Rubin-UVEX Synergies

Will Clarkson (University of Michigan-Dearborn)
Rubin Science Collaborations Coordinator

Weds March 15, 2023

The First UVEX Community Workshop
13-15 March 2023
Caltech

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

The Rubin Ecosystem

- The **Rubin Project**: is building and will operate the observatory and associated systems that will conduct the **L**egacy **S**urvey of **S**pace & **T**ime (LSST)

- The **LSST Corporation** (LSSTC) is a coalition of 33 member institutions that are invested in LSST and its scientific community

- The **Rubin Science Collaborations** are 8 independent communities that work on LSST science, and which advise the Rubin Project.

The Rubin Science Collaborations

Solar System Science Collaboration (Meg Schwamb, Colin Orion Chandler)

Dark Energy Science Collaboration (Katrin Heitmann, Renee Hlozek)

Informatics & Statistics Science Collaboration (Tom Loredo, Francois Lanusse)

Transients & Variable Stars (Igor Andreoni, Sara Bonito)

Galaxies Science Collaboration (Sugata Kaviraj, Simona Mei)

Stars, Milky Way & Local Volume (Peregrine McGehee, Will Clarkson)

Strong Lensing Science Collaboration (Timo Anguita, Graham Smith)

Active Galactic Nuclei (Niel Brandt, Gordon Richards)

SC Coordinator: Will Clarkson (wiclarks@umich.edu)

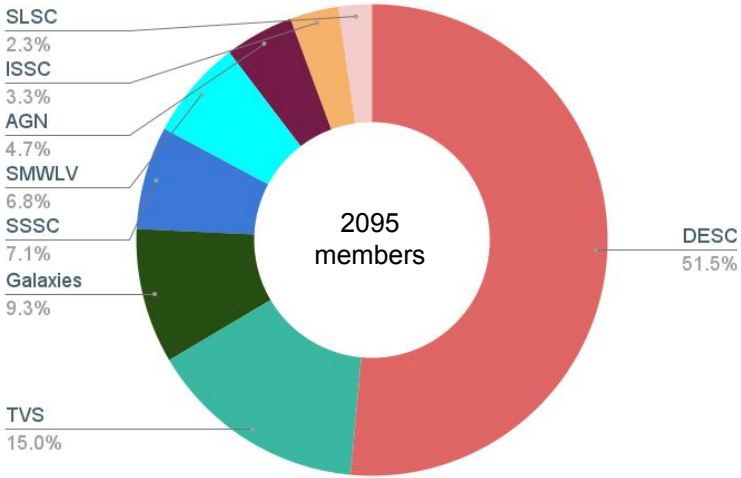
Find out how to join at *https://www.lsstcorporation.org/science-collaborations*

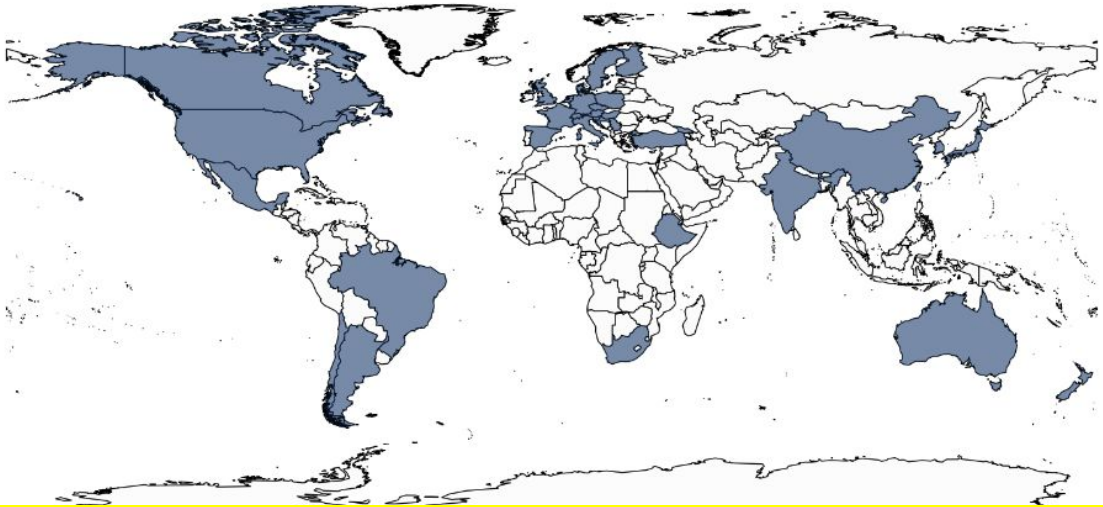
The Rubin Science Collaborations

SCs Federation Charter

8 Science Collaborations as autonomous, self-managed teams

>2000 people, 2500 affiliations, 6 continents, 33 countries





SC Coordinator: Will Clarkson (wiclarks@umich.edu)

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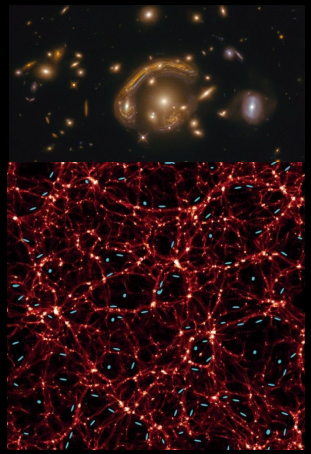
Rubin science pillars

Slide credit: Melissa Graham

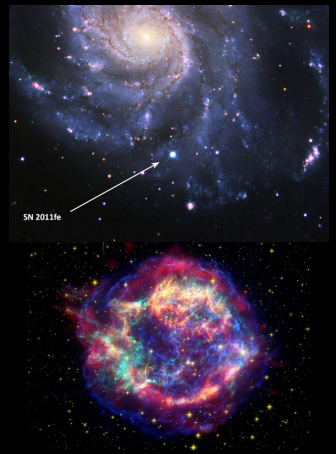
Cosmology

Understand dark energy and dark matter, and the origin and fate of the universe, by studying gravitational lensing and large-scale structures across cosmic time.



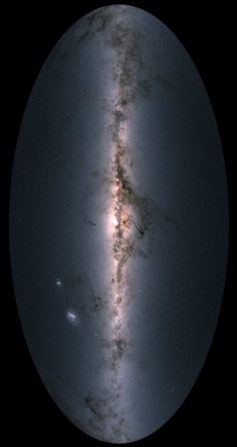
Transient Phenomena

Understand evolutionary processes by studying how stars and compact objects (e.g., black holes) change brightness, interact, merge, and explode.



The Milky Way

Understand the structure and evolution of our Galaxy's bulge, disk, and halo – and its satellites and tidal streams – by mapping the stars of the Milky Way.

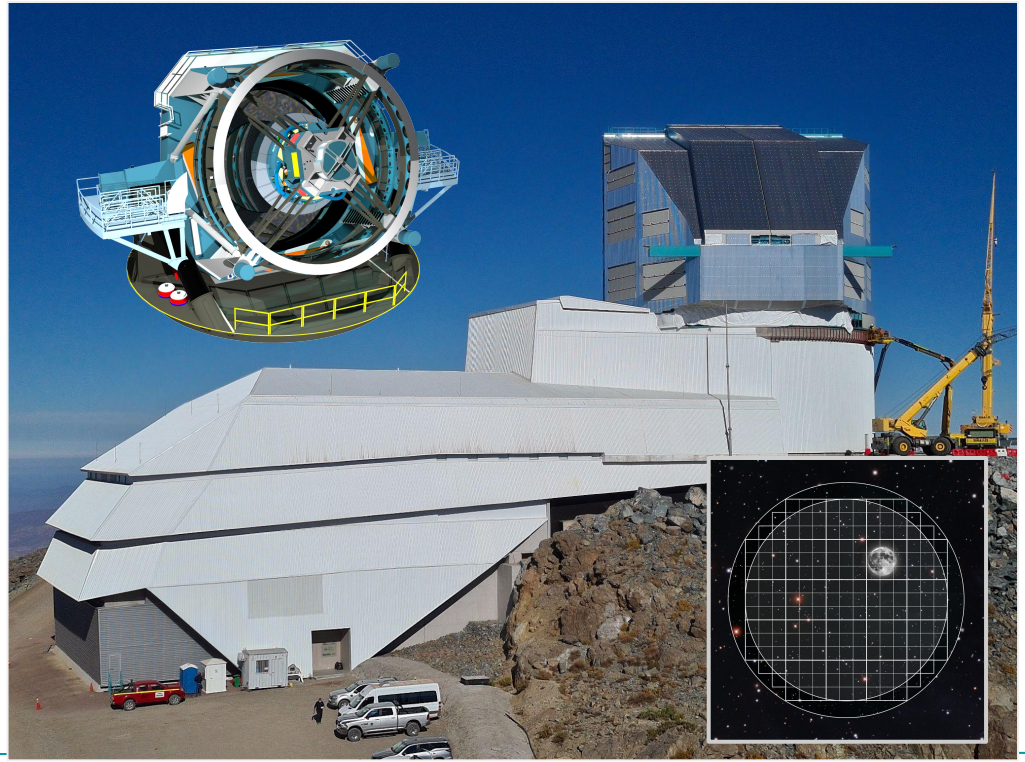


The Solar System

Understand the formation and evolution of our Solar System, and the risk of potentially hazardous asteroids, by making a full inventory of objects down to ~100 m scales.

The Vera C. Rubin Observatory

Slide credit: Melissa Graham



The Vera C. Rubin Observatory is located on Cerro Pachón in Chile. The Simonyi Survey Telescope's primary mirror has an 6.7 meter *effective* diameter and its camera an 9.6 deg^2 field-of-view and six optical-NIR filters: *ugrizy*.

Once construction and commissioning are complete, Rubin Observatory will execute the 10-year Legacy Survey of Space and Time (LSST):

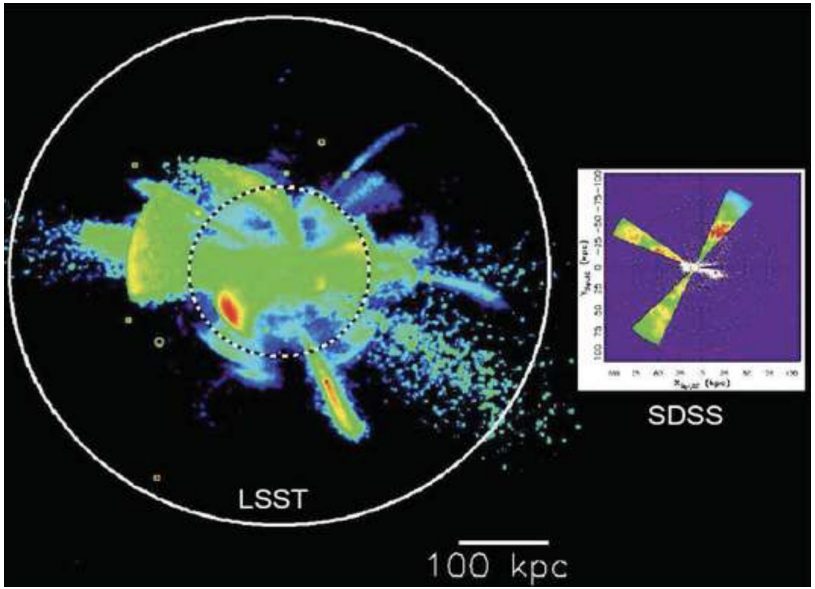
- single-image depths (point source; AB)
  - *ugrizy* = 23.9, 25.0, 24.7, 24.0, 23.3, 22.1 mag
- 10-year LSST depths (point source; AB)
  - *ugrizy* = 26.1, 27.4, 27.5, 26.8, 26.1, 24.9 mag

See Ivezić et al. (2019) for details about the design and the science goals. Also: https://www.lsst.org/scientists/keynumbers

The Legacy Survey of Space & Time (LSST)

Large, complex datasets:

- 20TB (~1 SDSS) per night for 10y
  - Catalog ~ 15 PB, total holdings ~300 PB
- ~17 billion stars, 20 billion galaxies, >800 visits each
  - e.g. ~300 million MS stars with photometric [Fe/H] out to ~100 kpc
- Orbits of ~6 million Solar System objects
- Variability measurements
  - ~10 million alerts ***per night*** within 60 seconds of shutter open
  - Sensitivity to variability on timescales ~30 minutes - 10 years



Main panel: simulation of star counts, color coded by density. Main-sequence [Fe/H] out to ~100 kpc (dashed circle); RR Lyrae out to ~300 kpc tidal radius (white circle). SDSS is at right, on the same spatial scale. From Ivezic et al. 2019.

Expected data products: **static sky (Stars & Galaxies)**

Source: Rubin Data Products, abridged (Graham et al.)

Images	> 80h	yearly
processed visit images (PVIs; calibrated)	x	x
deep CoAdds (stack of all LSST images; one per filter; calibrated)		x

Catalogs	<24 h	yearly
sources detected with SNR>5 in PVIs and CoAdds: the Source and Object tables		x
forced photometry in PVIs at the location of all Objects: the ForcedSource tables		x

Transients, Variables, Moving Objects

Source: Rubin Data Products, abridged (Graham et al.)

Images	> 80h	yearly
processed visit images (PVIs; “direct images”; calibrated)	x	x
difference images (template-subtracted; calibrated)	x	x
template images (transient-free annual stacks)		x

Catalogs	<24 h	yearly
sources detected with SNR>5 via difference image analysis (DIA), and associated forced photometry: the DIASource, DIAObject, and DIAForcedSource tables	x	x
DIASources linked as moving-objects in the solar system (SS) and their orbital parameters: the SSSource, SSObject, and MPCORB tables	x	x
sources detected with SNR>5 in PVIs, and associated forced photometry: the Source, Object, and ForcedSource tables		x

Static-Sky Objects (Stars and Galaxies)

Source: Rubin Data Products, abridged (Graham et al.)

Examples of additional specialized algorithms, data products, and analysis tools that will be left to the expertise of the science community include, but are not limited to:

- alternative deeply coadded images (e.g., intermediate timescales, multi-band, best-seeing)
- specialized deblending algorithms, or probabilistic catalogs (e.g., for crowded fields)
- stellar types or physical parameters (e.g., metallicity)
- Milky Way component associations (e.g., disk/bulge/halo stars)
- specialized low-surface brightness measurements
- galaxy PZ or physical parameters (e.g., star formation rates) beyond those from the adopted, community-vetted, general-use PZ algorithm
- galaxy shear estimates beyond those provided by the adopted shear algorithm
- other galaxy characterizations (e.g., AGN, group or cluster membership, morphology)
- cyberinfrastructure to support large-scale compute-intensive processing (e.g., wide-area joint pixel analyses with non-LSST data sets)

Transients, Variables, and Moving Objects

Source: Rubin Data Products, abridged (Graham et al.)

Examples of additional specialized algorithms, data products, and analysis tools that will be left to the expertise of the science community include, but are not limited to:

- photometric and spectroscopic follow-up observations
- object classifications (e.g., light-curve types, astronomical categorization)
- cyberinfrastructure for the large-scale acquisition, processing, and analysis of follow-up
- cross-matching to non-LSST catalogs
- host-galaxy confirmation (e.g., distinguishing faint or blended hosts)
- orbital and/or time-variability parameters beyond what is in the LSST tables
- light-curve parameters (e.g., rise/fall times, peak brightness, asteroid rotation rates)
- shifted-and-stacked images (e.g., to detect faint moving objects)
- multi-night stacks and/or difference-images (e.g., to detect fainter transients)
- physical parameters (e.g., redshift, distance, host extinction, composition, intrinsic magnitude)
- event occurrence rates (e.g., volumetric rates)

Project timescales

For monthly updates: https://www.lsst.org/about/project-status

Some schedule milestones (current expectations, not including 6 week schedule contingency):

System first light: **2024 August**
System validation surveys complete: **2024 December**
Main survey start: **2024 December - 2025 March**
(UVEX' science operations would likely start during LSST Year 4)
Main survey end: **10 years after survey start (~2035 Jan)**

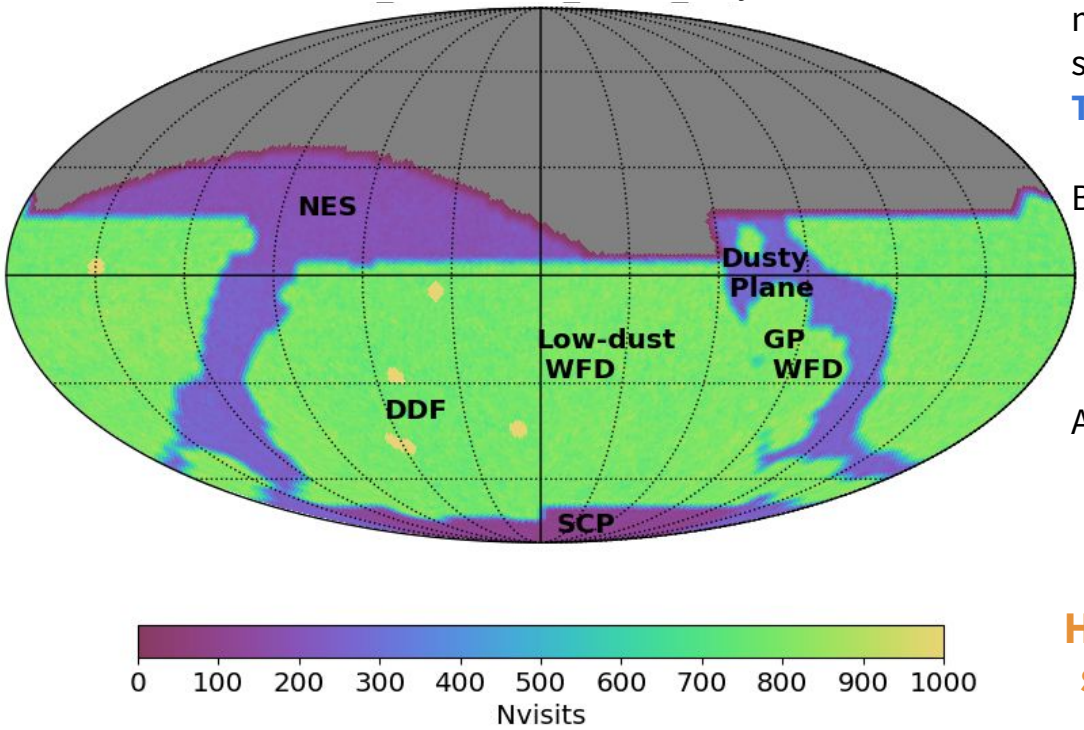
Data Preview 2 (commissioning w/ LSST Cam): **2025 May-Aug**
Data Release 1 (first 6 months survey): **2025 Nov- 2026 Aug**

Image credit: Jacqueline Ramseyer Orrell/SLAC National Accelerator Laboratory, 22 October 2022

LSST Survey Strategy

Slide credit: Melissa Graham

One of the most recent baseline survey simulations.



The **Baseline Survey Strategy** was designed to meet the basic requirements to achieve the core science goals of the **Legacy Survey of Space and Time** (LSST; requirements described in ls.st/srd).

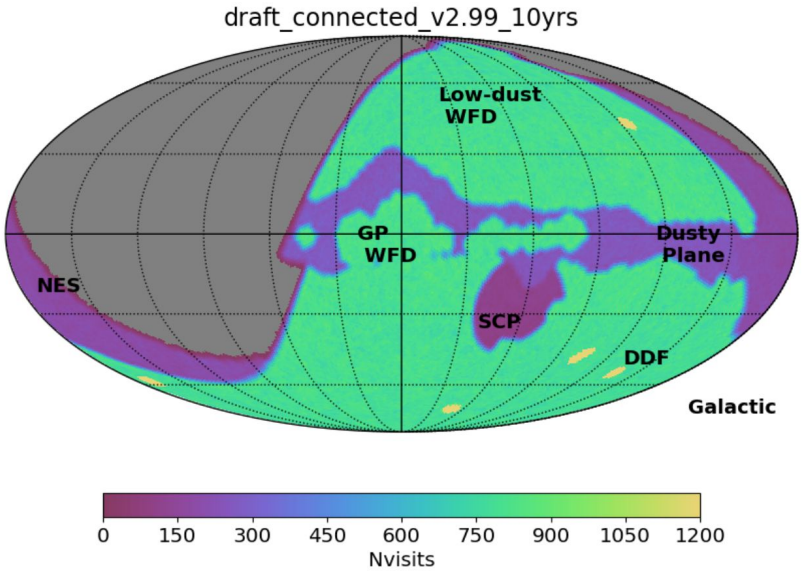
Baseline design elements for the WFD area:
- should cover at least 18000 deg^2
- average of 825 visits per field over 10 years
- same-night same-field re-visit "pairs"

Additional areas covered should include:
- at least 5 deep drilling fields
- the North Ecliptic Spur, the Galactic Plane, and the South Celestial Pole

How to optimize the LSST to maximize scientific return is an open question.

Survey Optimization Efforts

Slide credit: Melissa Graham



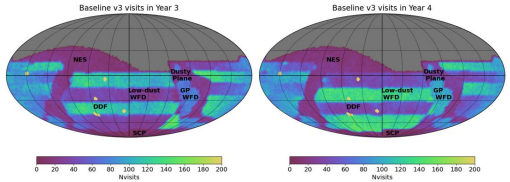
Survey Cadence Optimization Committee (SCOC)

Formed in 2020, and will stand throughout Rubin operations.

- takes community input on science impacts
- recommends cadence choices to Rubin Obs
- 10 members cover a variety of science areas

SCOC Recommendations, 2023 (ls.st/pstn-055)

- the “WFD” low-dust regions +Virgo cluster
- 2 visits/night with a ~33 min time gap (+ a third every ~7 nights)
- 5% of survey time spent on 5 deep drilling fields (all extragalactic)
- 3% of survey time spent on Target of Opportunity follow-up
- rolling cadence with a half-sky split (see below)



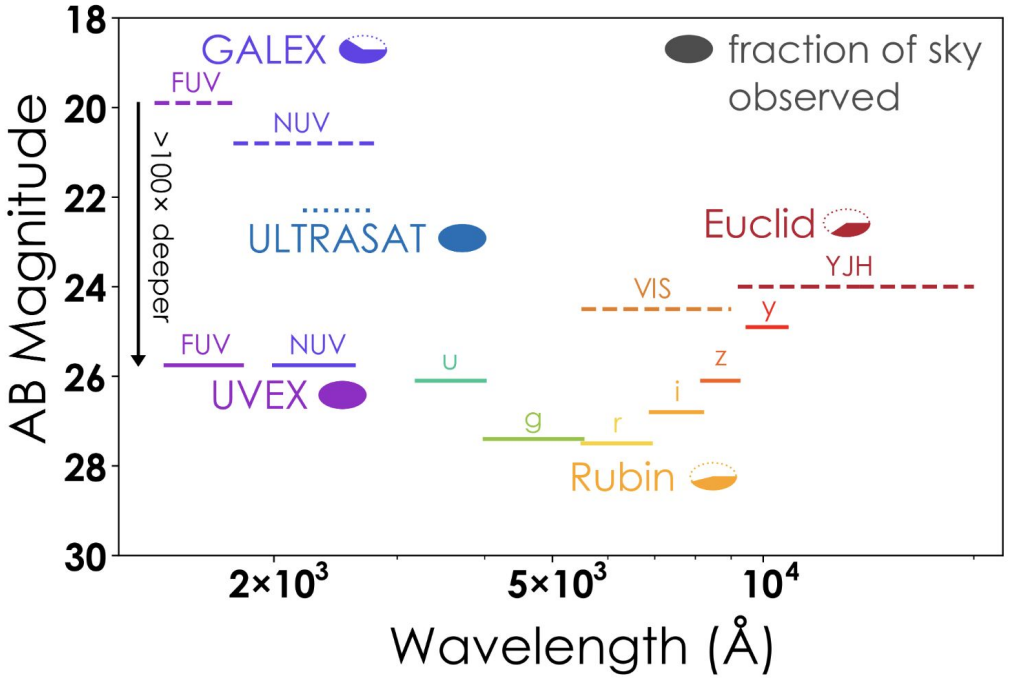
UVEX / Rubin synergies

Rubin: 3.5x3.5 deg {ugrizy}, ~0.7” FWHM, ~800 2x15s images over 10y

UVEX: 3.5x3.5 deg {FUV, NUV imaging + spectroscopy}, ~2” FWHM, at least 10 visits in 2 years, LSST years ~4-5

Complementary science goals:

- Low mass, low-metallicity galaxy frontier;
- New views on the dynamic Universe;
- Deep synoptic surveys including NUV and FUV



Kulkarni et al. 2023

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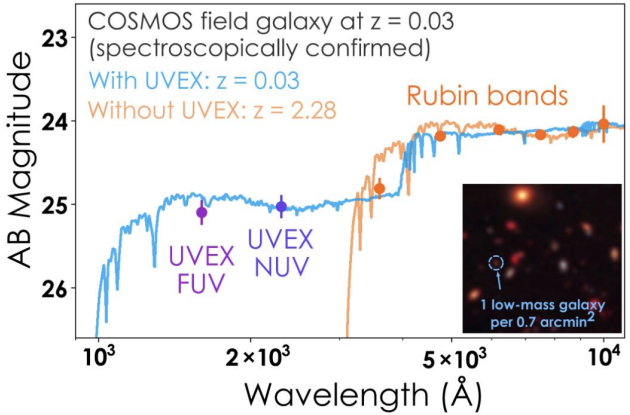
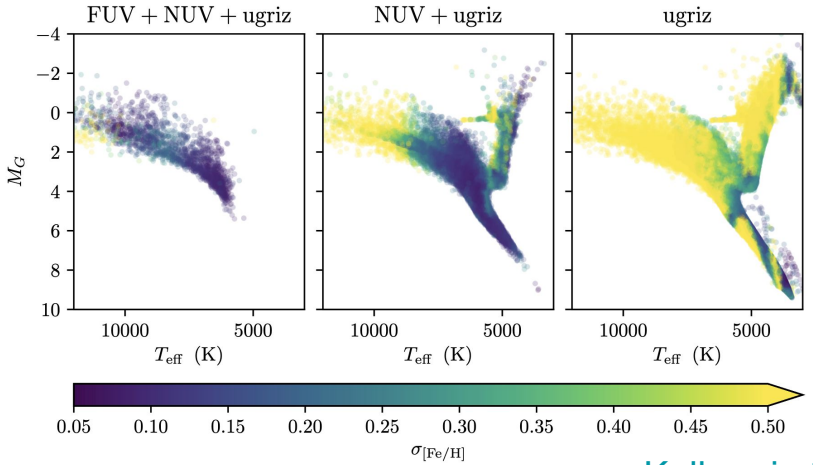
Very wide range of science synergies, e.g.

- Break the distance/spectral break degeneracy for galaxies;
- Better [Fe/H] for resolved stellar populations;
- Any UV-bright variability (e.g. XRB populations; CVs; TDEs; AGN; SNe, FBOTs; etc. etc.)
- ***And many more!!***





Kulkarni et al. 2023

What requirements will flow from Rubin/UVEX science?

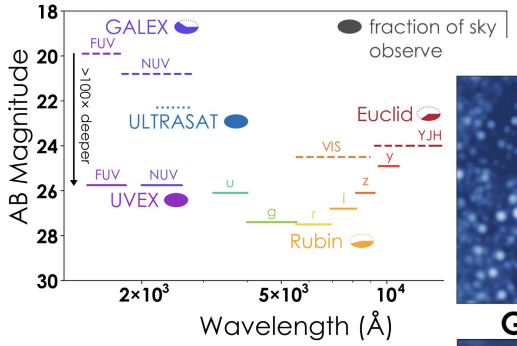
To actually realize UVEX+Rubin science, what capabilities are needed from either/both projects and the community?

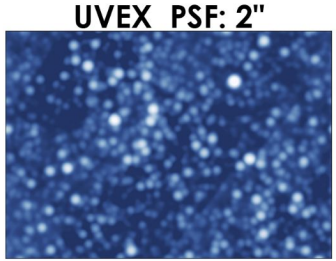
- E.g. UVEX spectra triggered by Rubin alerts? E.g. Rubin photo-z's to identify host galaxies of UVEX events?
- Cross-matching of independent point-source catalogs?
- Joint time series? Or combine indicators?

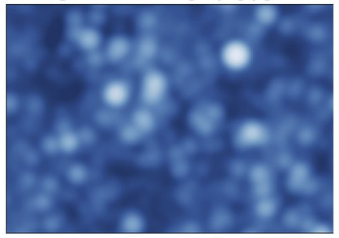
- Joint-processing at the pixel level? (point source? extended source?) Who would do this?

- Requirements on achieved u-band depth by year 3? Where?
- Coordinated observations?
- *"Simultaneous"* observations?
- What UVEX observing strategy maximizes joint science?
- UVEX observations after the initial 730-day science period?

- What data or data products should be shared? What data or data products *can* be shared?







Many of these will require Project leadership decisions (for both projects), supported by community engagement.

Kulkarni et al. 2023

Example: additional requirements on the Rubin observing strategy?

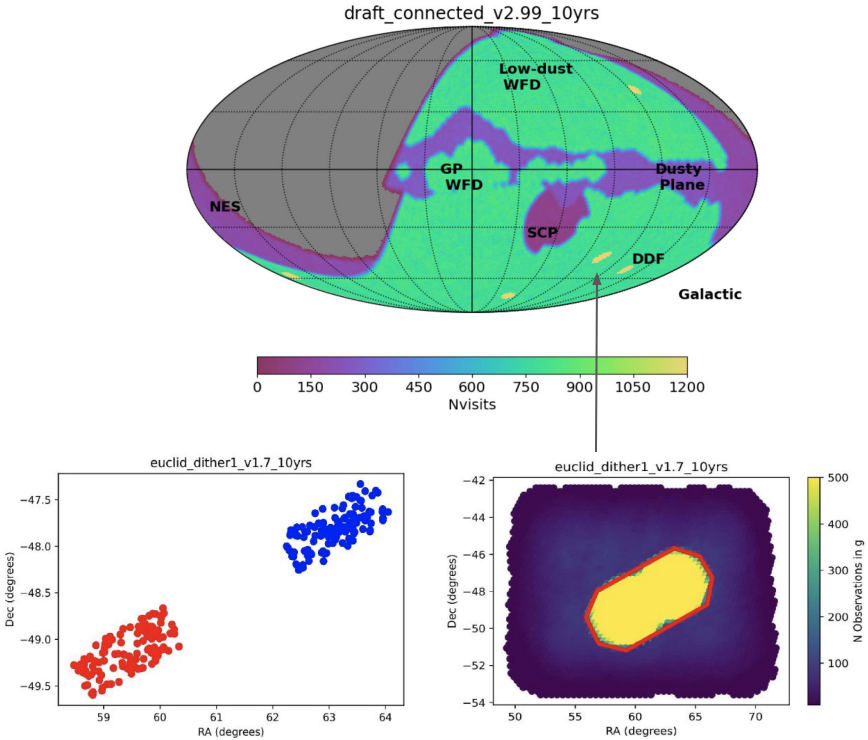
Phase II recommendation for the Rubin observing strategy is here: PSTN-055

- Large-scale changes are unlikely
- Still room for “optimization” (e.g. how a ToO program will work; e.g. filter balance in the Plane)

The observing strategy will be assessed ~annually, as real-world performance becomes better known.

There ***is*** precedent for influencing the survey strategy (for Rubin-Euclid; the addition of Euclid Deep-Field South)

- Euclid leadership approached the SCOC as an “interest group”
- For time-domain: recommend including the TVS (Transients & Variable Stars) Science Collaboration (chairs: Igor Andreoni & Sara Bonito)



PS-TN-055 (Bianco et al.)

Example: joint Data Products (Euclid/Rubin recommendations)

Just the cross-cutting DDP's recommended for Euclid/Rubin:

Recommended Rubin-Euclid Derived Data Products summary table [1/2]

Acronyms/Codes per column: 1) DDP code name; 2) Community served: B(oth), E(uclid), R(ubin); 3) Priority (P1 to P2) + Urgency (U1 to U3) + Timescale (Real Time, Yearly, Data Releases); 4) Production tier (T0 to T3)

Cross-Cutting (CC)

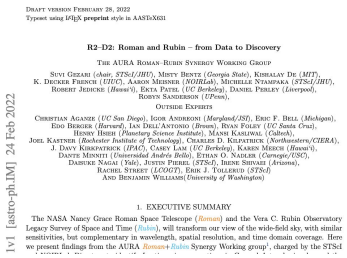
DDP-1-CC	B	P1+U1+YR	T1	Multi-band Rubin+Euclid photometry list-driven catalogs
DDP-2-CC	B	P1+U2+DR	T2	Multi-band Rubin+Euclid forced photometry catalog from joint-pixel processing
DDP-3-CC	B	P2+U2+DR	T3	Multi-band Rubin+Euclid deblended photometry catalog from joint-pixel processing
DDP-4-CC	B	P2+U2+DR	T3	Galaxy "pixel" photometric redshifts
DDP-5-CC	B	P1+U1+RT	T0	Image cutouts/stamps delivery service

Guy, L. et al. 2022: Euclid/Rubin

Engaging the science communities – e.g. Euclid/Rubin and Roman/Rubin

A few observations from the p.o.v. of the Science Collaborations:

- Community interest seems to have come first, noticed and encouraged by project leadership
- For both Euclid/Rubin and Roman/Rubin, the projects interacted at a project leadership level.
- Joint working groups formed to gather community input and translate into recommended products, with the ear of project leadership.
  - [Euclid, 2019-ongoing:] continuous engagement via Discourse-style platform
  - [Roman:] short 1-2 paragraph “science pitches” sought in several rounds
  - [Both:] Publications on timescale ~2-3 years, to synthesize community input and translate to project requirements
  - [Euclid:] 5 cross-cutting and 58 science-specific joint-data products specified



[Guy, L. et al. 2022: Euclid/Rubin]

[Gezari, S. et al. 2022: Rubin/Roman]

[Rubin Glossary & Acronyms]

Rubin has excellent community engagement:

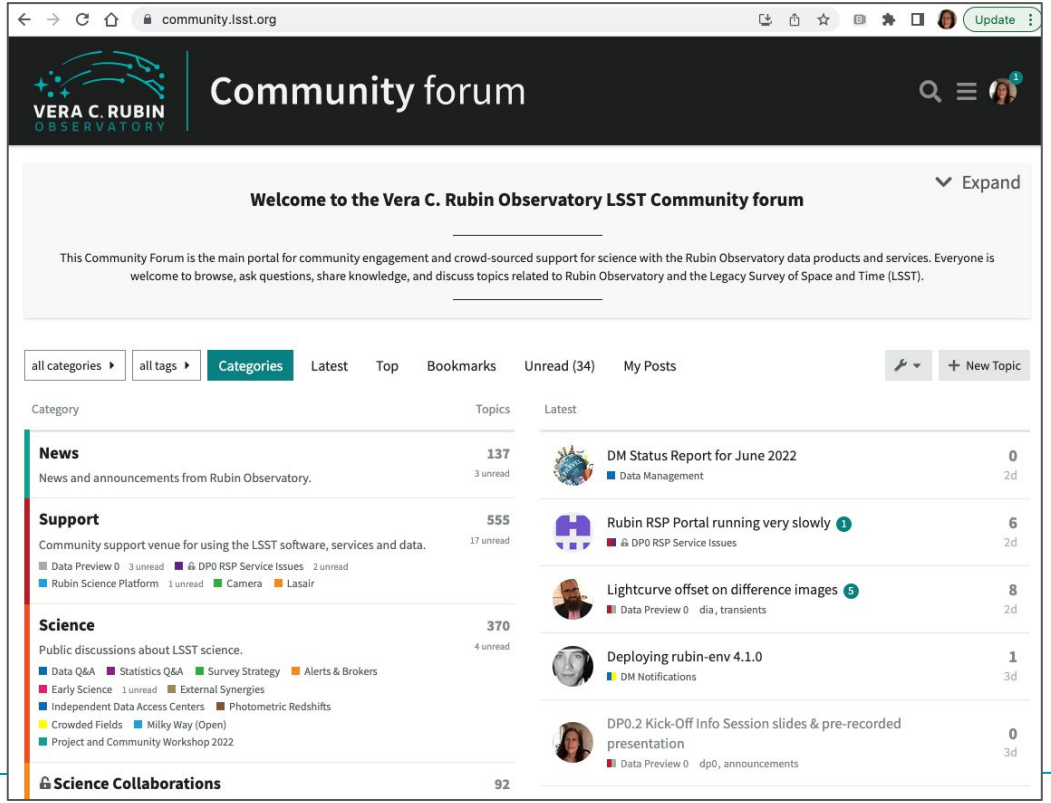
- Community Science Team (formerly Community Engagement Team)
  - Facilitate access to and analysis of LSST data (e.g. Data previews)
  - Coordinate expertise to resolve issues
  - Sustain a self-supporting community (e.g. Rubin Users' Committee)

- Science Collaborations
  - Developing Rubin LSST science, including products derived from the data
  - Performing precursor and post-survey-start investigations
  - Advising the project on scientific and technical issues (e.g. observing strategy)

- Community.lsst.org : Discourse-based platform for discussion of Rubin-related issues

Community.lsst.org

Slide credit: Melissa Graham



Rubin Community Forum

Most content is publicly viewable. Anyone may make an account to post new topics.

Three main use-cases:
1. Q&A with Rubin staff.
2. User discussions.
3. Information distribution.

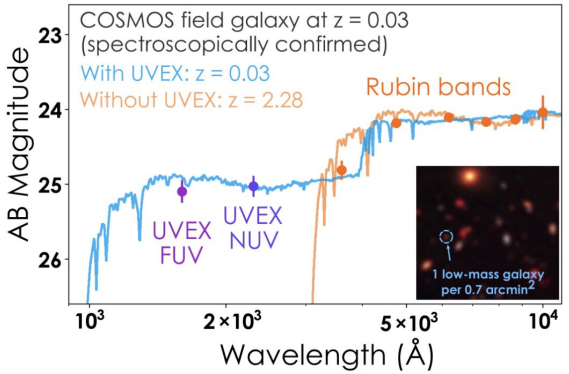
A browsable searchable archive and a dynamic interactive platform.

Functionality includes notifications, direct messaging, user groups, and moderation.

One possible way to start developing Rubin/UVEX synergies

Form a joint Rubin/UVEX community input team to make recommendations to Project(s) leadership and the scientific community

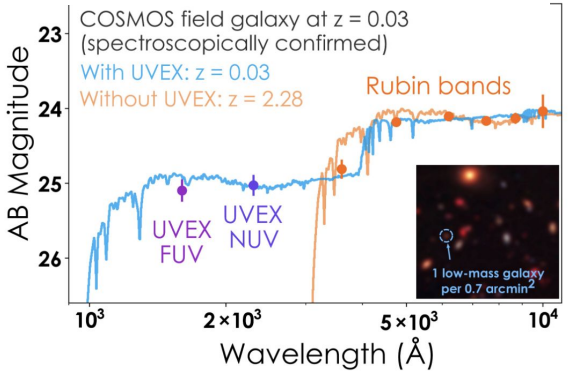
- Include Rubin SC members, UVEX science team members, Rubin Community Science Team members
  - Continuous engagement via Discourse-like platform);
  - Gather short science pitches;
  - Identify a product: recommended data products? Survey strategy inputs? Suggested timescale ~2 years (mid-2025) for science synergy requirements (on both data products and any observing strategy tweaks);
  - At least one online or in-person workshop to develop ideas



Guy, L. et al. 2022: Euclid/Rubin

Gezari, S. et al. 2022: Rubin/Roman

For more information:



- Rubin Key Numbers
- Project status (updated ~monthly)
- Science drivers, system characteristics: Ivezic et al. 2019
- Current LSST survey strategy recommendation (via SCOC)
  - The Deep Drilling fields
- Rubin Data Rights policy
- Data products that Rubin will and will not provide: Melissa Graham et al. 2022 (Zenodo).

- Community.lsst.org
- The Rubin Science Collaborations (coordinator: Will Clarkson: wiclarks@umich.edu)

- Examples of synergy development w/ upcoming space missions
  - Guy, L et al. 2022: Euclid/Rubin
  - Gezari, S. et al.: Roman/Rubin

Rubin-UVEX Synergies

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Caltech

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

SPARE SLIDES

VERA C. RUBIN OBSERVATORY

Rubin Glossary & Acronyms

Rubin Data Policy

Slide credit: Melissa Graham

Rubin Data Policy: ls.st/rdo-013
List of international data rights holders: lsst.org/scientists/international-drh-list

Data rights holders: scientists (and students) working (or enrolled) at US or **Chilean** institutes, and named members of the international in-kind contribution teams.

Proprietary: Annual data release data products, images and catalogs, and the prompt-processed images (for 2 years). Access to the Rubin Science Platform.

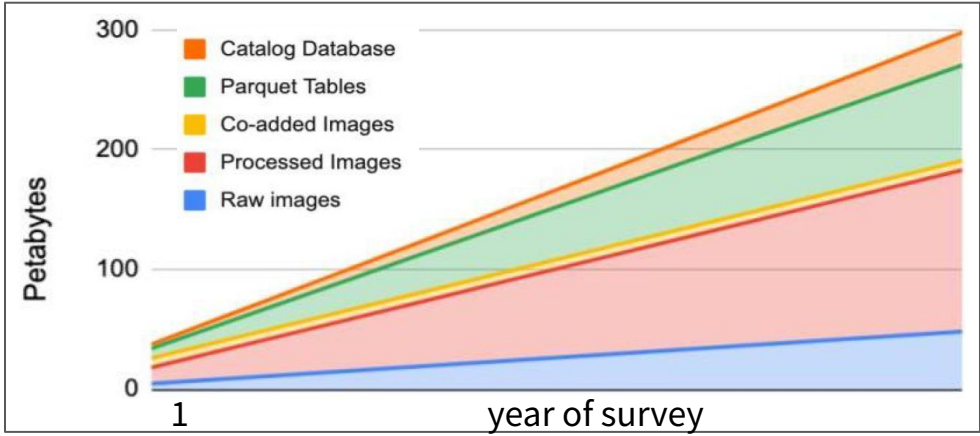
Public: alert packets and prompt catalogs, all other data after 2 years, and all documentation and support resources such as the Community Forum (Community.lsst.org).

The Legacy Survey of Space & Time (LSST)

Large, complex datasets:

- 20TB (~1 SDSS) per night for 10y
  - Catalog ~ 15 PB, total holdings ~300 PB
- ~17 billion stars, 20 billion galaxies, >800 visits each
  - e.g. ~300 million MS stars with photometric [Fe/H] out to ~100 kpc
- Orbits of ~6 million Solar System objects
- Variability measurements
  - ~10 million alerts ***per night*** within 60 seconds of shutter open
  - Sensitivity to variability on timescales ~30 minutes - 10 years

The Rubin Observatory's total data holdings will start at ~40 PB and grow to ~300 PB over the 10-year LSST.



O'Mullane et al. 2021 (RTN-003.lsst.io)

Rubin Science Platform (RSP)

Slide credit: Melissa Graham

It will not be possible to download the entire LSST data set, and scientists will need a venue for **“next-to-the-data analysis”**.

The **Rubin Science Platform (RSP)** is a set of integrated web-based applications and services running at the Rubin Observatory Data Access Centers (DACs).

Portal Aspect
exploratory analysis and visualization of the Rubin archive

Notebook Aspect
in-depth ‘next-to-data’ analysis and creation of added-value data products

API Aspect
remote access to the Rubin archive via industry-standard APIs

The RSP will include tools to query, visualize, subset, and analyze the full LSST data archives in a stable software environment located “next-to-the-data”, along with storage space, compute resources, and remote access options.