Rubin Observatory Legacy Survey of Space and Time

Synergies with SPHEREx

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Department of Physics and Astronomy, Biden School of Public Policy and Administration

Data Science Institute

Rubin Observatory LSST Science Collaborations Coordinator

Transient and Variable Stars Collaboration Co-Chair

What's in a name?

What's in a name?

Rubin
Observatory

For the first ten years of operation, Vera C. Rubin Observatory will perform the Rubin Observatory Legacy Survey of Space and Time, using the Rubin Observatory LSST Camera and the Simonyi Survey Telescope.

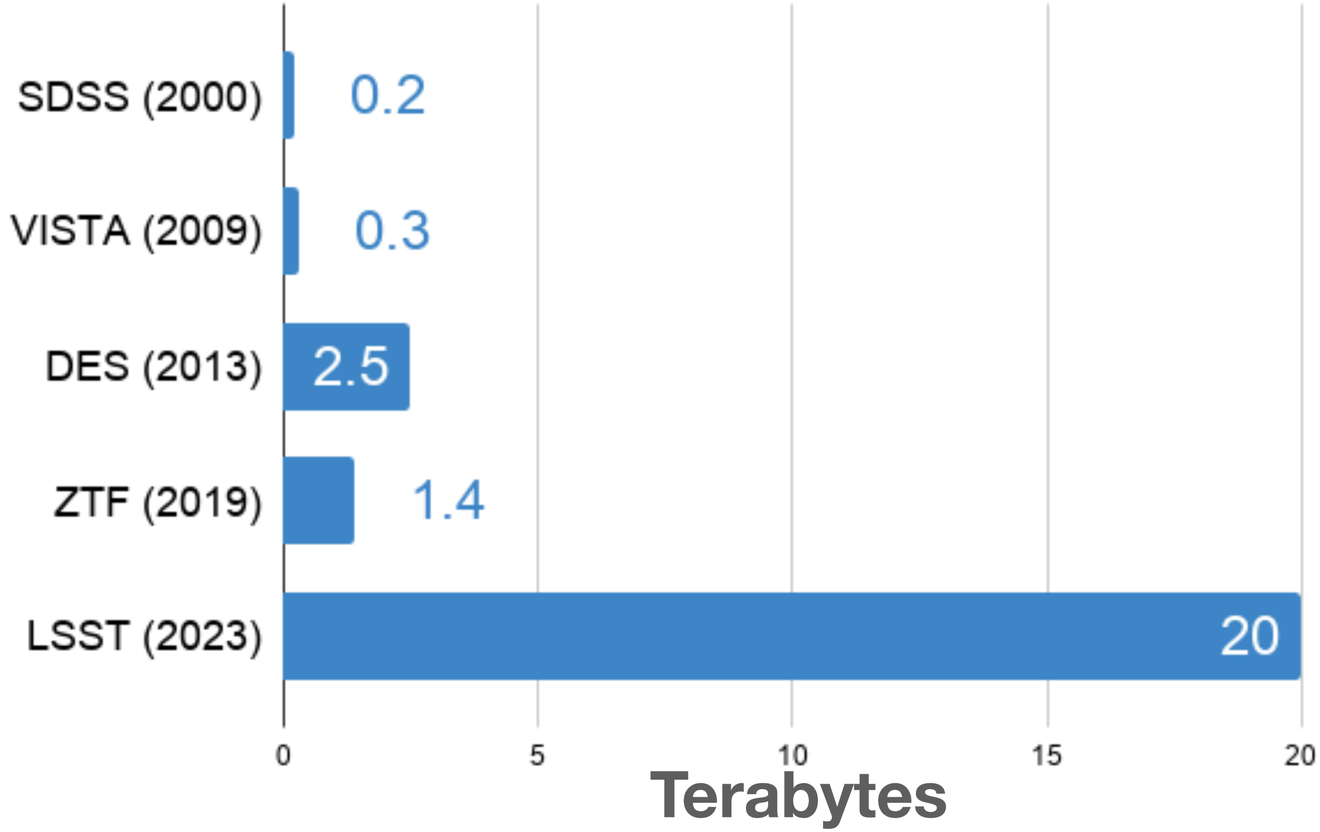
LSST
Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

How is LSST transformational?

1

x10 increase in data volume



Rubin Observatory

LSST Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

How is LSST transformational?

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Rubin Observatory

LSST Legacy Survey of Space and Time

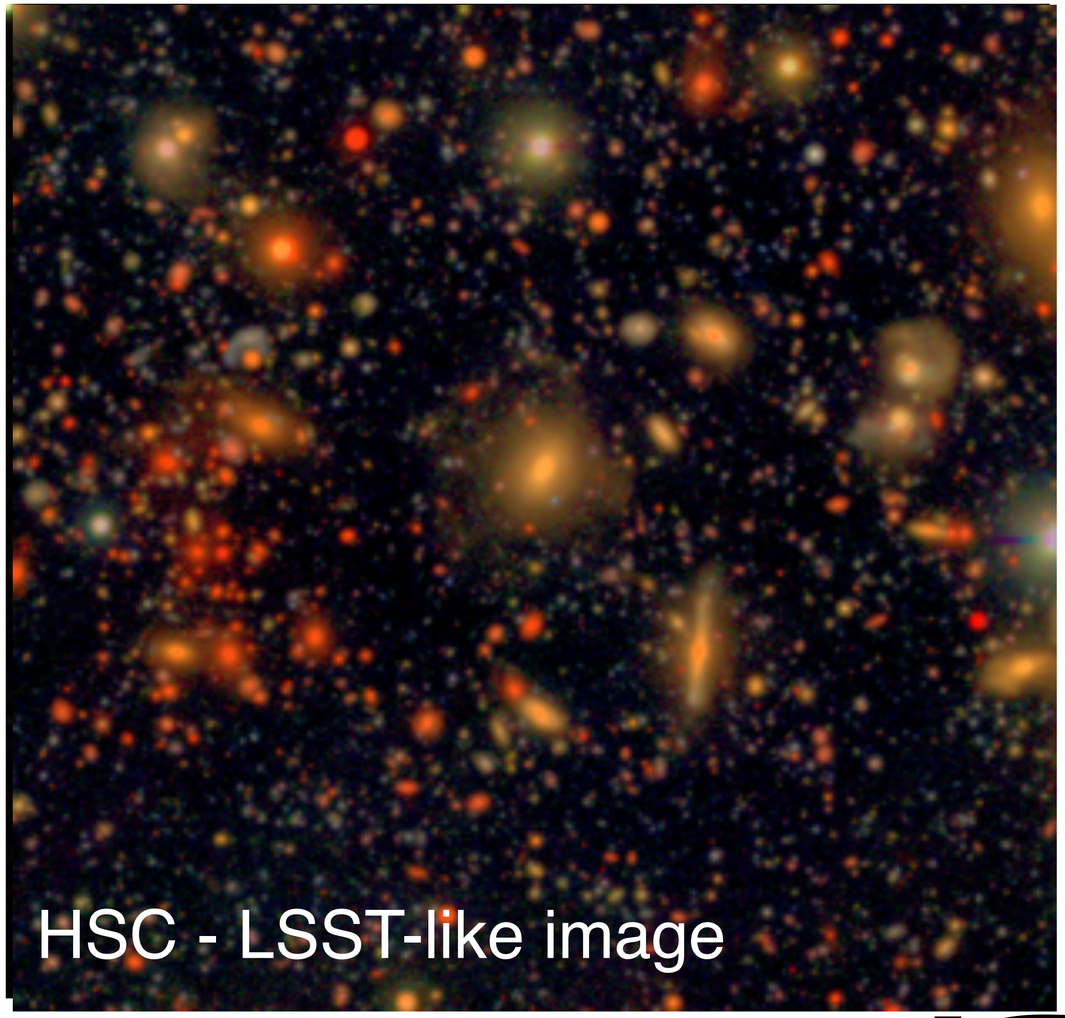
Rubin Legacy Survey of Space and Time

How is LSST transformational?

1

x10 increase in data volume

0.2”/pixel - site PSF easily ~0.5”



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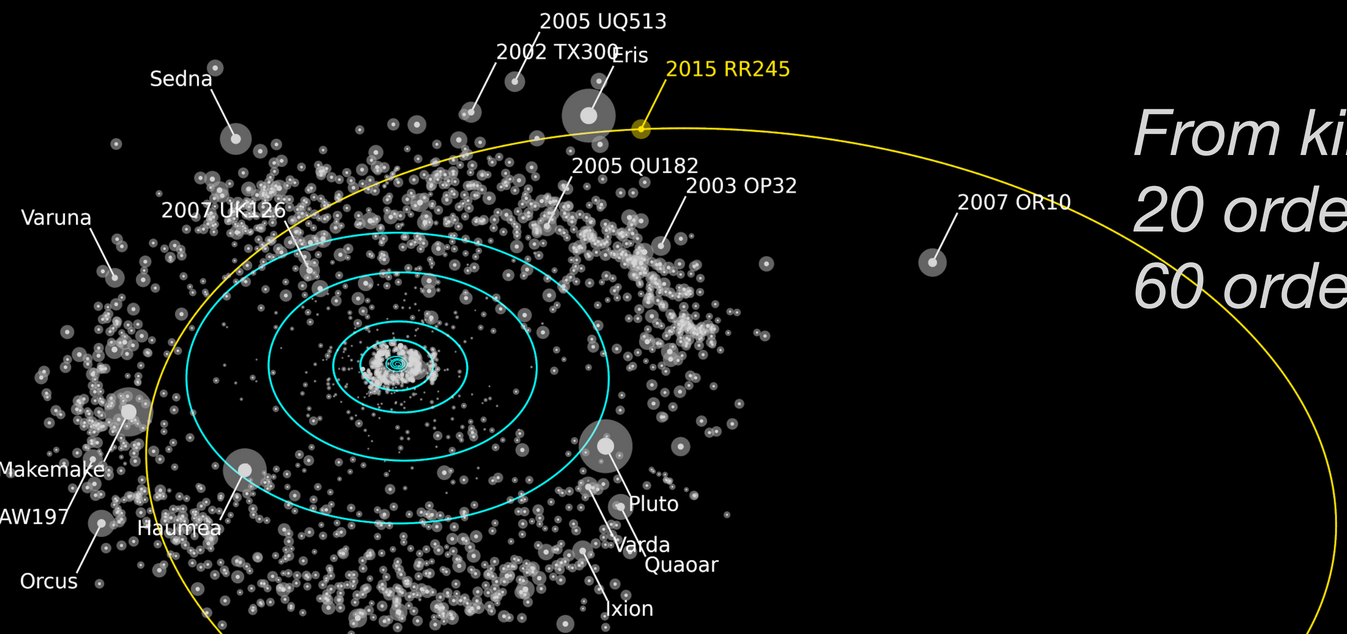
LSST Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

How is LSST transformational?

2

information data to be leveraged
for multiple science goals



From killer asteroids to the most distant Universe:
20 orders of magnitude in distance scales
60 orders of magnitude in energy scales!

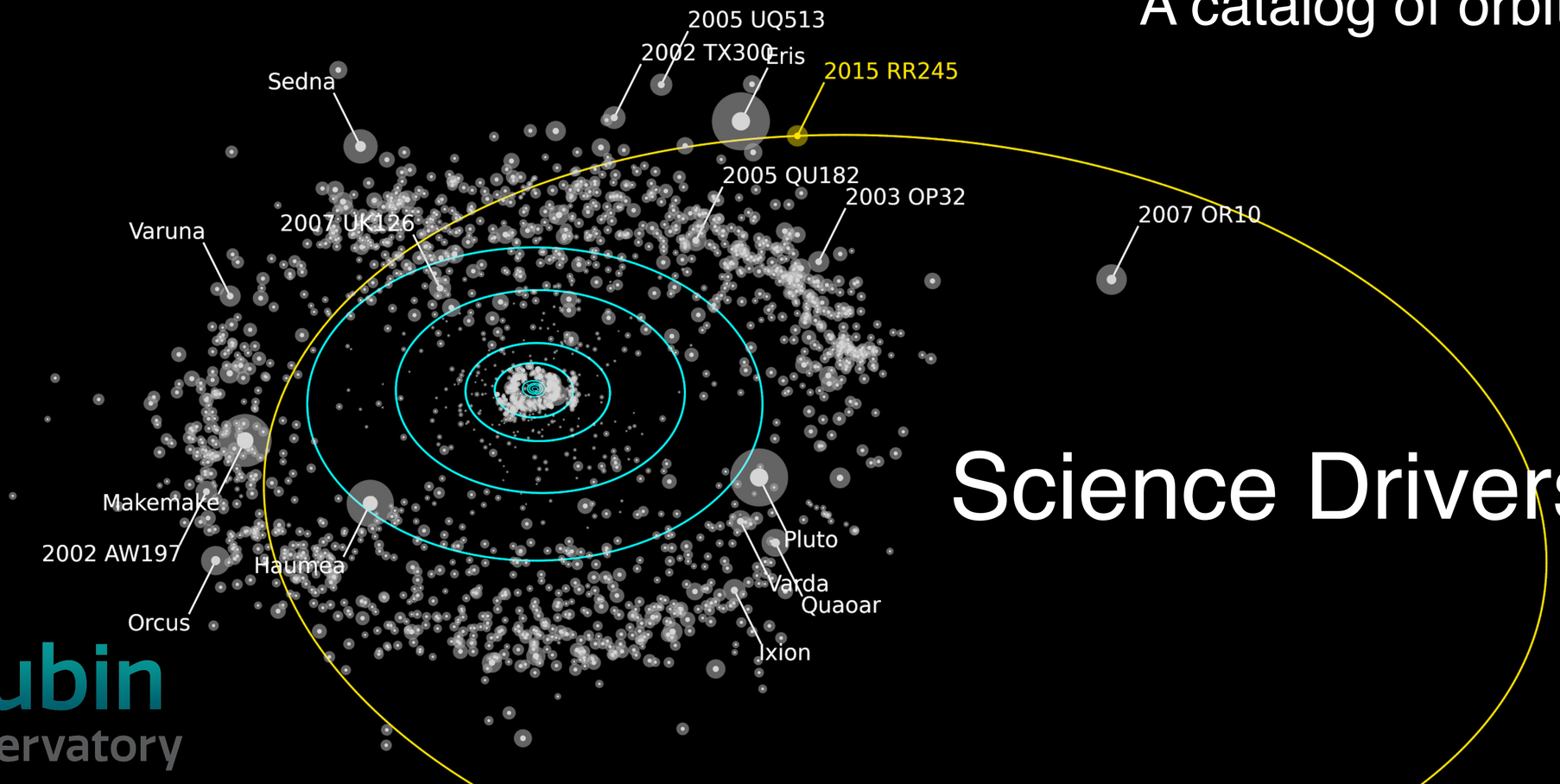
: TVS-SC CoChair - @fedhere

Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

***Providing an inventory* of the Solar System, including Near Earth Asteroids and Potential Hazardous Objects, Main Belt Asteroids, and Kuiper Belt Objects**

A catalog of orbits for 6 million bodies



Science Drivers

Rubin Observatory

here

LSST Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

***Mapping* the Milky Way and Local Volume via resolved stellar populations**

20B galaxies, 17B stars characterized in shape, color, and variability.

Science Drivers

Rubin Observatory

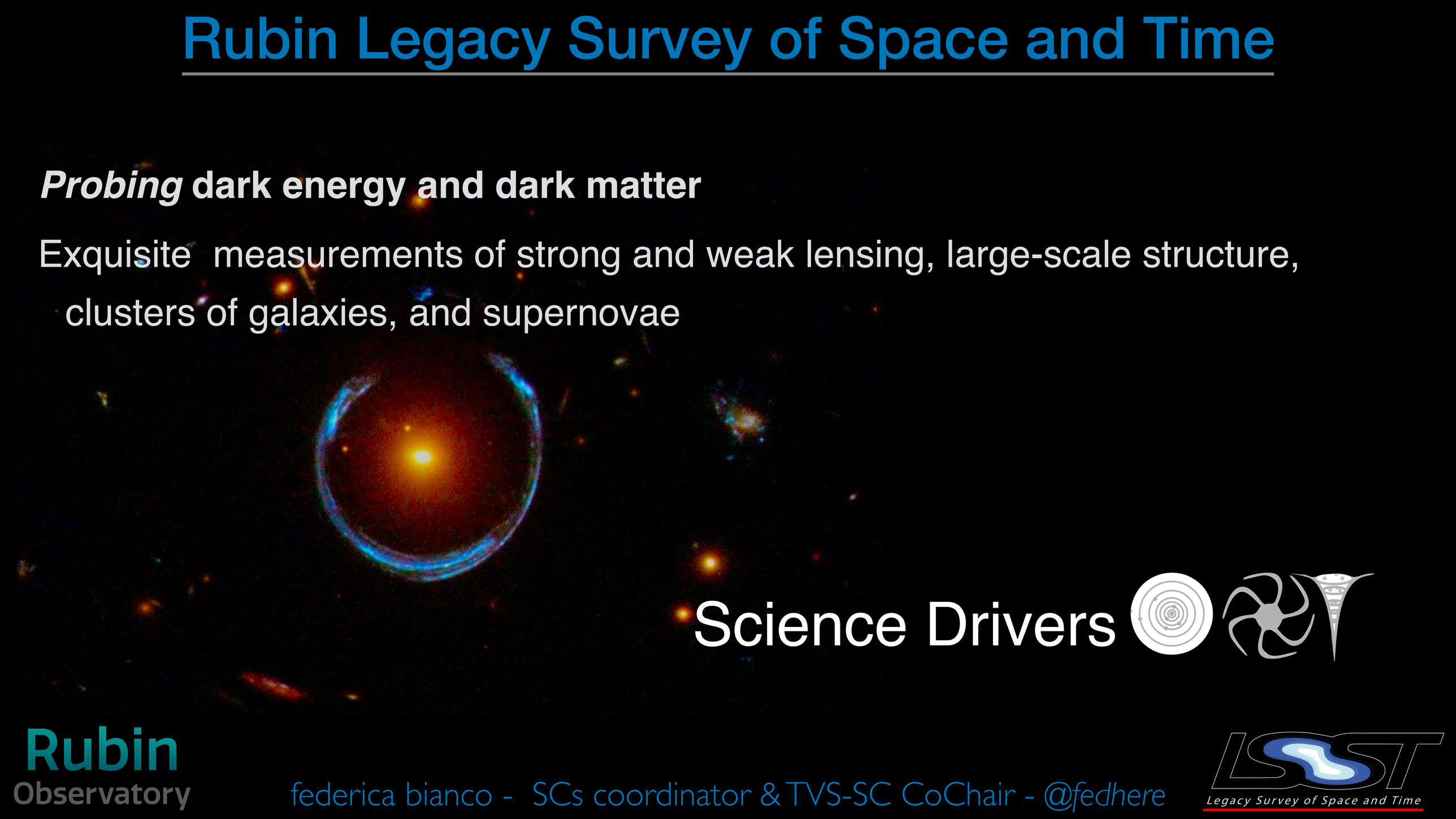
federica bianco - SCs coordinator & TVS-SC CoChair - @fedhere

Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

Probing **dark energy and dark matter**

Exquisite measurements of strong and weak lensing, large-scale structure, clusters of galaxies, and supernovae



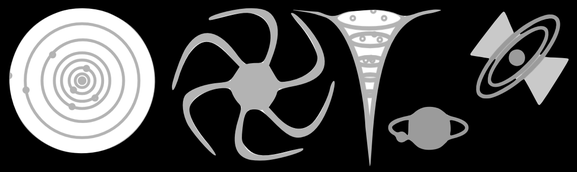
Science Drivers

Rubin Legacy Survey of Space and Time

Exploring **the transient and variable Universe**

A stream of 1-10 million events/night, *detected and transmitted* *within 60 seconds of observation.*

Science Drivers



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@fedhere

LSST Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

How is LSST transformational?

3

- No internal science team
- No science topic is reserved for anyone

8 Science Collaborations

1500+ members

Since there is no science team, science preparation is done by the Science Collaborations… for free!

Rubin Legacy Survey of Space and Time

How is LSST transformational?

3

- No internal science team
- No science topic is reserved for anyone

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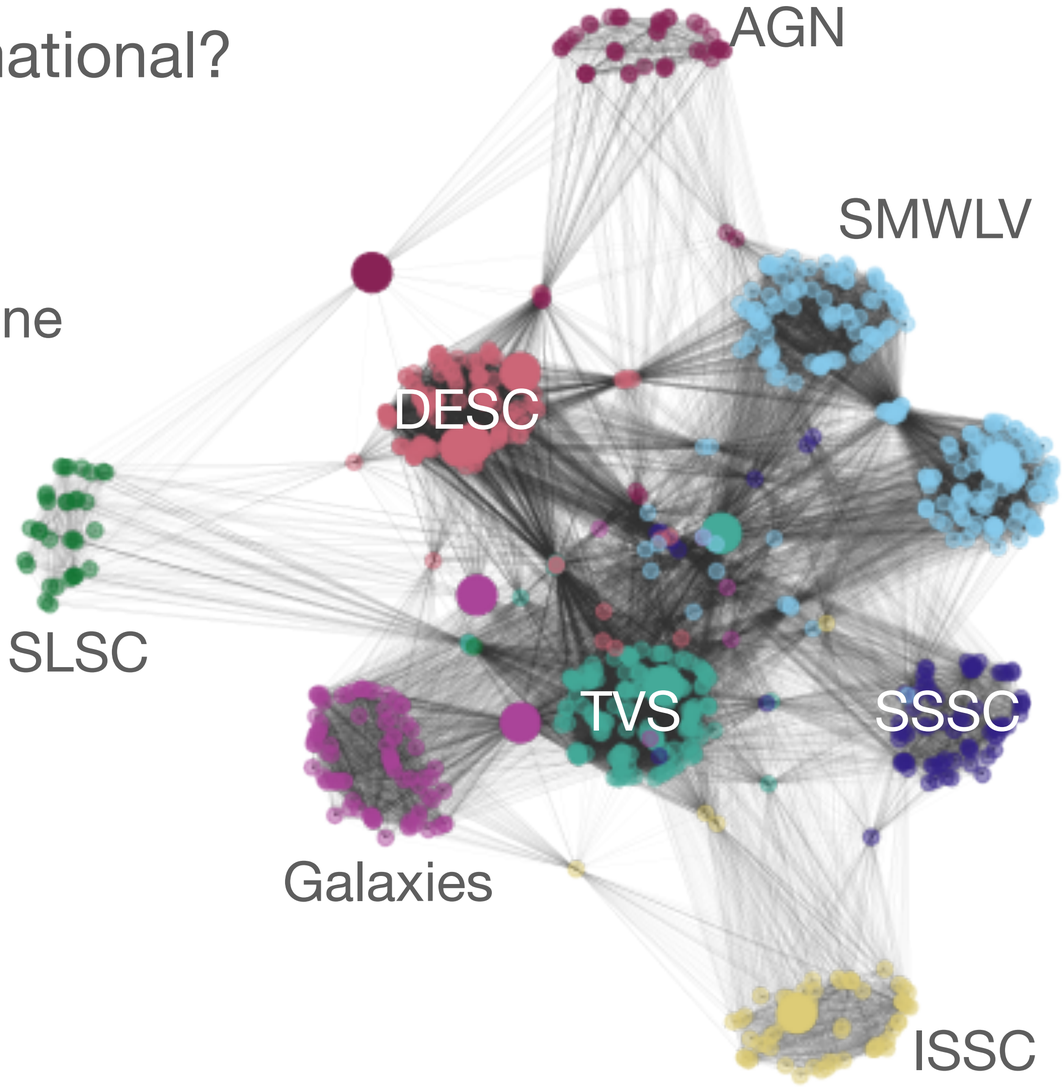
1500+ members



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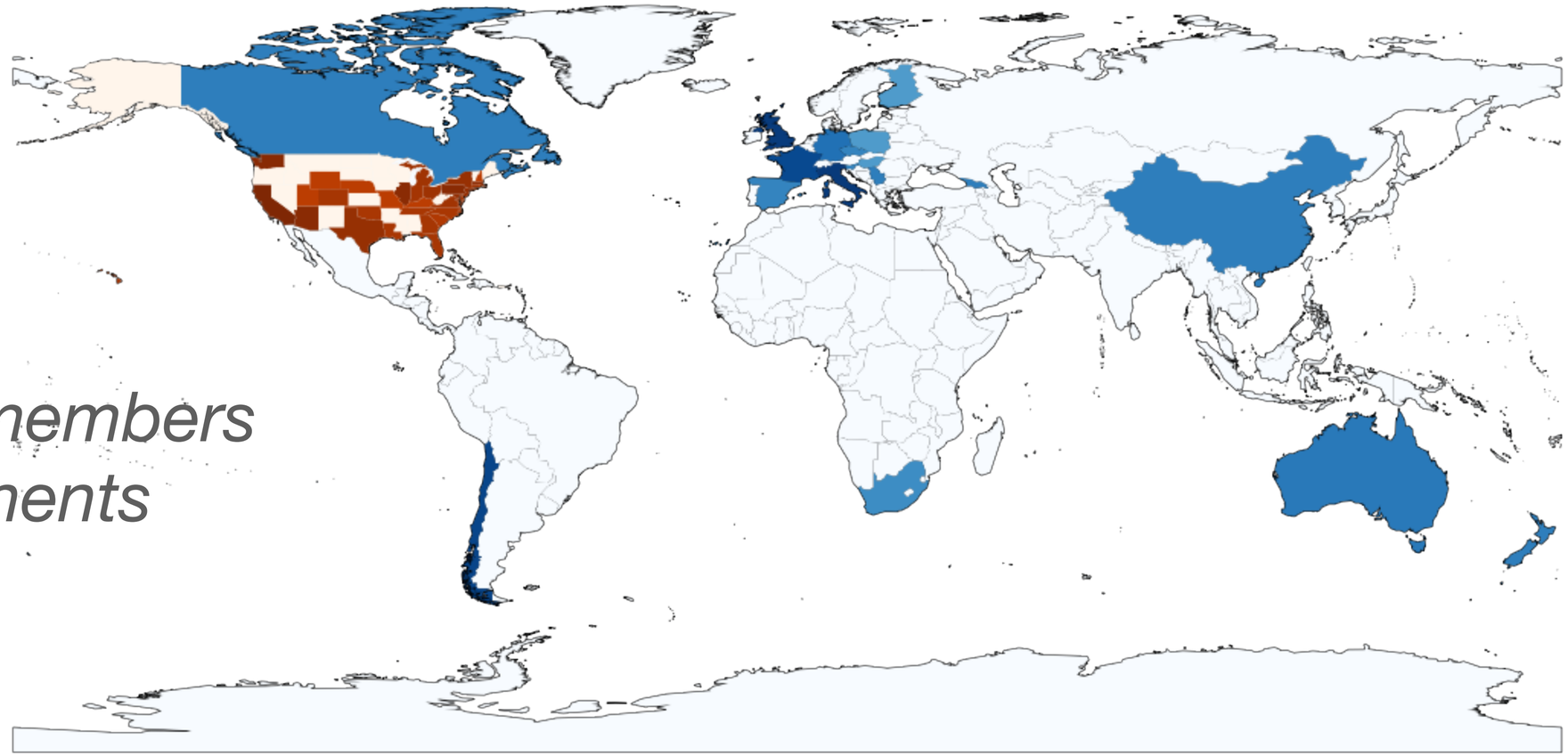
LSST Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

How is LSST transformational?

3

1500+ members
6 continents



US-wide public data
Chile-wide public data
World can acquire data rights with *in-kind* contributions

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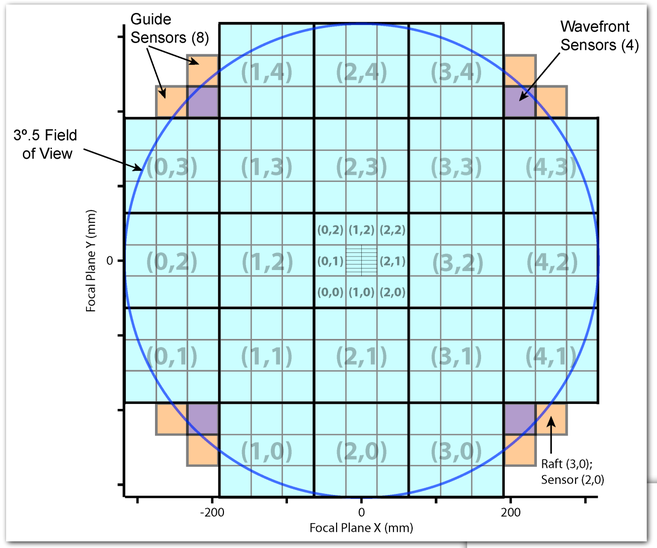
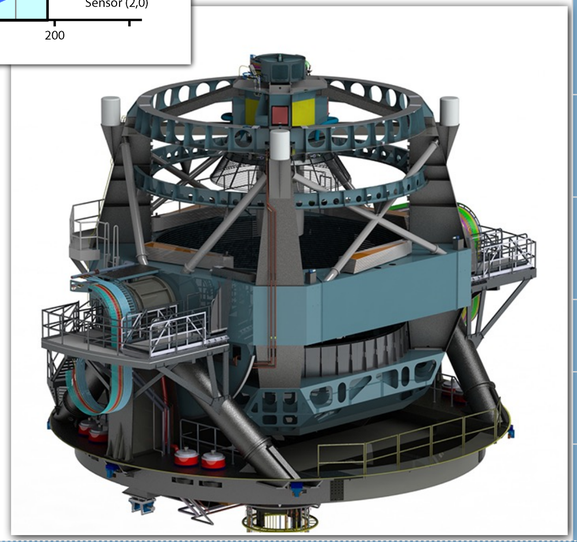
LSST Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time





field of view	9.6 deg²
camera fill factor	>90 %
filters	*u g r i z y*
standard visit exposure	30s (2x15s)
standard visit depth	~ 24, 25, 24.7, 24, 23, 22
saturation	~ 15, 16, 16, 16, 15, 14
survey visits/field	56,80,184,184,160,160 (824)
survey full depth	~ 26, 27, 27.5, 27, 26, 25
survey full area	~18000°²
max filter change	90 sec
max slew (180° az)	<120 sec
standard visit processing time	60 sec

fast response, large aperture, wide field of view, optical filter set, high resolution, excellent PSF characterization and prompt processing

"Science Drivers to Reference Design", Ivezić et al. (2008), arXiv:0805.2366

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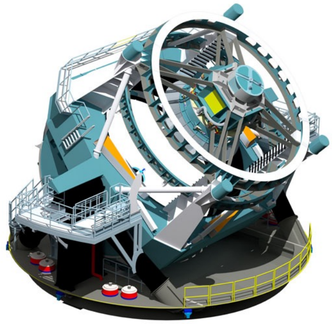
LSST Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

Data Management System Overview

Raw Data: 20TB/night

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



Prompt Data Products

Alerts: up to 10M/night

via nightly alert streams

60s

Community Brokers

LSST Alert Filtering Service

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

Solar System Objects: ~6M by year 10

24h

via Prompt Products Database

Data Release Data Products

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

via Data Releases

LSST DACs (Chile & NCSA)

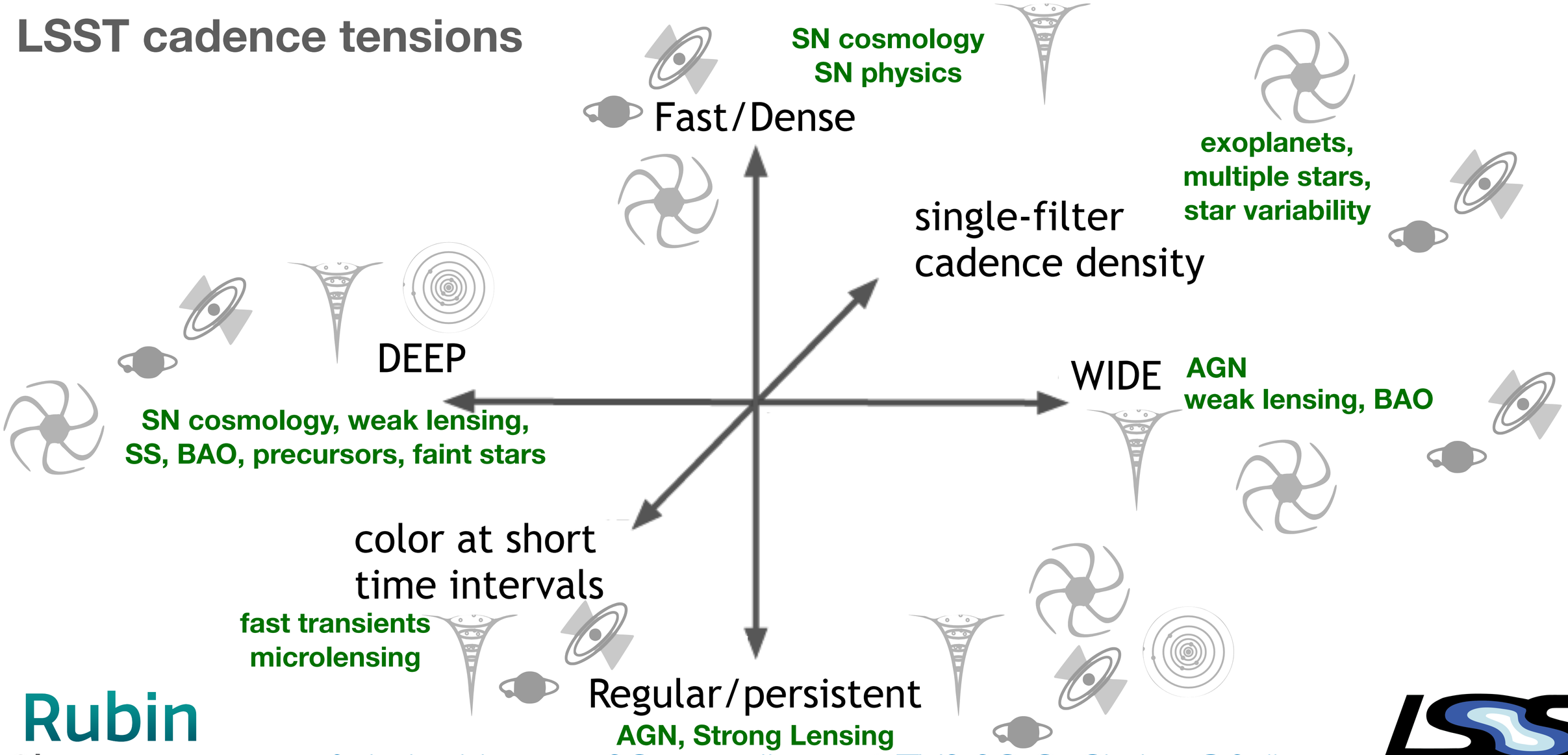
Independent DACs (iDACs)

Data Products Definition Document
http://ls.st/dpdd

Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

LSST cadence tensions



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LSST Legacy Survey of Space and Time

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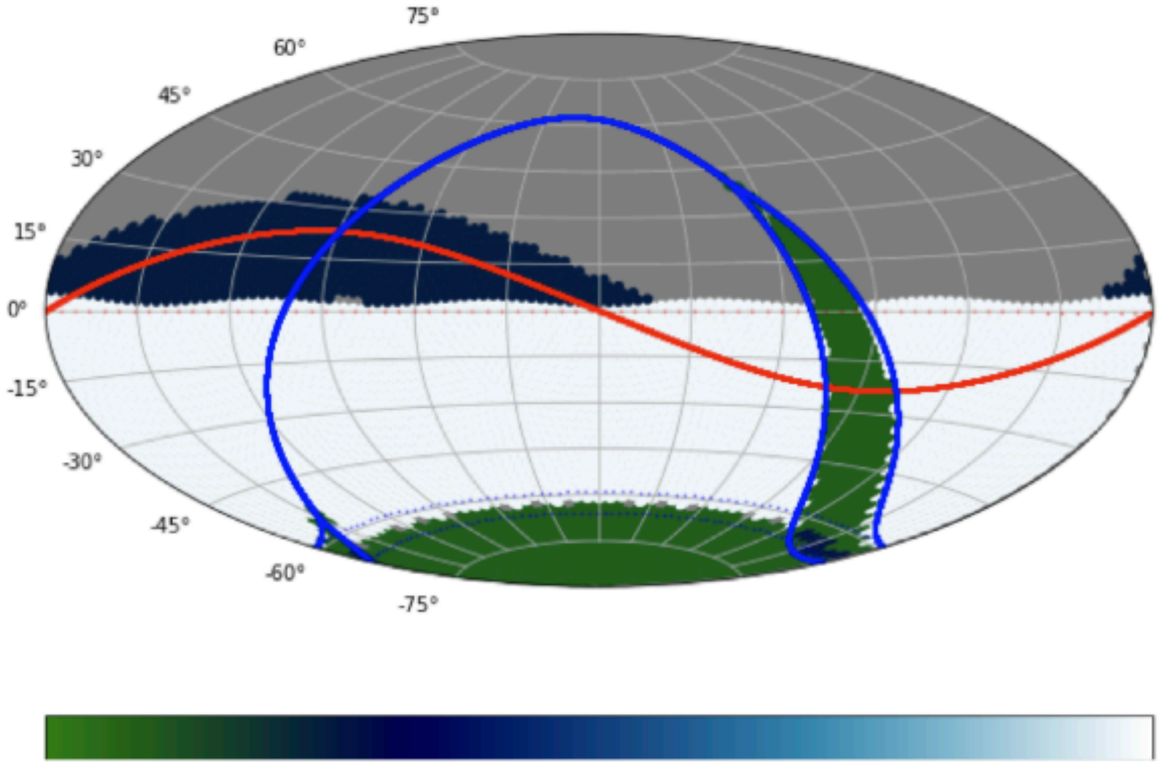

2022-2032

0 *Original footprint: N visits* *1000*

Wide-Fast-Deep
(~80%)

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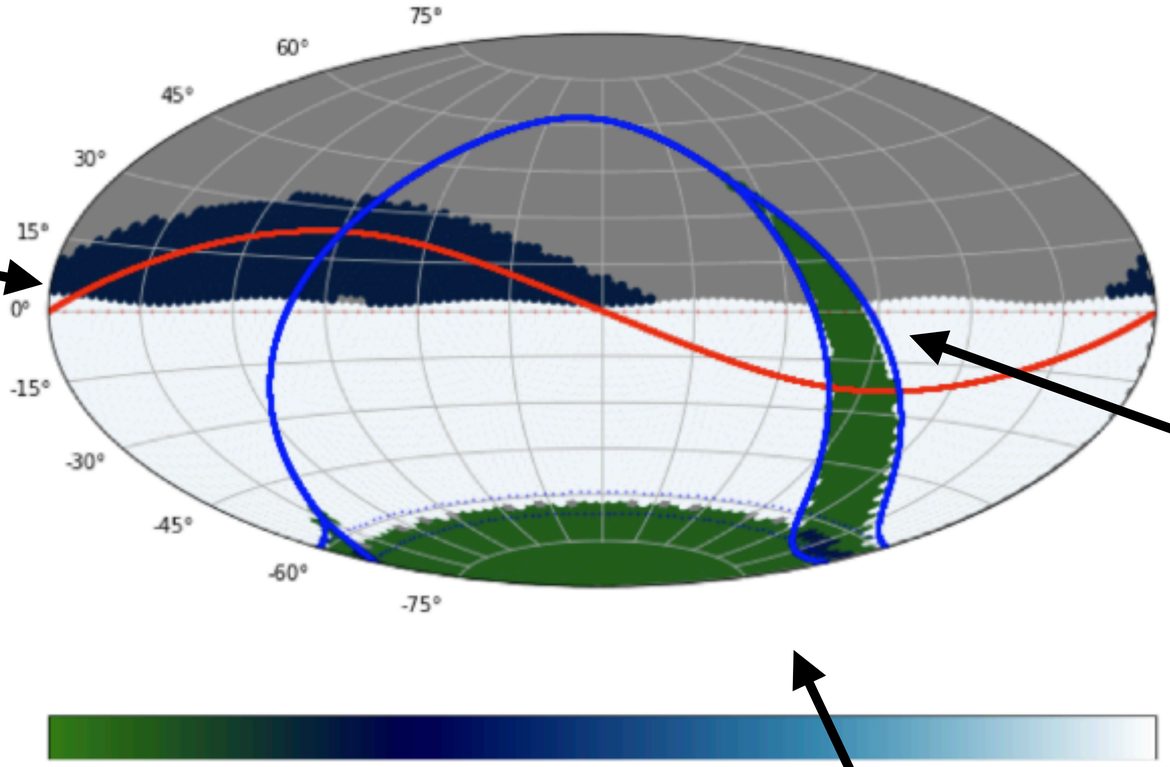
Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

2022-2032

North Ecliptic Survey
The NES is an extension to reach the Ecliptic at higher airmass than the WFD survey typically covers, no *u*



Galactic Plane (1.7%): covers the region where LSST is expected to be highly confused by the density of stellar sources; fewer total exposures/ field and does **not collect in pairs**

Wide-Fast-Deep (~80%)

South Celestial Pole (2.2%): higher airmass decl>–65 degrees. includes *ugrizy*, but takes fewer exposures/field than the WFD and does **not collect in pairs**.

Rubin Observatory

Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time

2022-2032

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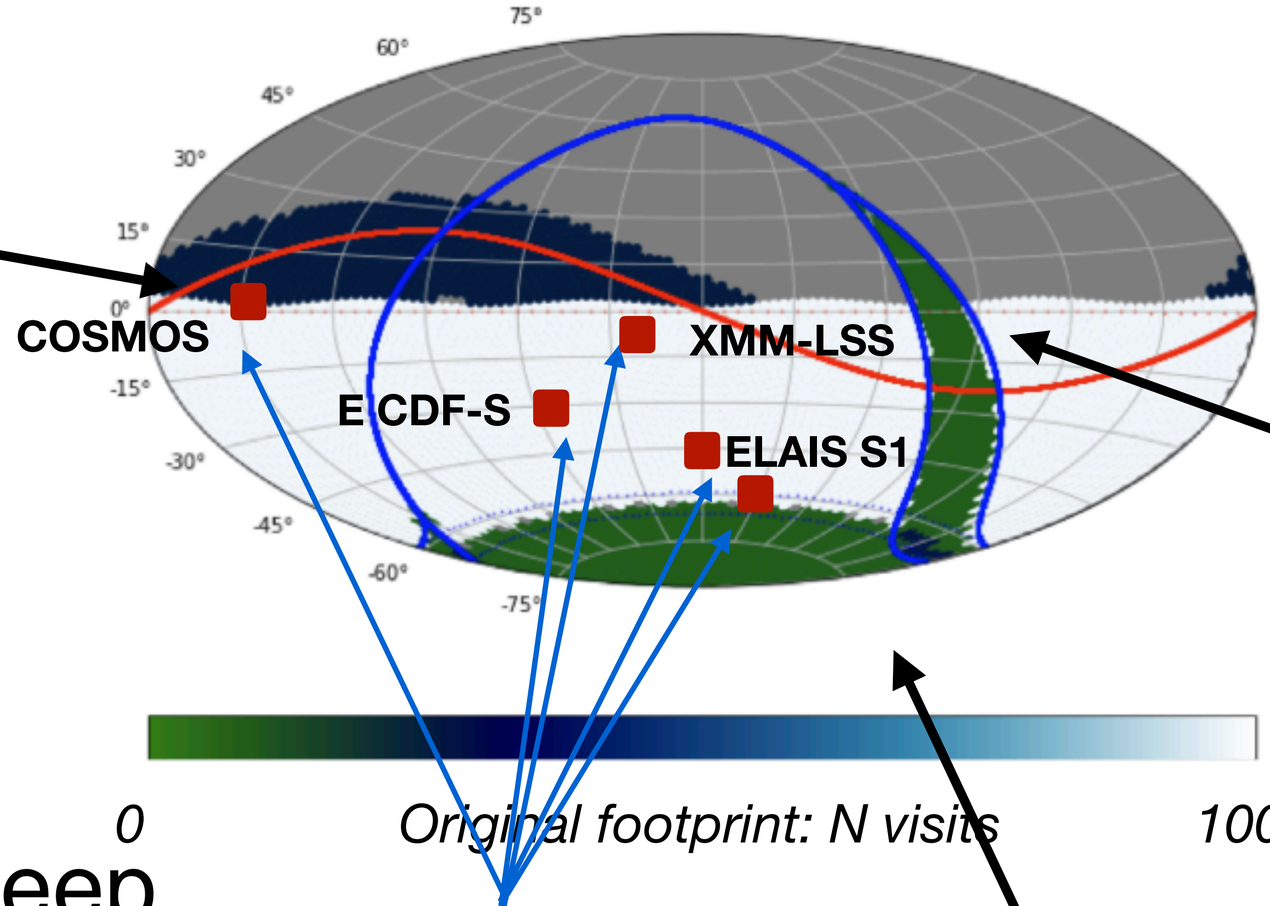

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Wide-Fast-Deep (~80%)

Deep Drilling Fields DDF (4.5%)

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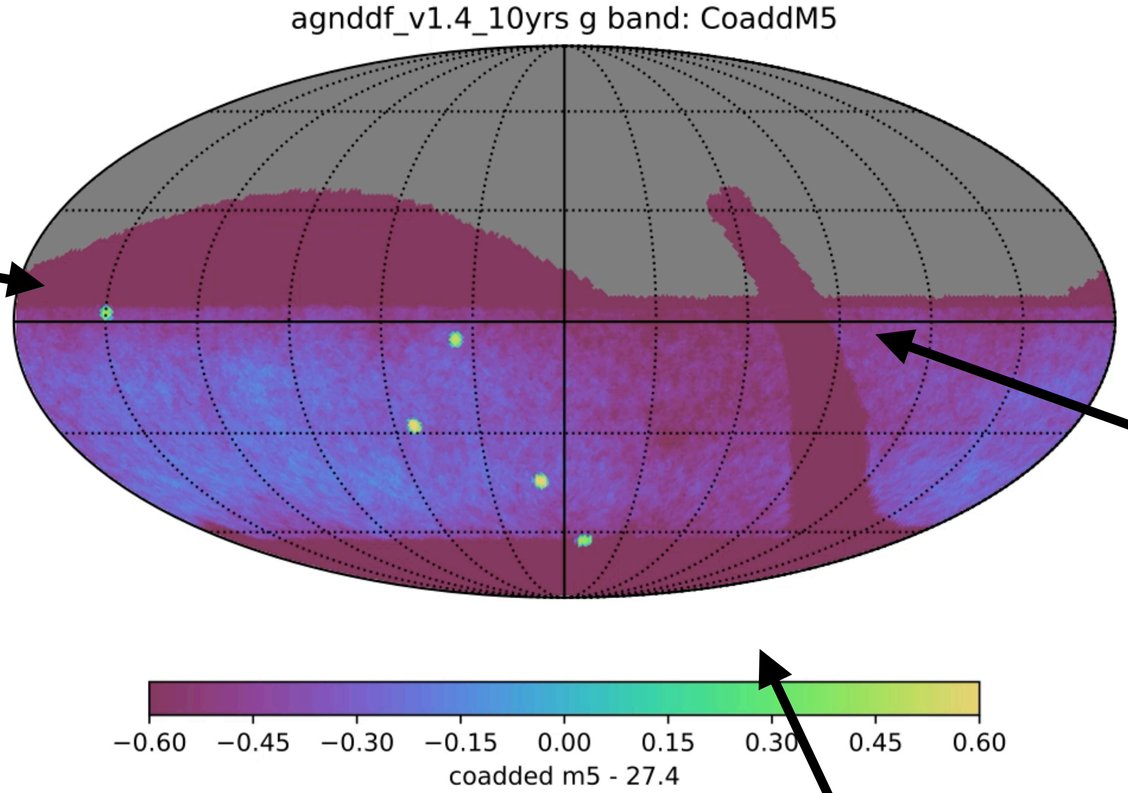
Legacy Survey of Space and Time

Rubin Legacy Survey of Space and Time



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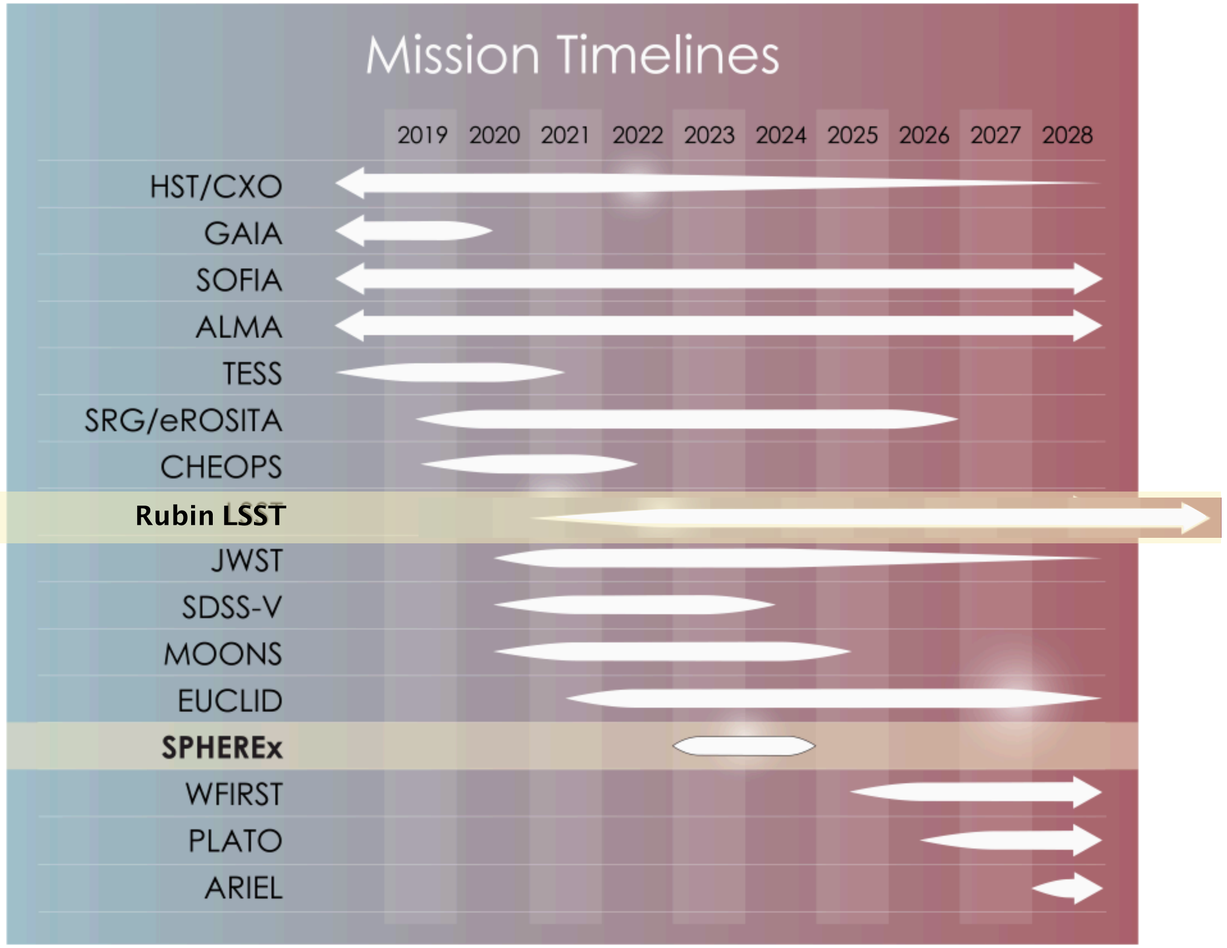
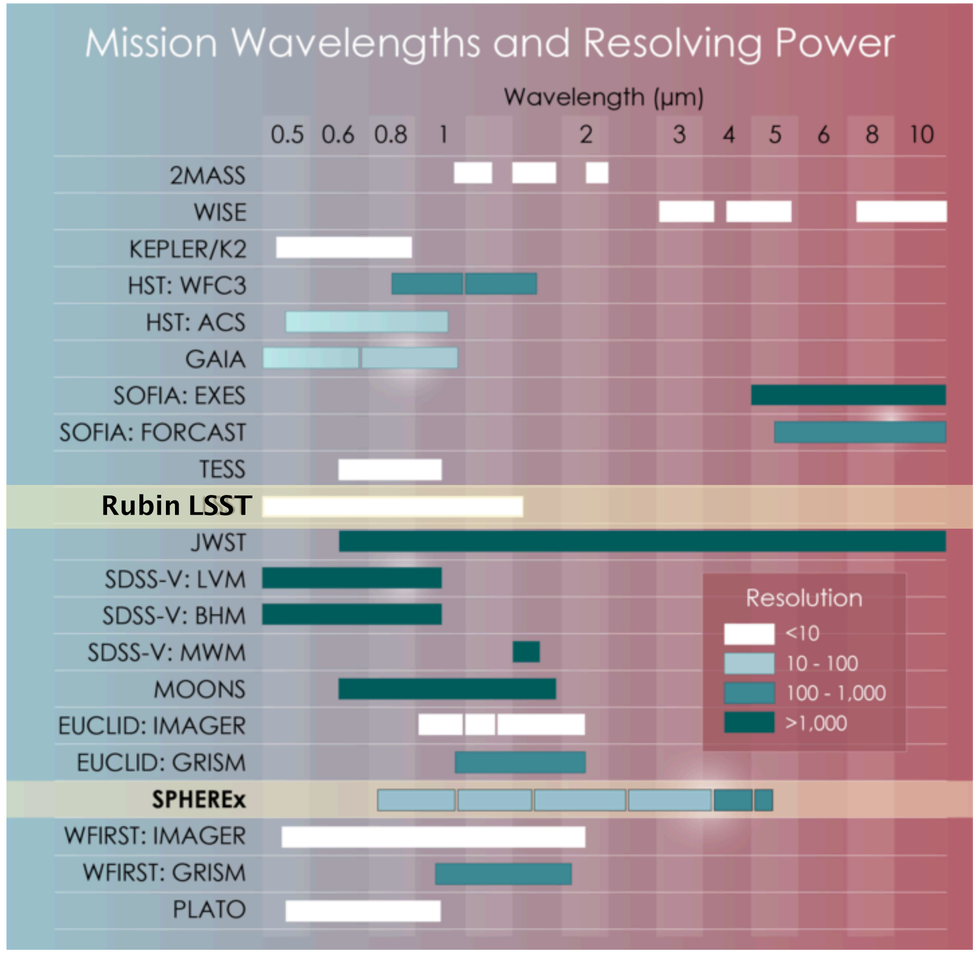
Legacy Survey of Space and Time

Rubin LSST + SPHEREx



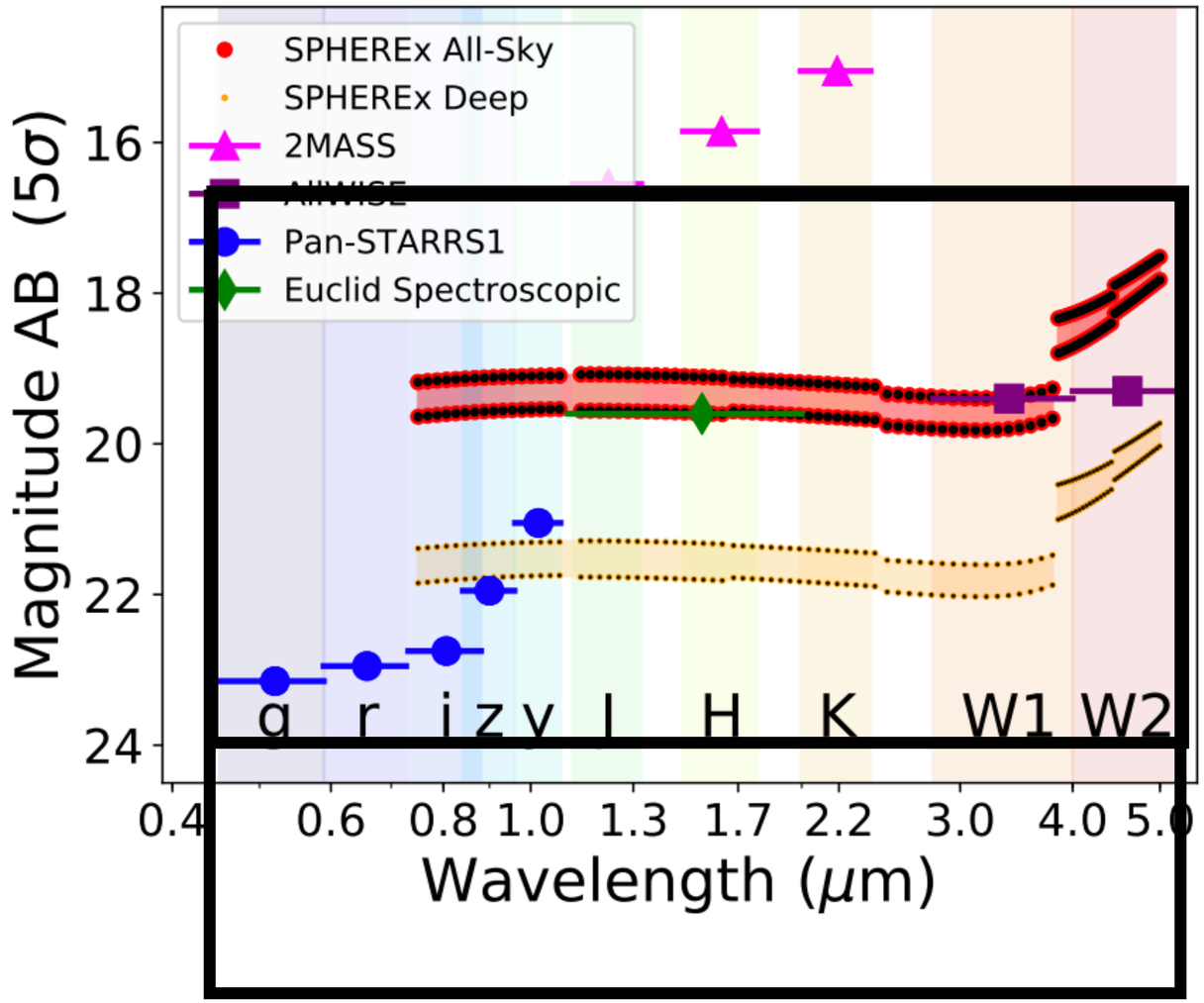
timeline overlap

Rubin LSST + SPHEREx



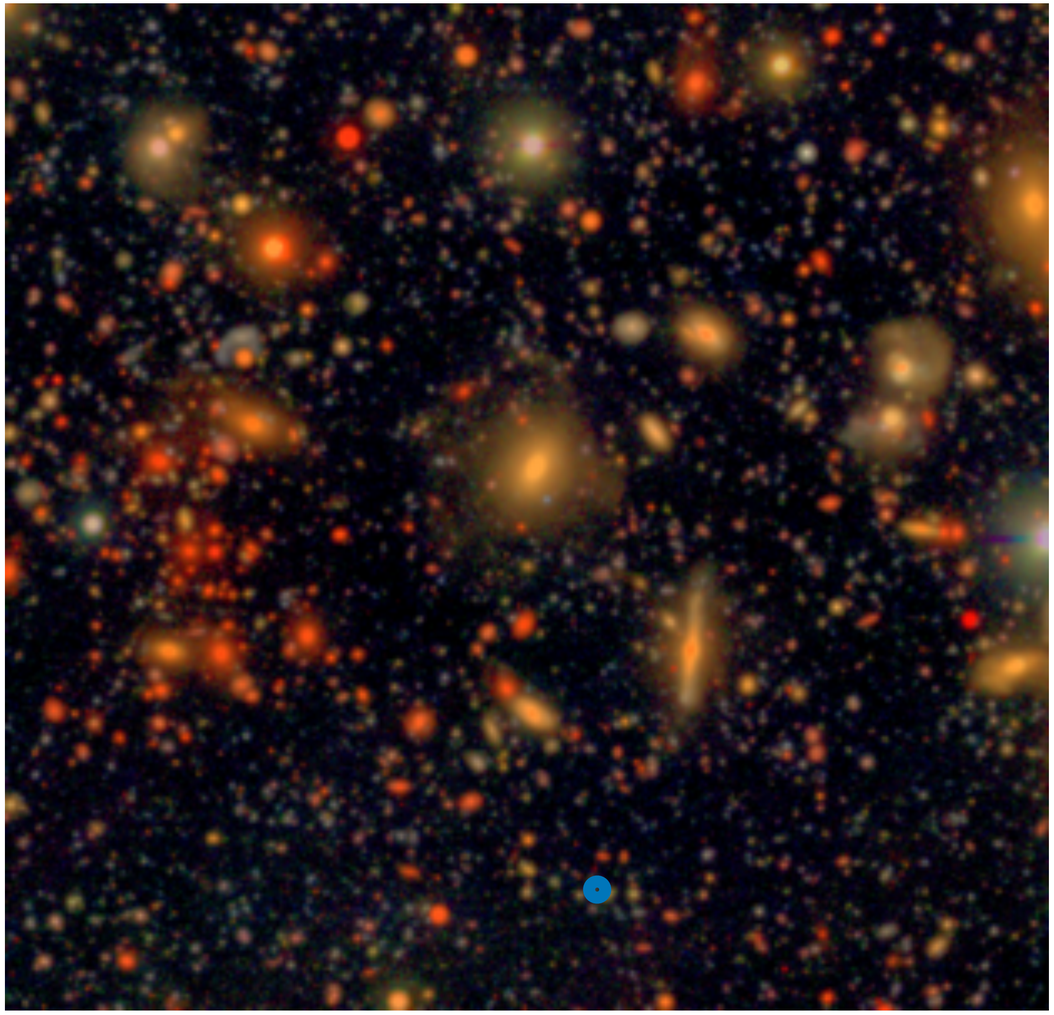
wavelength coverage overlap

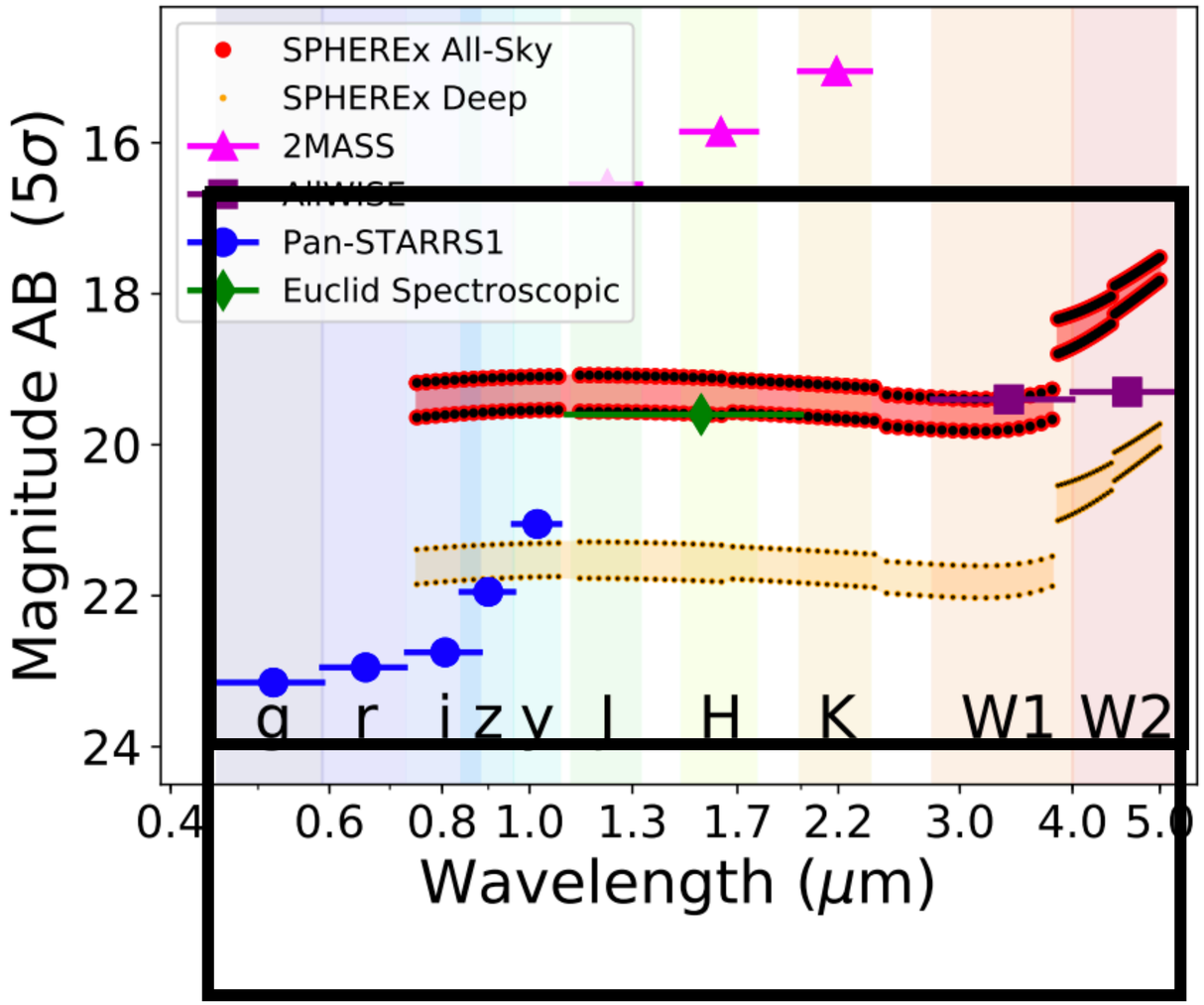
Rubin LSST + SPHEREx



… magnitude overlap

Rubin LSST + SPHEREx





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Legacy Survey of Space and Time

Rubin LSST + SphereX

Help calibrate out Rubin LSST depth fluctuations

cross-correlate large scale fluctuations from SPHEREx

+

small scales fluctuations from Rubin LSST

Anže Slosar (DESC)

Cross-correlations of LSST galaxy samples against SPHEREx spectroscopic samples will help constrain the ensemble redshift distributions of LSST galaxies, which is one of the major uncertainties for LSST cosmological analyses with weak lensing

Rachel Mandelbaum (DESC)

Code SPHEREx science - I will not talk about it

Rubin LSST + SphereX

Solar System comets and asteroids

Comets molecules from SPHEREx

Comets activity from Rubin LSST

Code SPHEREx science - I will not talk about it

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LSST Legacy Survey of Space and Time

Rubin LSST + SphereX

Obvious synergy
LSST has better resolution,
Sphere-X has IR color
but the magnitude gap is significant.

Photo-z

Euclide has resolution and overlap with SphereX … is it redundant?

Rubin LSST + SphereX

LSST has a problem…

Transients classification

1-10M transients each night… ~100 telescopes to take spectra

Transients & variables with the Rubin Observatory's LSST

Prepared by the LSST Science Collaborations,

with contributions from the LSST Project.

Science-Driven Optimization of the LSST Observing Strategy

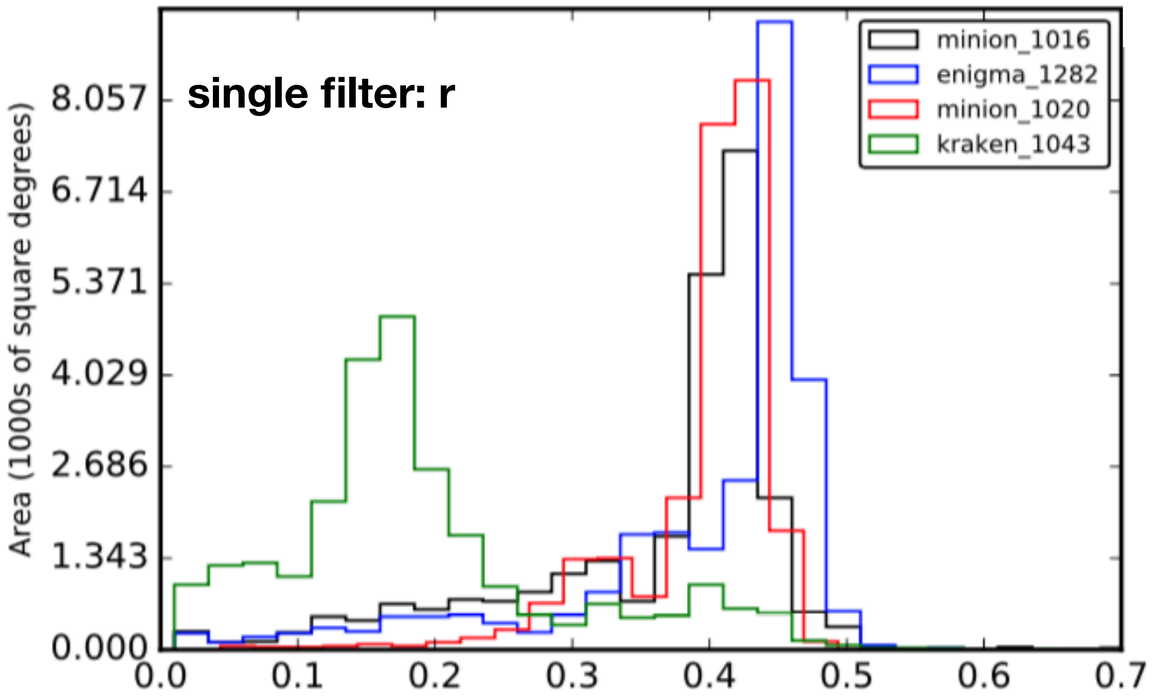
Phil Marshall,[1] Scott Anderson,[2] Timo Anguita,[3] Iair Arcavi,[4] Humna Awan,[5] Federica B. Bianco,[6] Rahul Biswas,[7] Keaton J. Bell,[8] Eric C. Bellm,[9] David Bennett,[10] Niel Brandt,[11] Chris Britt,[12] Dana I. Casetti-Dinescu,[13] Laura Chomiuk,[14] Will Clarkson,[15] Chuck Claver,[16] Andy Connolly,[17] Kem Cook,[18] Victor Debattista,[19] Seth Digel,[20] Zoheyr Doctor,[21] Wen-fai Fong,[22] Eric Gawiser,[23] John E. Gizis,[24] Carl Grillmair,[25] Zoltan Haiman,[26] Patrick Hartigan,[27] Željko Ivezić,[28] C. Johns-Krull,[29] Peter Kurczynski,[30] Lynne Jones,[31] Shashi Kanbur,[32] Vassiliki Kalogera,[33] Vishal Kasliwal,[34] Michael C. Liu,[35] Michelle Lochner,[36] Michael B. Lund,[37] Ashish Mahabal,[38] Raffaella Margutti,[39] Peregrine McGehee,[40] Tom Matheson,[41] Josh Meyers,[42] Dave Monet,[43] David Nidever,[44] Knut Olsen,[45] Eric Neilsen,[46] Matthew T. Penny,[47] Christina Peters,[48] Gordon Richards,[49] Stephen Ridgway,[50] Jeonghee Rho,[51] Jason Rhodes,[52] David Rubin,[53] Ohad Shemmer,[54] Avi Shporer,[55] Colin Slater,[56] Nathan Smith,[57] Marcelles Soares-Santos,[58] Jay Strader,[59] Michael Strauss,[60] Rachel Street,[61] Christopher Stubbs,[62] Paula Szkody,[63] David Trilling,[64] Virginia Trimble,[65] Miguel de Val-Borro,[66] Stefano Valenti,[67] Kathy Vivas,[68] Robert Wagoner,[69] Lucianne Walkowicz,[70] Beth Willman,[71] Peter Yoachim,[72] Bevin Ashley Zauderer,[73]

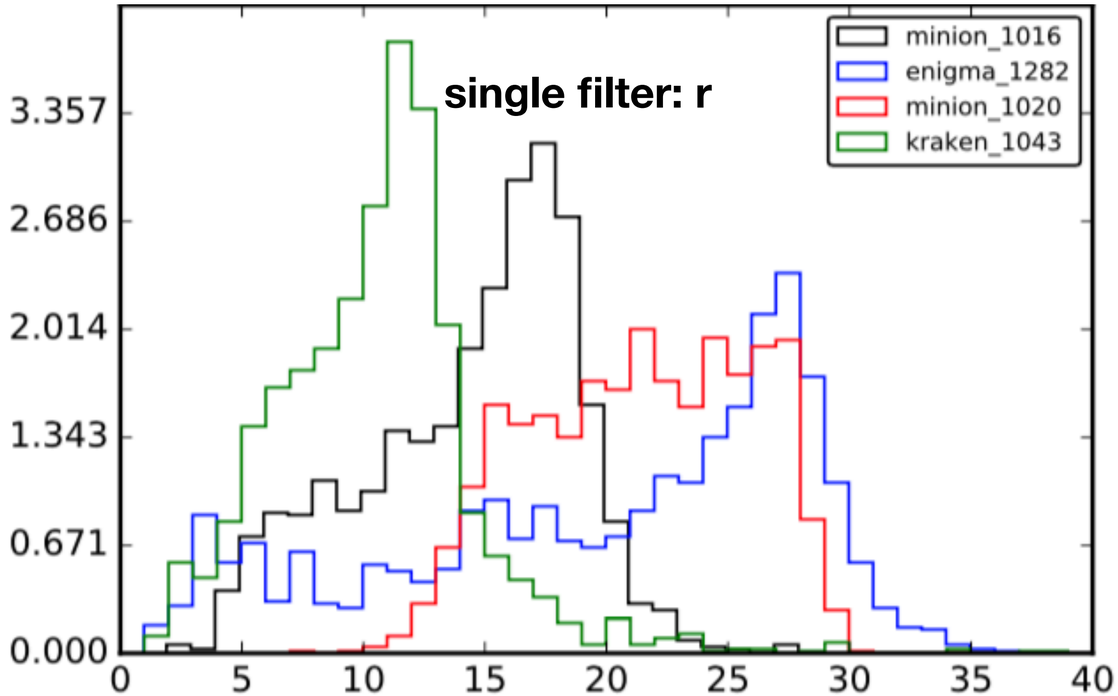
http://www.slac.stanford.edu/~digel/ObservingStrategy/whitepaper/LSST_Observing_Strategy_White_Paper.pdf

https://github.com/LSSTScienceCollaborations/ObservingStrategy

Rubin Observatory

Transients & variables with the Rubin Observatory's LSST





	minion_1016	enigma_1281	kraken_1043	minion_1020
any filter	3.0	3.9	2.0	3.0
r-band	15.0	22.8	11.0	21.9

Rubin Observatory

LSST Legacy Survey of Space and Time

Transients & variables with the Rubin Observatory's LSST

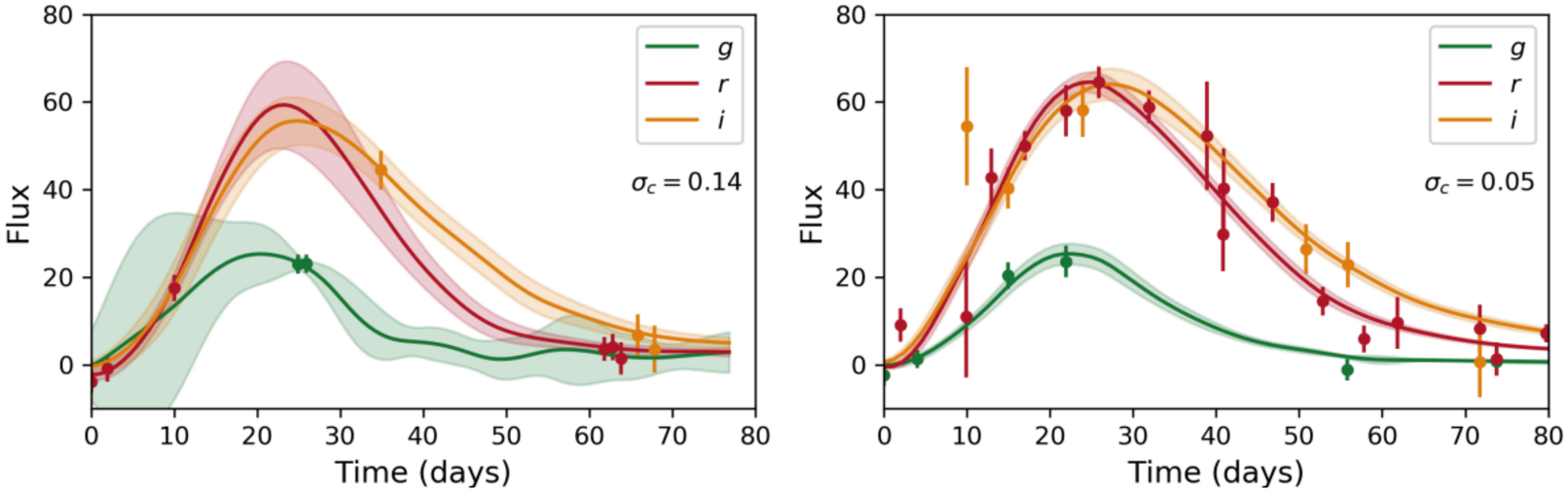
LSST photometry will not be dense

Optimizing the LSST Observing Strategy for Dark Energy Science: DESC Recommendations for the Wide-Fast-Deep Survey

Michelle Lochner[1,2], Daniel M. Scolnic[3], Humna Awan[4], Nicolas Regnault[5], Philippe Gris[6], Rachel Mandelbaum[7], Eric Gawiser[4], Husni Almoubayyed[7], Christian N. Setzer[8,9], Simon Huber[10,11], Melissa L. Graham[12], Renée Hložek[13,14], Rahul Biswas[9], Tim Eifler[15], Daniel Rothchild[16], Tarek Allam Jr[17], Jonathan Blazek[18,19], Chihway Chang[20], Thomas Collett[21], Ariel Goobar[9], Isobel M. Hook[22], Mike Jarvis[23], Saurabh W. Jha[4], Alex G. Kim[24], Phil Marshall[25], Jason D. McEwen[17], Marc Moniez[26], Jeffrey A. Newman[27], Hiranya V. Peiris[9,28], Jason Rhodes[29], Ignacio Sevilla-Noarbe[30], Anže Slosar[31], Sherry H. Suyu[10,11,32], J. Anthony Tyson[33], Peter Yoachim[34]

(The LSST Dark Energy Collaboration)

Lochner et al. 2019

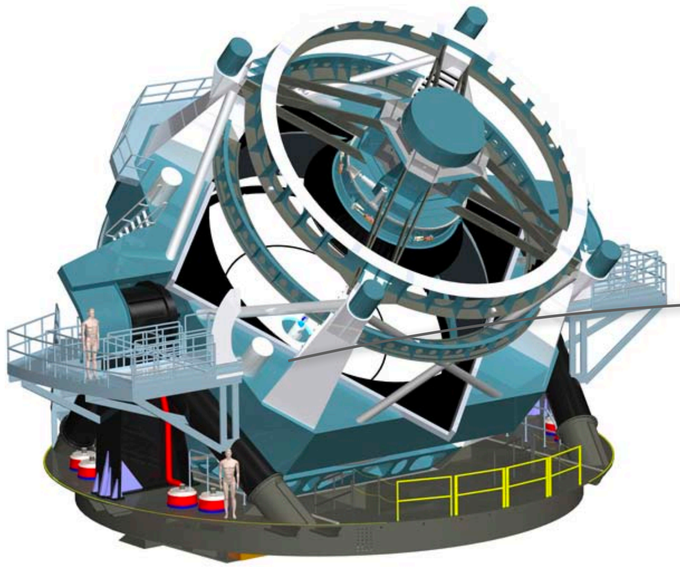


Rubin LSST simulated strategy

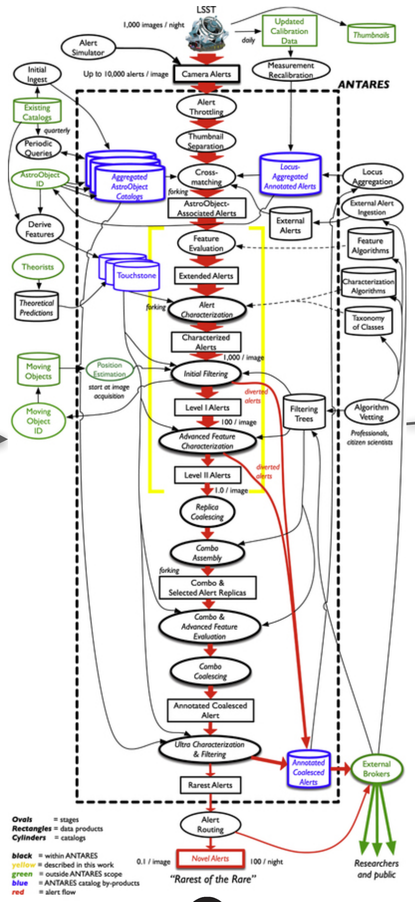
Transients & variables with the Rubin Observatory's LSST

Possibly the principal LSST challenge

Classification of 1M alerts/night from sparse photometry+biased training sets



10M alerts/night



Target & Observation Manager Systems

Observing facilities

Follow-up will put huge strain on existing facilities

Broker services

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LSST Legacy Survey of Space and Time

Rubin LSST + SPHEREx

Possibly the principal LSST challenge

Classification of 1M alerts/night from sparse photometry+biased training sets

Classification of transients serendipitously co-observed by LSST & SPHEREx

The magnitude gap is significant, but in the context of ML probabilistic classification the SPHEREx information is extremely valuable

Reduce the burden on follow-up facilities

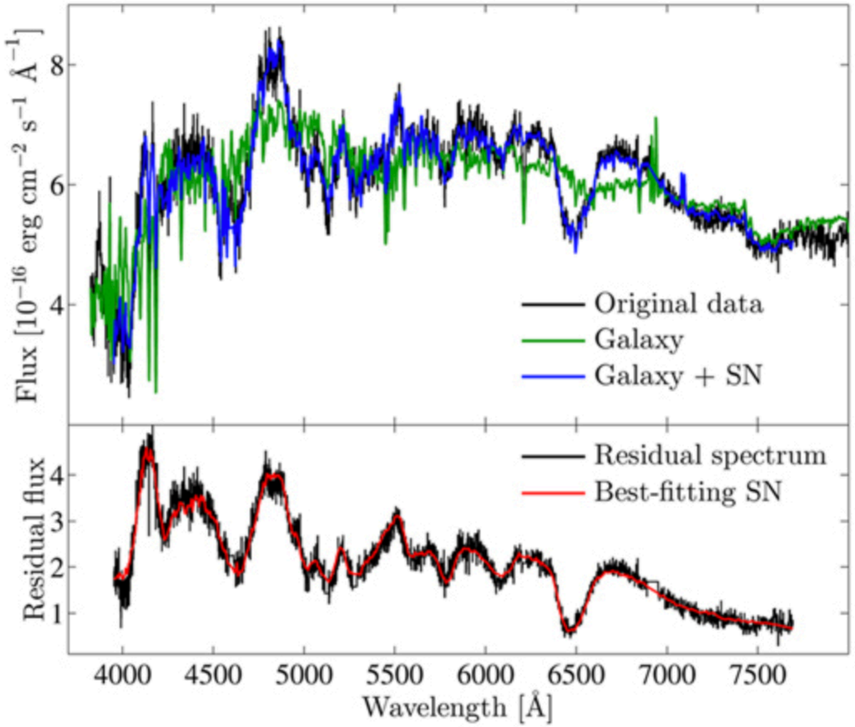

Fig. 1: One of 90 SNe Ia discovered in SDSS DR7 galaxy spectra. Top: fitting the original data (black) with a galaxy model composed of 10 Yip et al. (2004a) eigenspectra (green) results in a poor fit ($\chi^2 = 7.6$). When fit with both eigenspectra and transient templates (blue), a SN Ia template produces $\chi^2 = 1.1$. Bottom: residual spectrum (black) and best-fitting SN Ia template (red).

Can near-real time classification can be performed (close to time of LSST discovery that can be after SPHEREx observation by ~days)

SN classification in galaxy spectroscopic surveys , e.g. Graur et al. 2015

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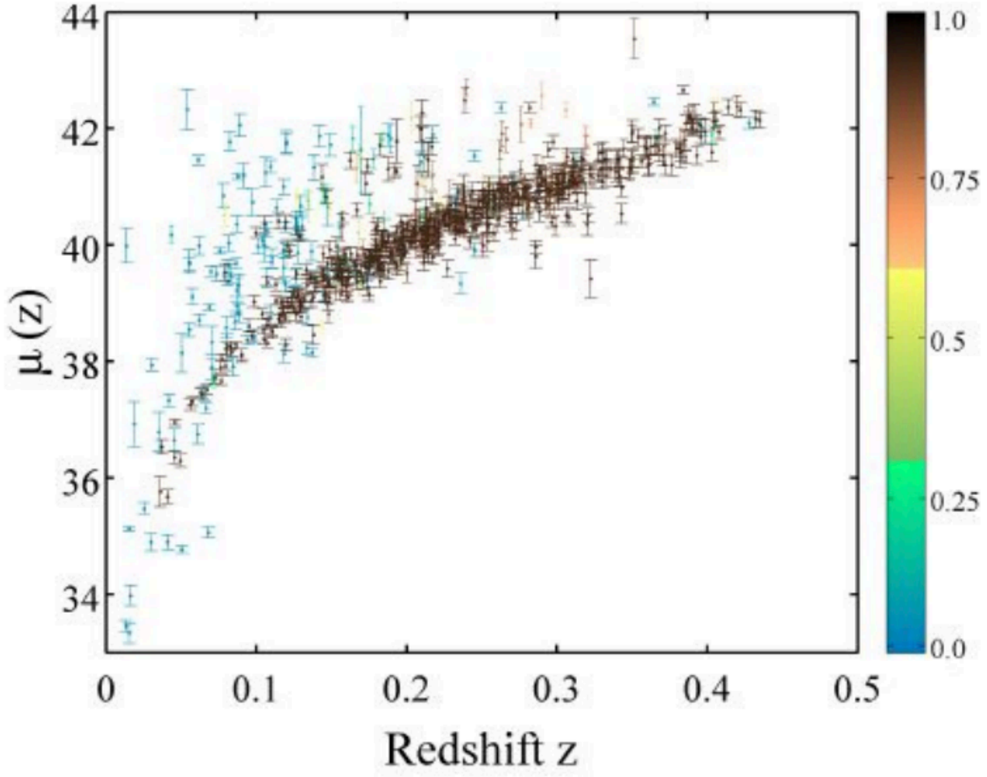
LSST Legacy Survey of Space and Time

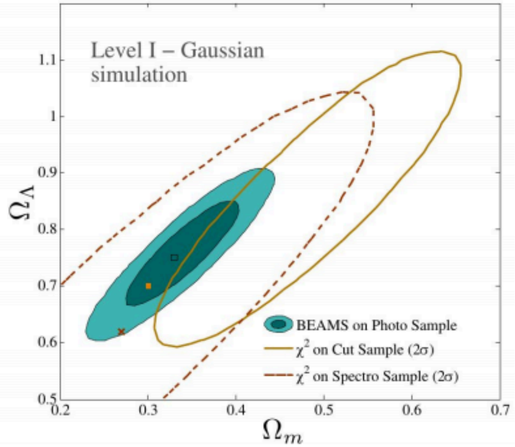
Rubin LSST + SphereX

Possibly the principal LSST challenge

Classification of 1M alerts/night from sparse photometry+biased training sets

Spectroscopic information helps reduce bias in sample science and improve sample purity





Bayesian Estimation Applied to Multiple Species (BEAMS)

Kunz, Bassett & Hlozek - 0611004
Newling et al. - 1110.6178
Hlozek et al. - 1111.5328
Lochner et al. - 1205.3493
Roberts et al. - 1704.07830

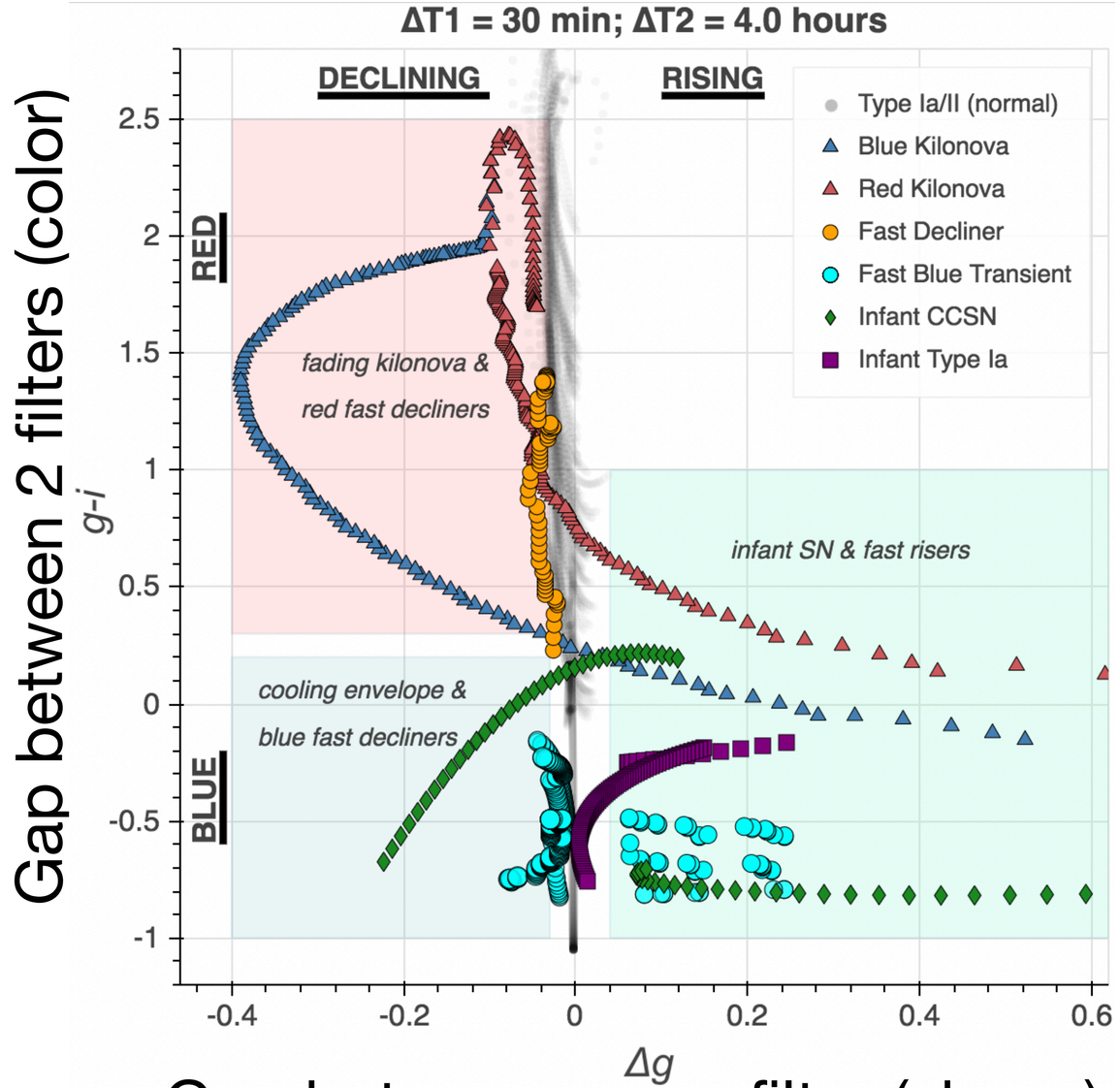
Transients and MMA with the Rubin Observatory's LSST

Rapid Transients

Presto-Color: A Photometric Survey Cadence for Explosive Physics and Fast Transients

Bianco, Federica B.; Drout, Maria R.; Graham, Melissa L.; Pritchard, Tyler A.; Biswas, Rahul; Narayan, Gautham; Andreoni, Igor; Cowperthwaite, Philip S.; Ribeiro, Tiago; LSST Transient, (With Support of the; Variable Stars Collaboration

We identify minimal observing cadence requirements that enable photometric astronomical surveys to detect and recognize fast and explosive transients and fast transient features. Observations in two different filters within a short time window (e.g., g-and-i, or r-and-z, within <0.5 hr) and a repeat of one of those filters with a longer time window (e.g., >1.5 hr) are desirable for this purpose. Such an observing strategy delivers both the color and light curve evolution of transients on the same night. This allows the identification and initial characterization of fast transient—or fast features of longer timescale transients—such as rapidly declining supernovae, kilonovae, and the signatures of SN ejecta interacting with binary companion stars or circumstellar material. Some of these extragalactic transients are intrinsically rare and generally all hard to find, thus upcoming surveys like the Large Synoptic Survey Telescope (LSST) could dramatically improve our understanding of their origin and properties. We colloquially refer to such a strategy implementation for the LSST as the Presto-Color strategy (rapid-color). This cadence's minimal requirements allow for overall optimization of a survey for other science goals.



Bianco et al. 2019

Rubin Observatory

federica bianco - SCs coordinator & TVS-SC CoChair - @fedhere

Legacy Survey of Space and Time

Transients and MMA with the Rubin Observatory's LSST

Rapid Transients

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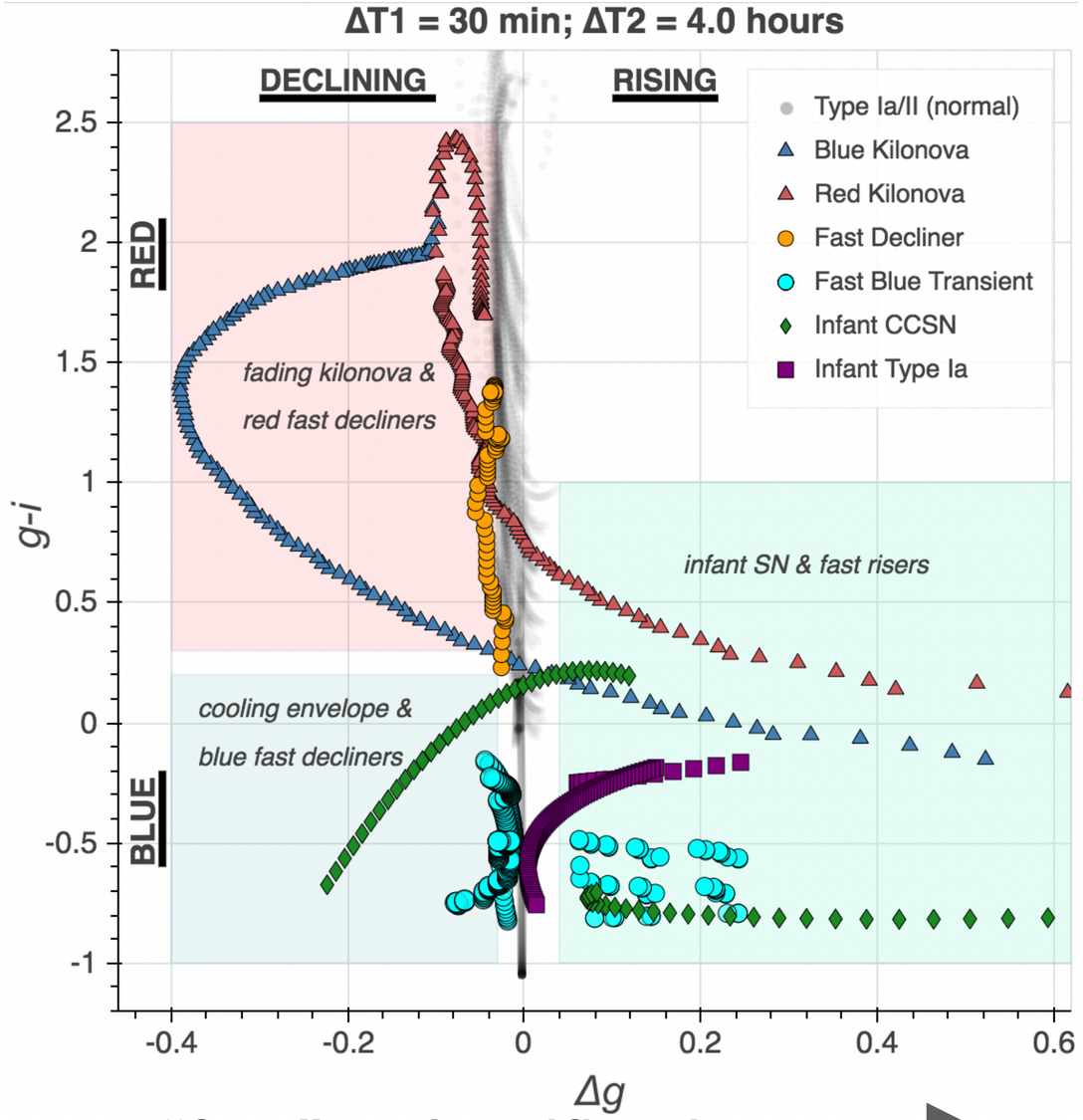

physics

"fast" classification

[Bianco et al. 2019]

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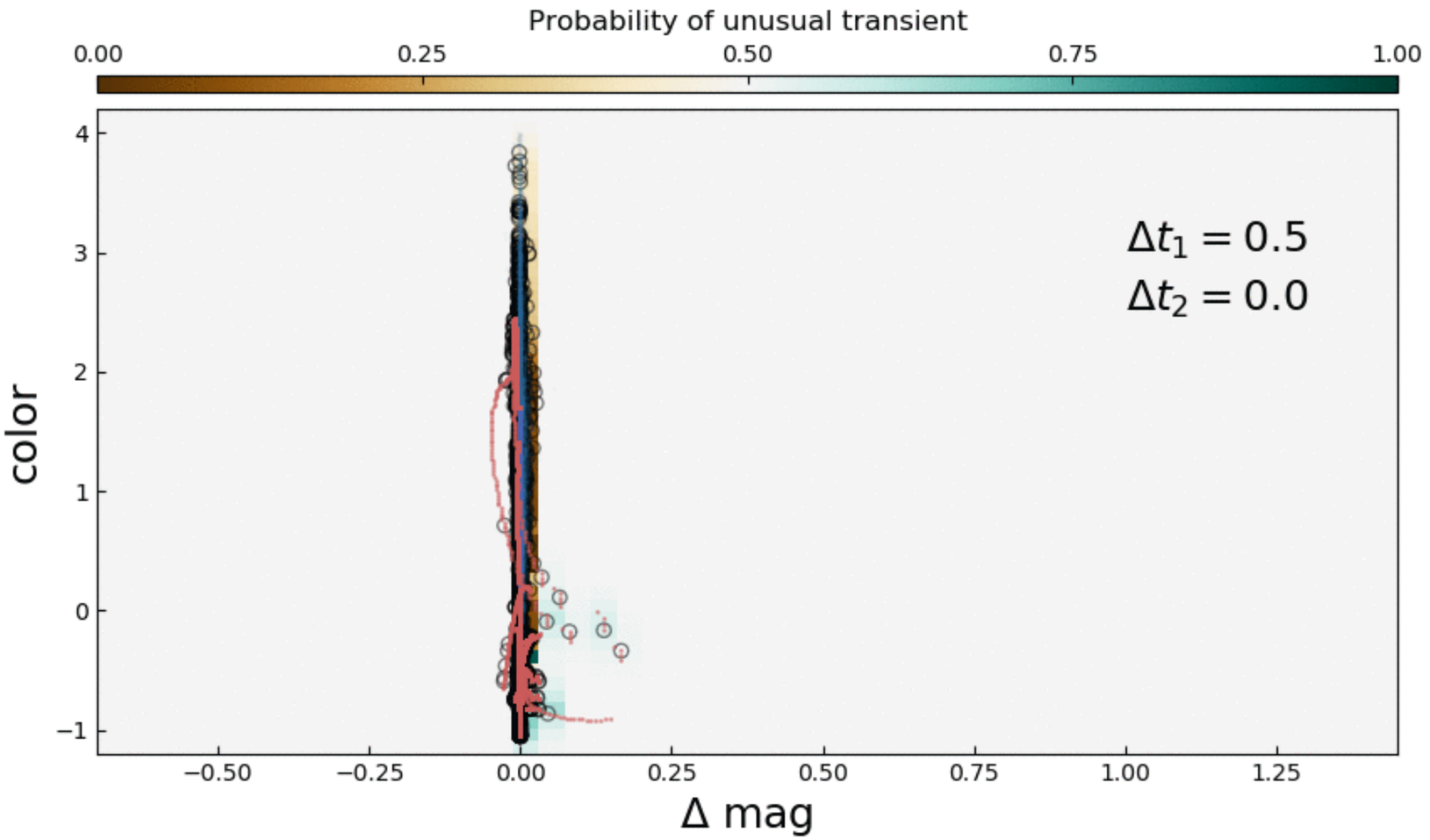
LSST Legacy Survey of Space and Time

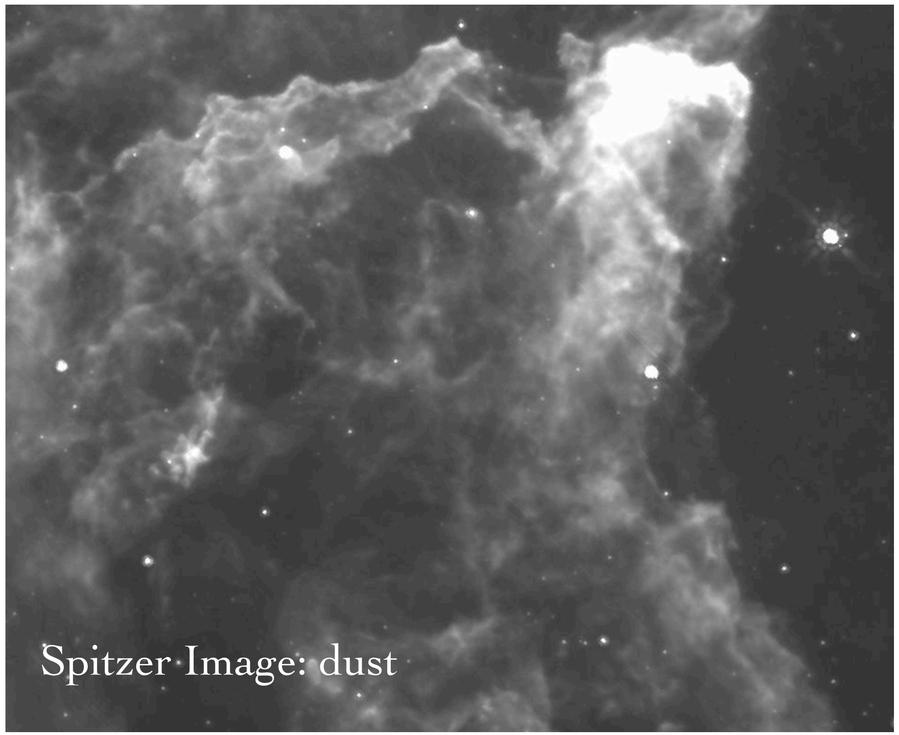
Rubin LSST + SphereX

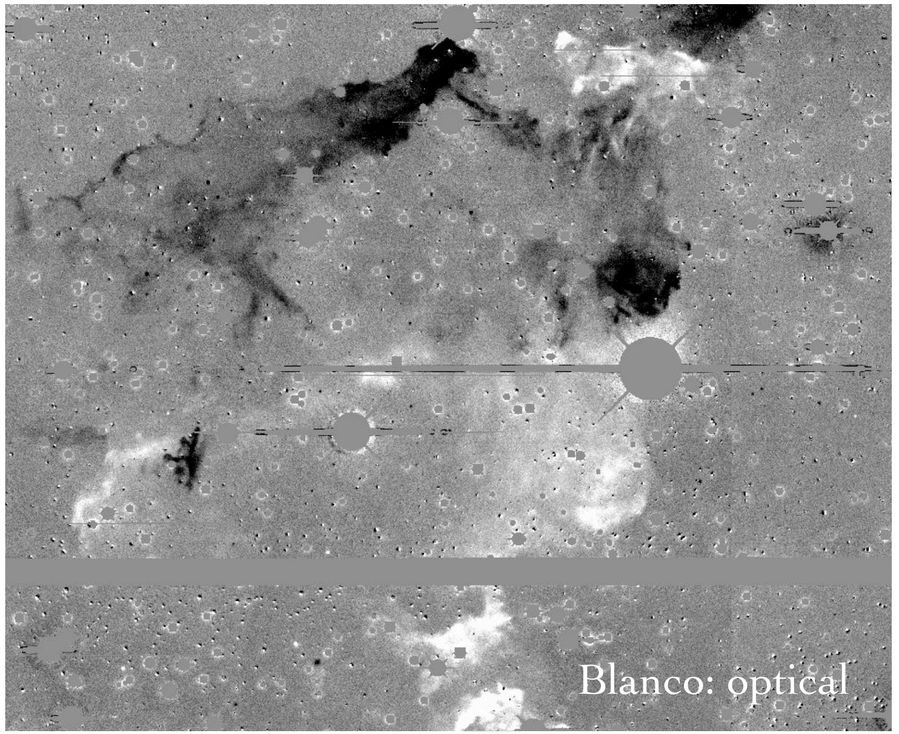


- ***3 observations in two filters within a night - SPHEREx color can be one of them!***
- ***maximum separation in different filters 30 minutes***
- ***optimal same-filter repeat ~4 hours***

Rubin LSST + SphereX

Light echoes





Light Echoes with LSST: discovering and studying unserved transients

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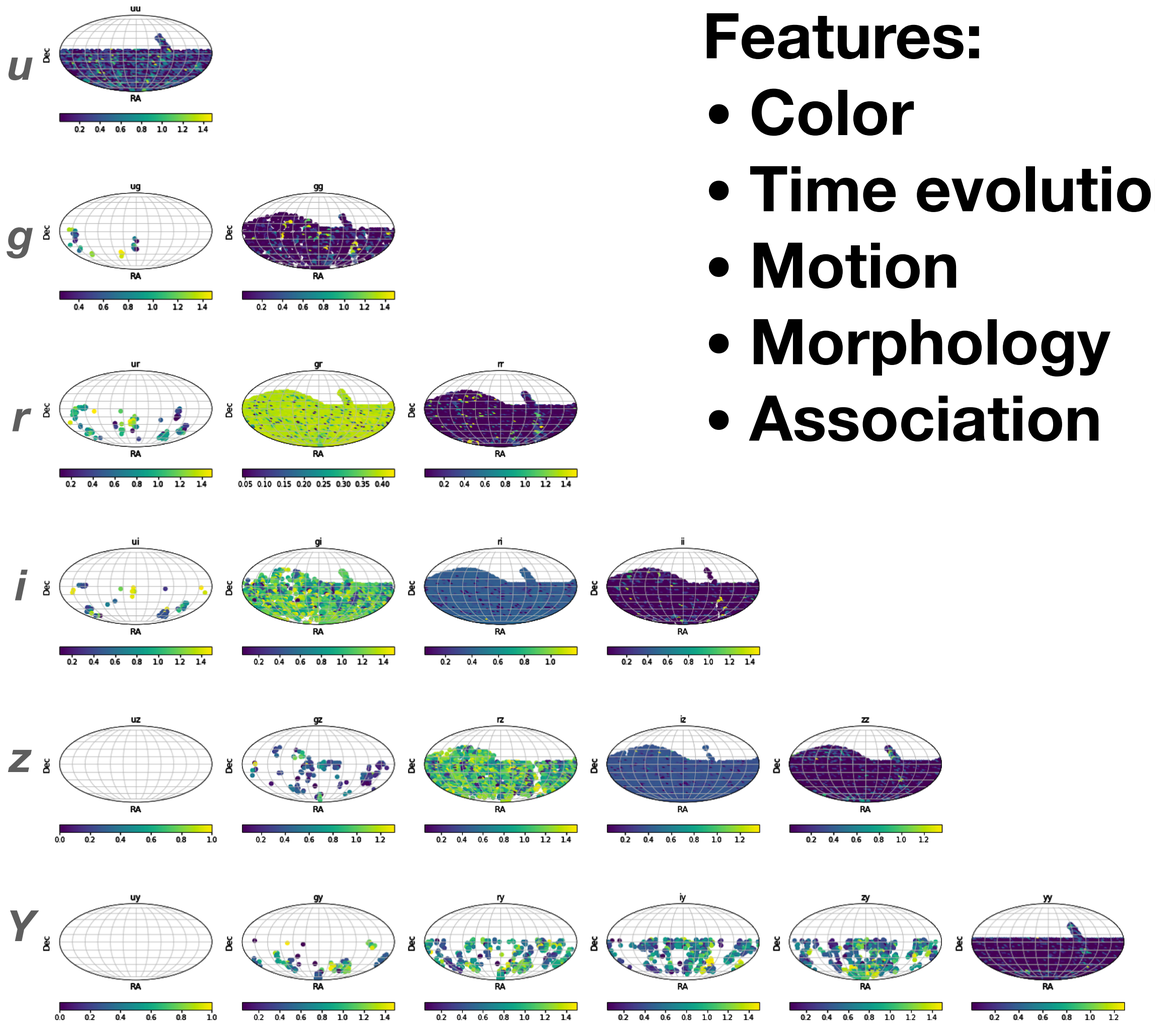
LSST Legacy Survey of Space and Time

Transients and MMA with the Rubin Observatory's LSST



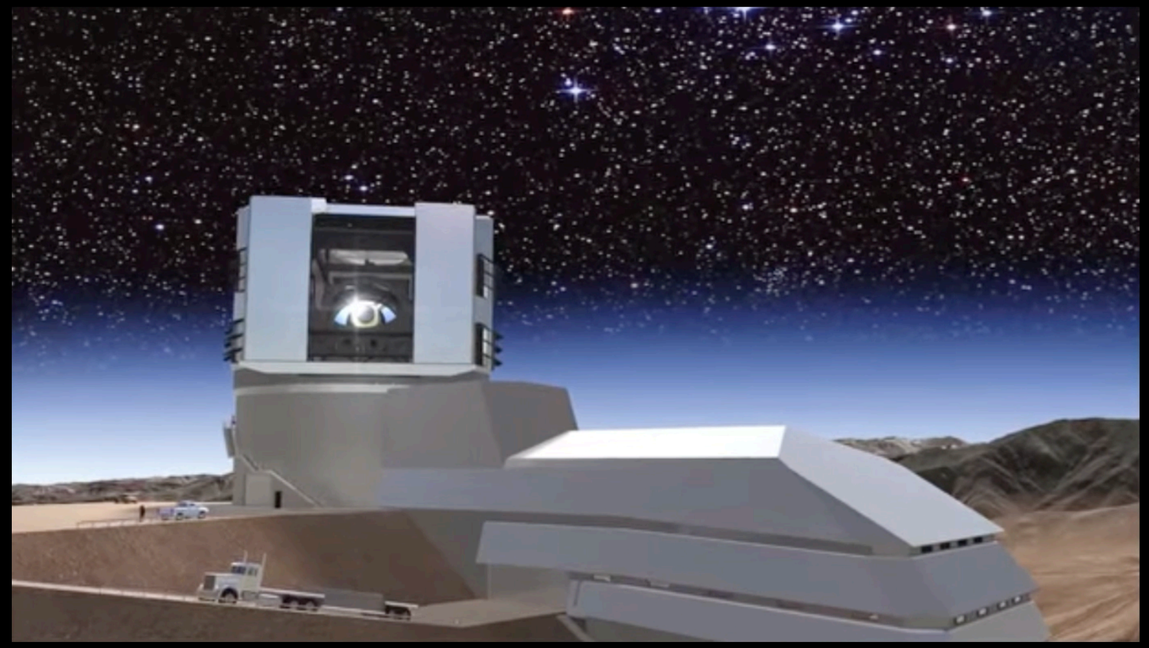
Features:

- **Color**
- **Time evolution**
- **Motion**
- **Morphology**
- **Association**

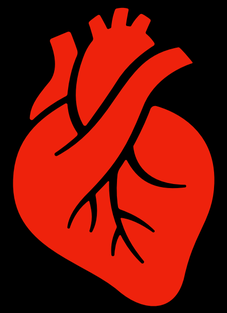
Unknown unknowns

Would LSST discover unknown unknowns?
Measure gaps in *feature* space hypercubes for different observing strategies

Xiaolong Li, University of Delaware
Fabio Ragosta, INAF



SPHEREx + LSST =



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