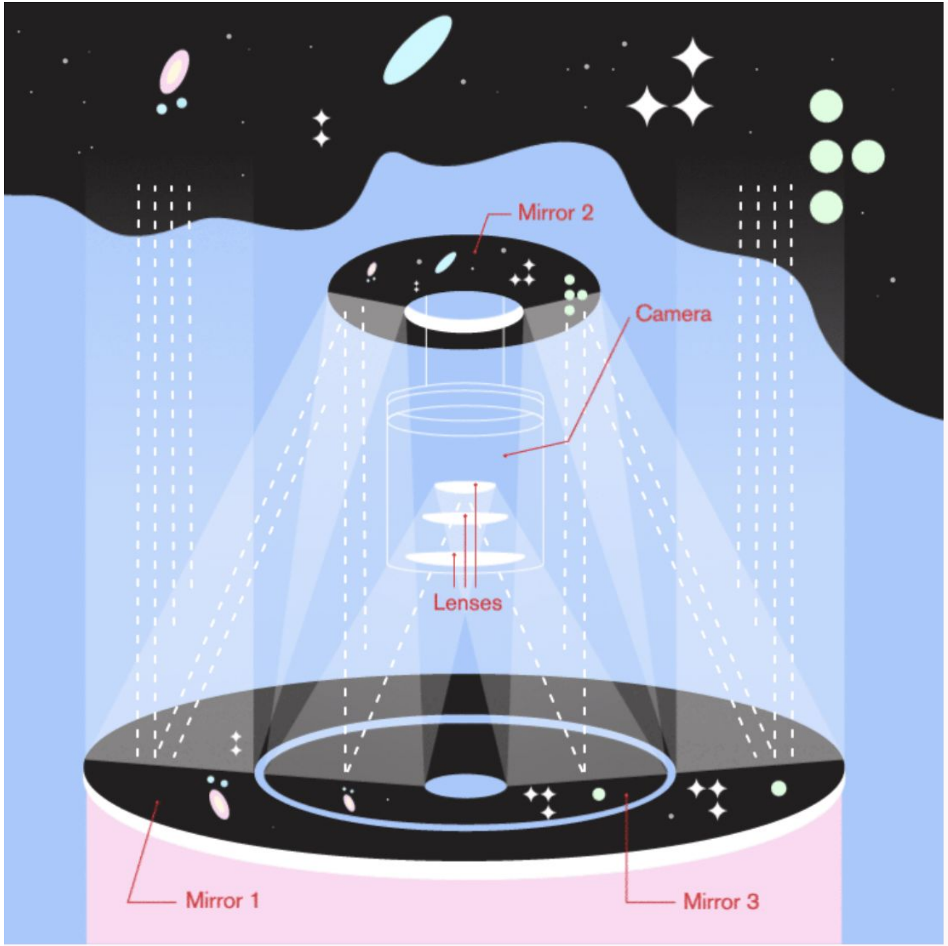
- distances & redshifts of type Ia supernovae
- optical ID of sources of gravitational waves
- time delays in strong lensing systems

Engineered to control systematics and achieve precision

Rubin Observatory is coming to life

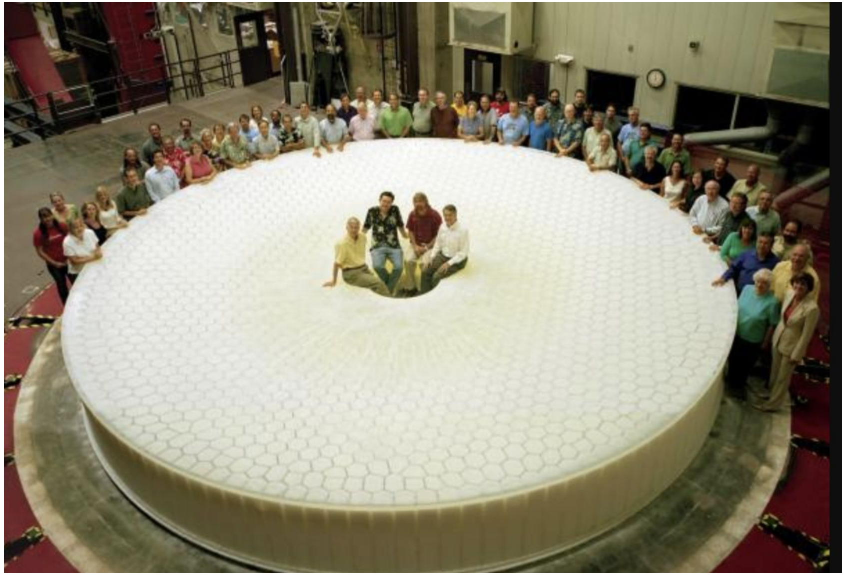


Big Glass + Big Silicon + Big Data



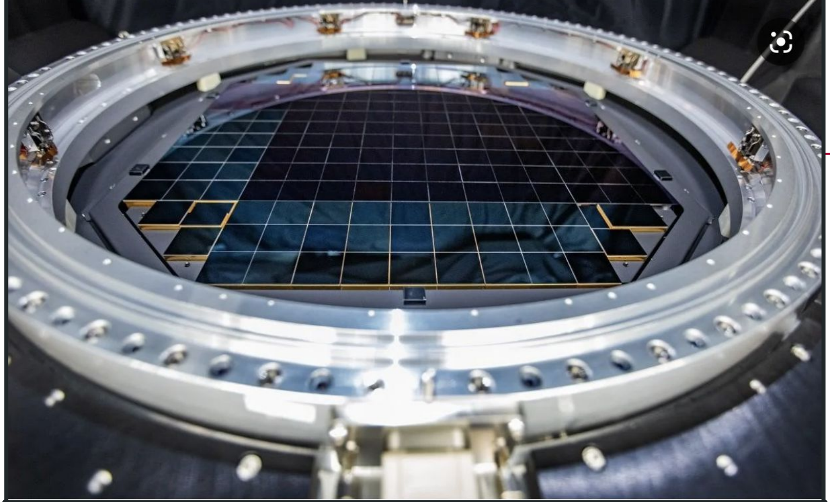
Big Glass

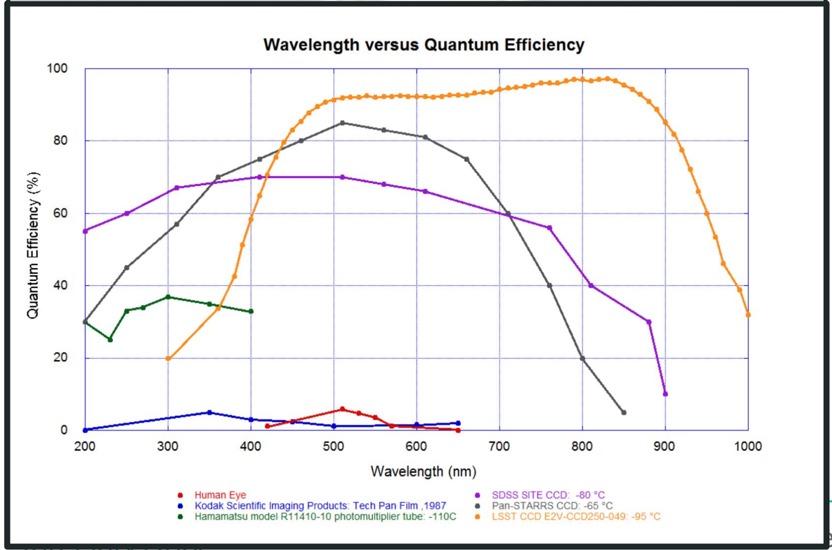
f/1.2 beam feeds 3.5 deg FOV
Active control of mirror figure



Big Silicon

LSST DESC Dark Energy Science Collaboration





3.5 Gigapixel camera

10 micron pixels
100 microns thick
enhanced NIR sensitivity

2 second readout

Noise limited by sky background

6 optical passbands

Big Data

Immediate transfer of images to US, 20 TB/night

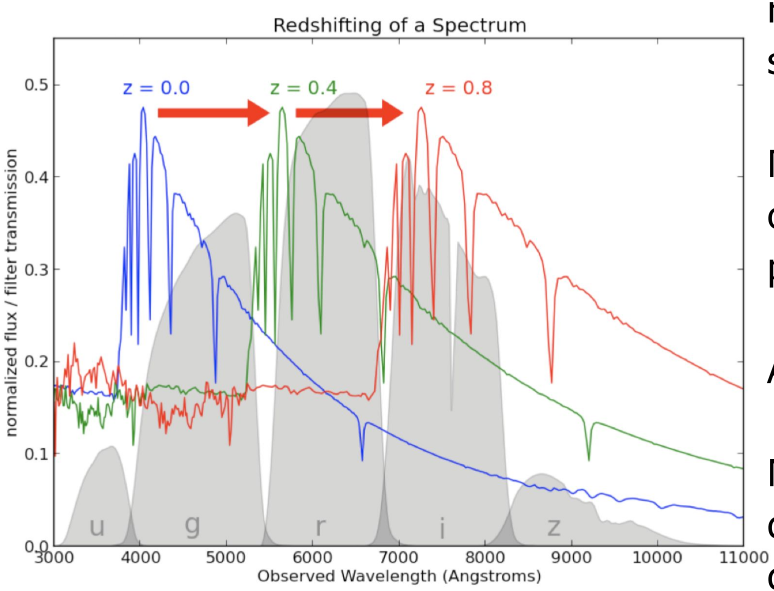
Generation & dissemination of alerts within 60 sec

User access includes education and public outreach aspects

All Rubin software in public domain, open-source

Data processing at the Rubin Data Facilities in the US (SLAC), France (CC-IN2P3) and UK (IRIS)

Six Optical Passbands provide 3-d mapping



http://www.astroml.org/sklearn_tutorial/regression.html

Broadband fluxes (aka colors) provide ‘photometric redshifts’. Snowmass 2021 report stresses importance of spectroscopic training sets.

Not as precise as spectroscopic redshifts, but many more objects measured; roughly 10^5 useful galaxies measured per Rubin FOV.

Allows for 3-d gravitational lensing tomography.

Multiple bands also essential for precise distance determination of type Ia supernovae and for galaxy cluster detection.

Additional (and narrower) filters increase redshift precision.

LSST is an incisive probe of Fundamental Physics

- The most robust evidence for physics beyond the standard model comes from astrophysical observations
  - Non-baryonic Dark Matter
  - Dark Energy, in particular equation of state parameter w(z)
  - Inflation

- Observations (as opposed to experiments) are particularly prone to systematic uncertainties. We need multiple, independent, probes of this new physics: Rubin's Legacy Survey of Space and Time (LSST) will deliver this.

- Rubin will make essential contributions to our understanding of Dark Matter and Dark Energy. It was *designed* to do so.

- Joint analyses with other data sets is stronger than any of them alone

Testing the “Standard Model”, ΛCDM

- Tests of the isotropy of cosmic expansion and its acceleration
- Modified gravity constraints on length scales from Milky Way to cosmological
- Dark matter constraints from refined lensing measurements of halos of both galaxies and clusters
- Improved neutrino mass constraints
- Census of satellite galaxies in the local group, which is a current tension in CDM
- Refined distance indicators and maps of large scale structure
- Identification and characterization of sources of gravitational waves, allowing secure determination of their redshifts and use as a new cosmological probe
- Assessing the emerging tensions in H_o and S_8 from near-field and far-field cosmology measurements.
- **Discoveries and evolution of this science will guide evolution of Rubin system**

The Rubin Observatory and the LSST Dark Energy Science Collaboration (DESC)

Observatory

Construction of System
Carry out the LSST survey, deliver high-quality processed images, catalogs to the science community

DESC

Carry out high-precision and high-accuracy cosmological analysis of LSST data, with simulation, re-processing, and analysis pipelines

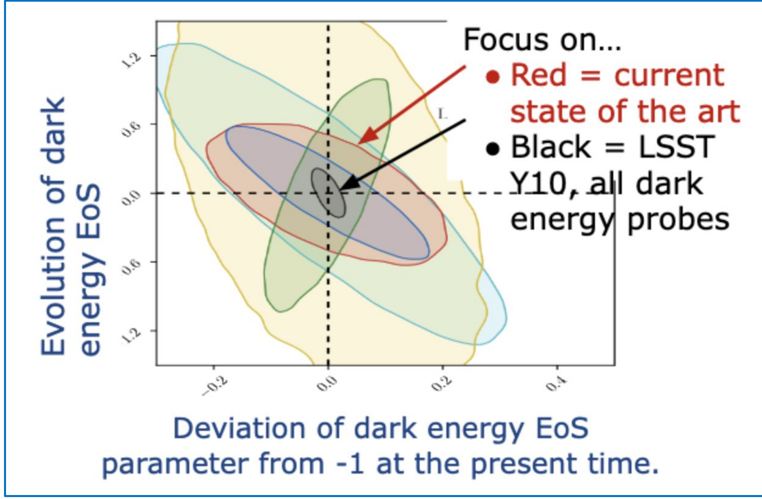
Highlights of important Rubin-DESC connections

- Observing strategy: DESC white papers led to shift in survey footprint
- LSST DESC simulated data underpin the Rubin Data Preview 0
- More than 100 DESC scientists are involved in commissioning, providing input on calibration, measurement algorithms, V&V, …

Dark Energy Science Collaboration

- Scientific aim: explore the physics of the Dark Universe
  - Dark Energy, Dark Matter, inflation
  - Multiple complementary probes from Rubin alone
- Large international collaboration with more than 1,000 members
  - 50% US based, 50% international
  - France (IN2P3) and UK (STFC) are strong partners
  - Over half are early career researchers
  - Strong DEIB component
- DESC Science Requirements Document defines success as *%-level precision in DE parameters*

DESC Operations supports the development of mission-critical software



R. Mandelbaum, T. Eifler, R. Hlozek, T. Collett, E. Gawiser, D. Scolnic et al., arXiv:1809.01669

Forecast 68% confidence level constraints on (w_0,w_a) for individual probes and for their combination.

DESC Collaboration Meeting, August 2022

Hybrid Collaboration Meeting in Chicago, more than 300 participants

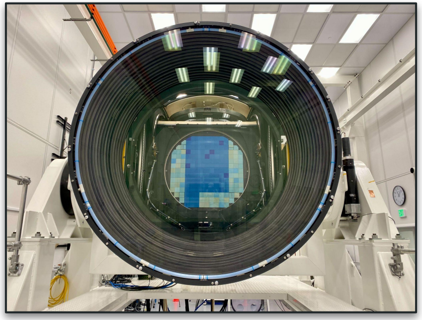
DESC Primary Science Goals

LSST DESC is planning to carry out full cosmology analyses (dark energy, dark matter, neutrinos, inflation, …)

- Goal #1: Cosmological constraints from Rubin-only data from shear and clustering (3x2pt), clusters of galaxies and supernovae
- Goal #2: Consistency checks between different Rubin DESC probes
- Goal #3: Cosmological constraints and tensions from Rubin + External Data Sets
- Goal #4: Be prepared for serendipity
- Goal #5: Assess possibly needed changes in observing strategy, processing for upcoming data releases in the earlier years

Commissioning is joint DESC + project effort

- System integration is well under way
- Commissioning includes strong DESC and international in-kind contributions
- System “First Light” Summer 2024
- Legacy Survey of Space and Time (LSST) projected to begin ~end of calendar 2024
- See ls.st/dates for live schedule



Augmented/complementary data: leverage

The ten-year LSST survey is designed to address primary science goals. High leverage gained from adding:

- Host galaxy redshifts for LSST supernovae; to reap full benefits we need both SN distances & redshifts
- Infrared SN data points to constrain host galaxy and Milky Way extinction due to ‘dust’ attenuation
- Identification and light curves for gravitational wave optical counterparts
  - Spectroscopy and/or photometric redshifts breaks degeneracy between redshifts and chirp mass
- Re-reduction of the archived data using better tools, algorithms, and fusion with other data sets (CMB-S4…)
- Enhanced spectroscopic training sets for photometric redshift determination.
- References:

  Astro2020 Decadal Survey White Papers, examples & links provided in backup slide.

  “Rubin Observatory after LSST” Snowmass 2021 White Paper

Discoveries drive progress, agility paramount

- We should be prepared for one or more of the following:

  Indications of Dark Energy inconsistent with cosmological constant (w=-1, w'=0)
  Anisotropy of Dark Energy properties
  Inconsistencies in cosmological parameter constraints- H_o and/or S_8 tensions increase
  Evidence for new physics arising from stellar astrophysics anomalies
  …..?

- Evolution of Rubin system, in response to science demands, could include one or more of the following:

  1. Observations in additional passbands (emission line galaxies & better photo-z's for structure mapping)
  2. New instrument(s) to take advantage of high AΩ optics . Fiber-fed spectrograph w re-use of camera?
  3. Complementary observing strategies (e.g. femto-lensing search for PBHs?)
  4. Entirely different science mission (asteroids?, satellite traffic management?)

References: Proceedings from next-phase workshop at ANL,
Snowmass white paper on "Rubin Observatory After LSST."

Preparing for Rubin’s Next Generation Surveys

- LSST will run for 10 years, 2025-2034 inclusive, with annual data releases and one post-survey data release.
- What Rubin does after the LSST depends on what we find, and how the science context evolves.
    - NOIRLab and SLAC will facilitate a series of community workshops to drive and digest the needed investigations of possible new technical capabilities
    - Efforts need to begin soon. Significant technical efforts will take of order 10 yr to make ready for deployment on the timescale of 2036
    - See Snowmass white paper on "Rubin Observatory After LSST.", Snowmass white paper on "Rubin Observatory After LSST."

Needs for the coming decade…

- Specific goals for the 2024-2034 timeframe include:
  - Finalize construction and commissioning, transition into operations
  - Successful system operations, data analysis, and dissemination
  - Enable science across a range of topics, however DESC focus is fundamental physics
  - Look ahead and plan for evolution and extensions.

- This effort receives critical science, operations, and computing support from DOE HEP, the NSF, and international partners.

- Stable support is crucial to ensure the vitality of our research program and to deepen our understanding of the physics of the dark Universe. Our success will depend on the continuation of this support for both labs and universities.

The LSST data will enable multiple probes of the dark sector, and the Rubin system is a foundational platform for further investigations

Back-up slides

Why focus on precision and systematic uncertainties?

Dark Energy discovery data 1998	~20 distant SNe	10% precision
ESSENCE and CFHTLS surveys, 2008	200 SNe	3% precision
DES, 2020	2000 SNe	1% precision
Rubin	>20,000 SNe	< 1% precision

Links to Astro-2020 decadal survey white papers

Joint Gravitational Wave and Electromagnetic Astronomy with LIGO and LSST in the 2020's
Gravitational probes of ultra-light axions
Partnering space and ground observatories - Synergies in cosmology from LSST and WFIRST
The Most Powerful Lenses in the Universe: Quasar Microlensing as a Probe of the Lensing Galaxy
Single-object Imaging and Spectroscopy to Enhance Dark Energy Science from LSST
Wide-field Multi-object Spectroscopy to Enhance Dark Energy Science from LSST
Deep Multi-object Spectroscopy to Enhance Dark Energy Science from LSST
LSST Narrowband Filters
Dark Matter Science in the Era of LSST
Testing Gravity Using Type Ia Supernovae Discovered by Next-Generation Wide-Field Imaging Surveys