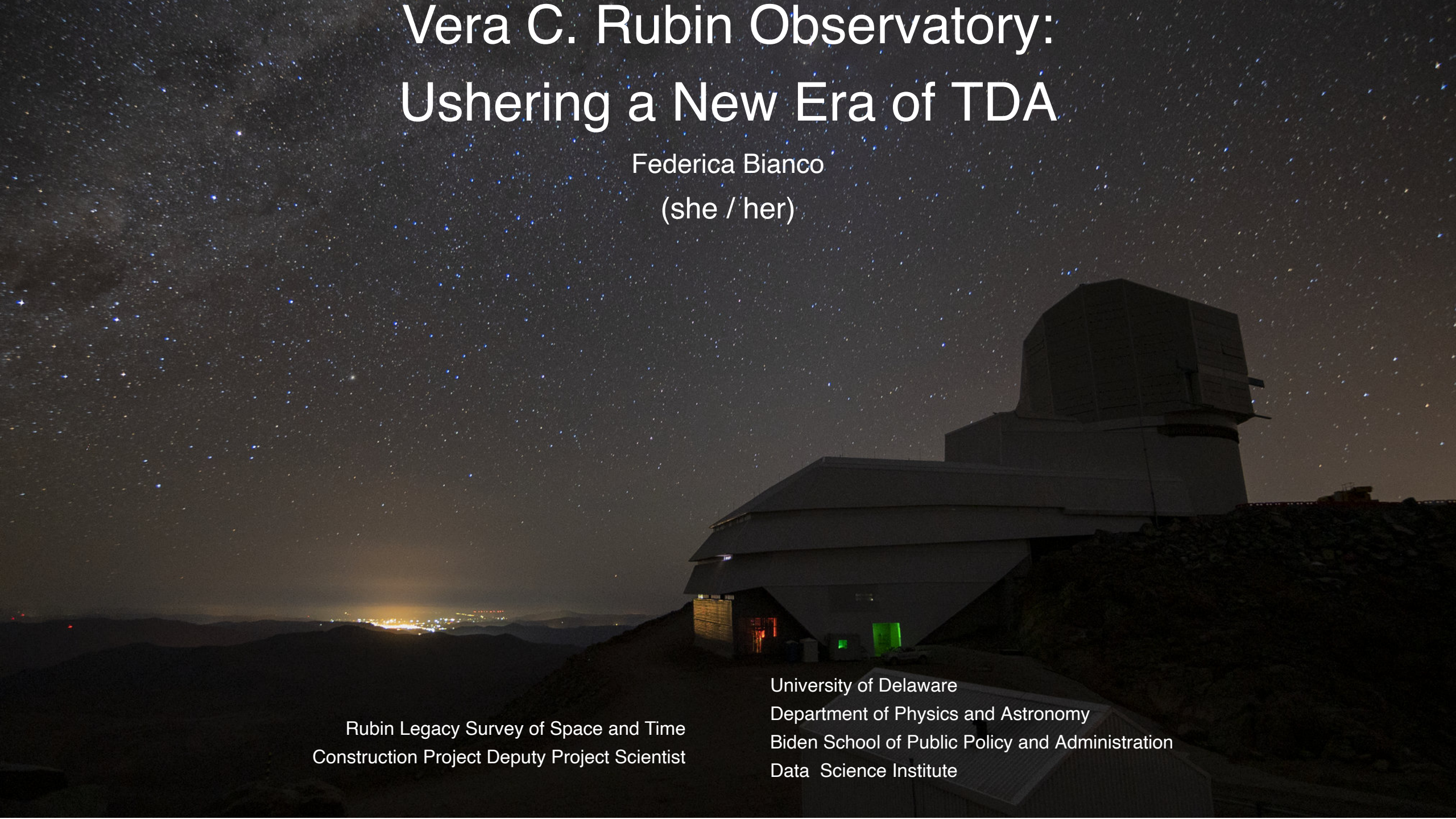
Vera C. Rubin Observatory: Ushering a New Era of TDA

Federica Bianco
(she / her)

Rubin Legacy Survey of Space and Time
Construction Project Deputy Project Scientist

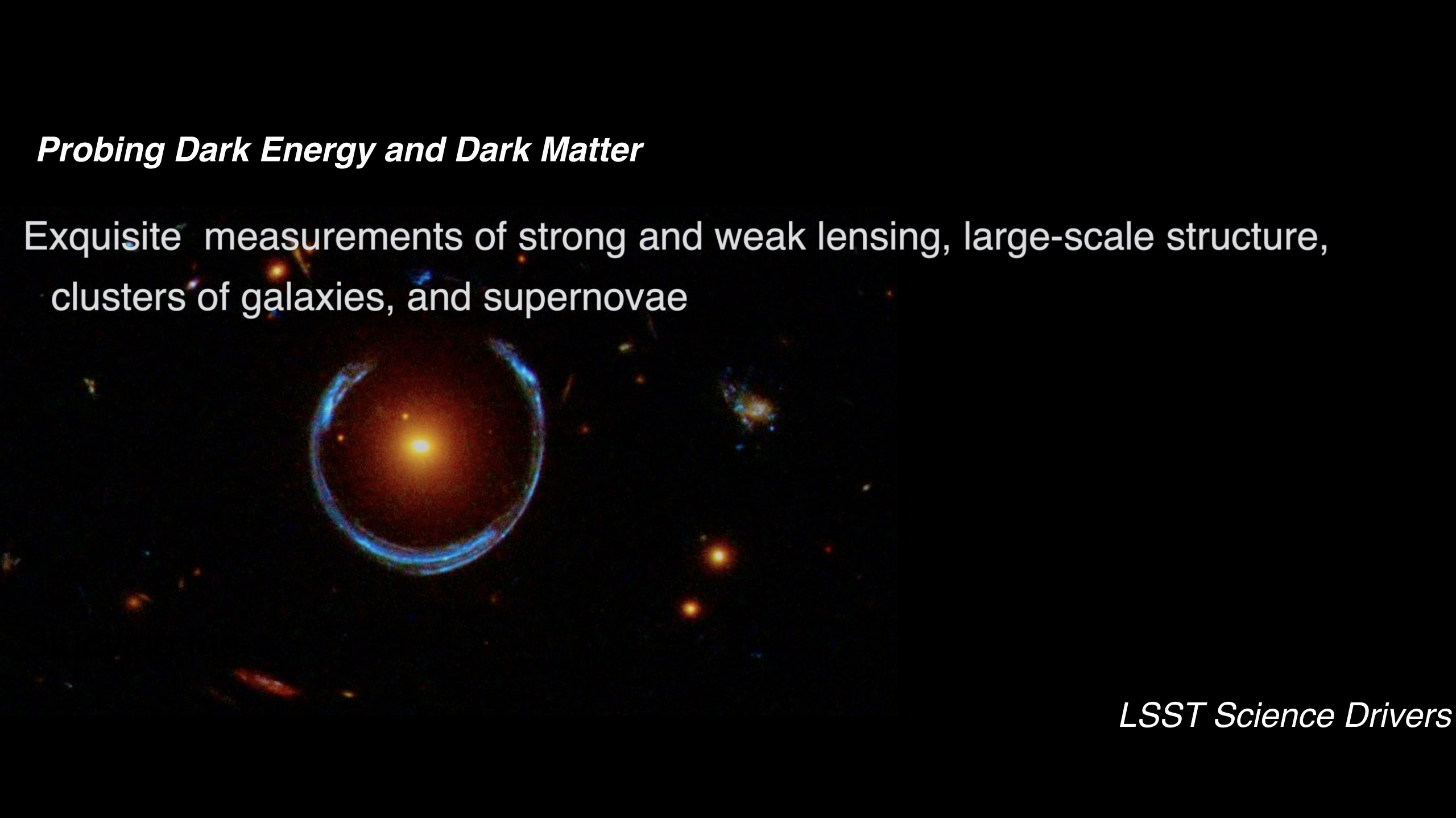
University of Delaware
Department of Physics and Astronomy
Biden School of Public Policy and Administration
Data Science Institute



The Vera C. Rubin and the Legacy Survey of Space and Time

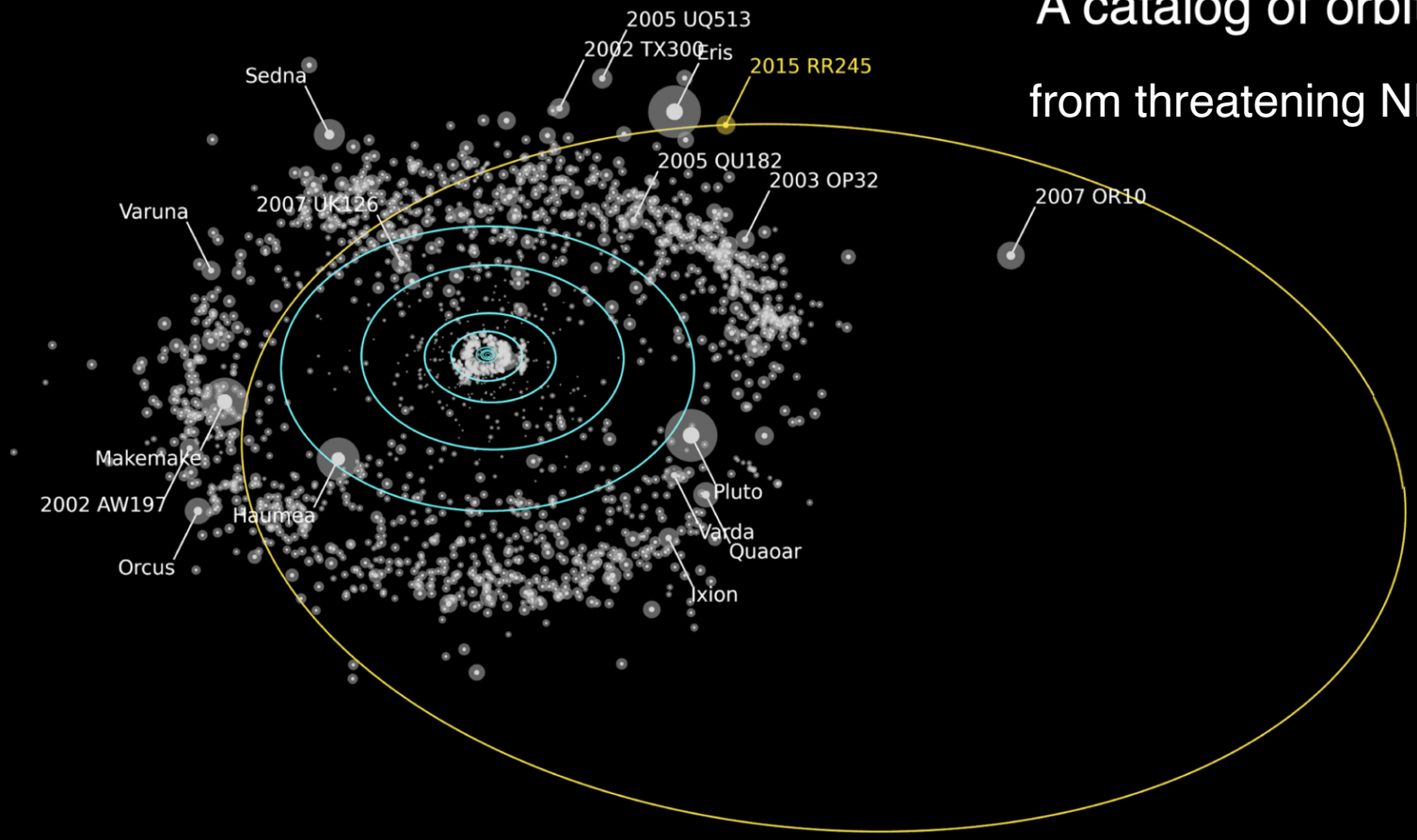
Probing Dark Energy and Dark Matter

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



LSST Science Drivers

Taking an inventory of the solar system



A catalog of orbits for 6 million bodies

from threatening NEO to the distant Oort Cloud

LSST Science Drivers

Mapping the Milky Way (and Local Volume)

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

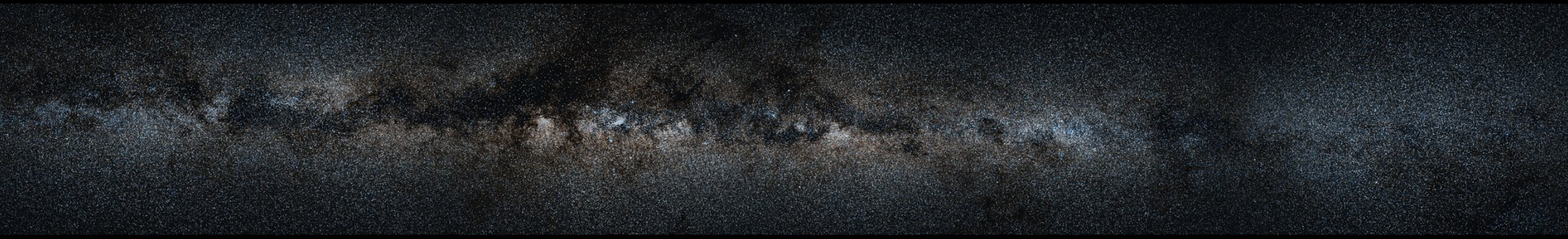
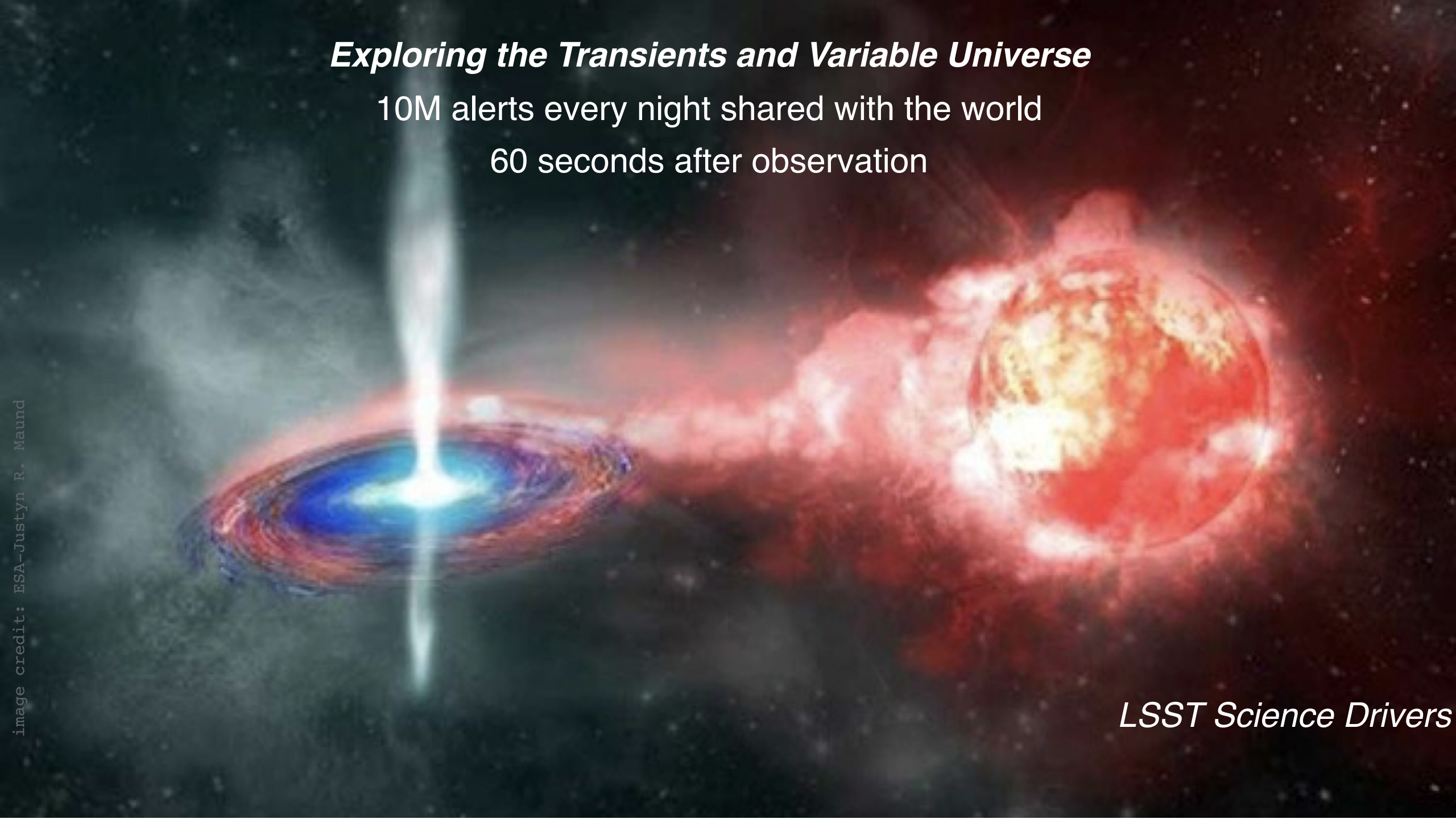


image credit ESO-Gaia

LSST Science Drivers



Exploring the Transients and Variable Universe

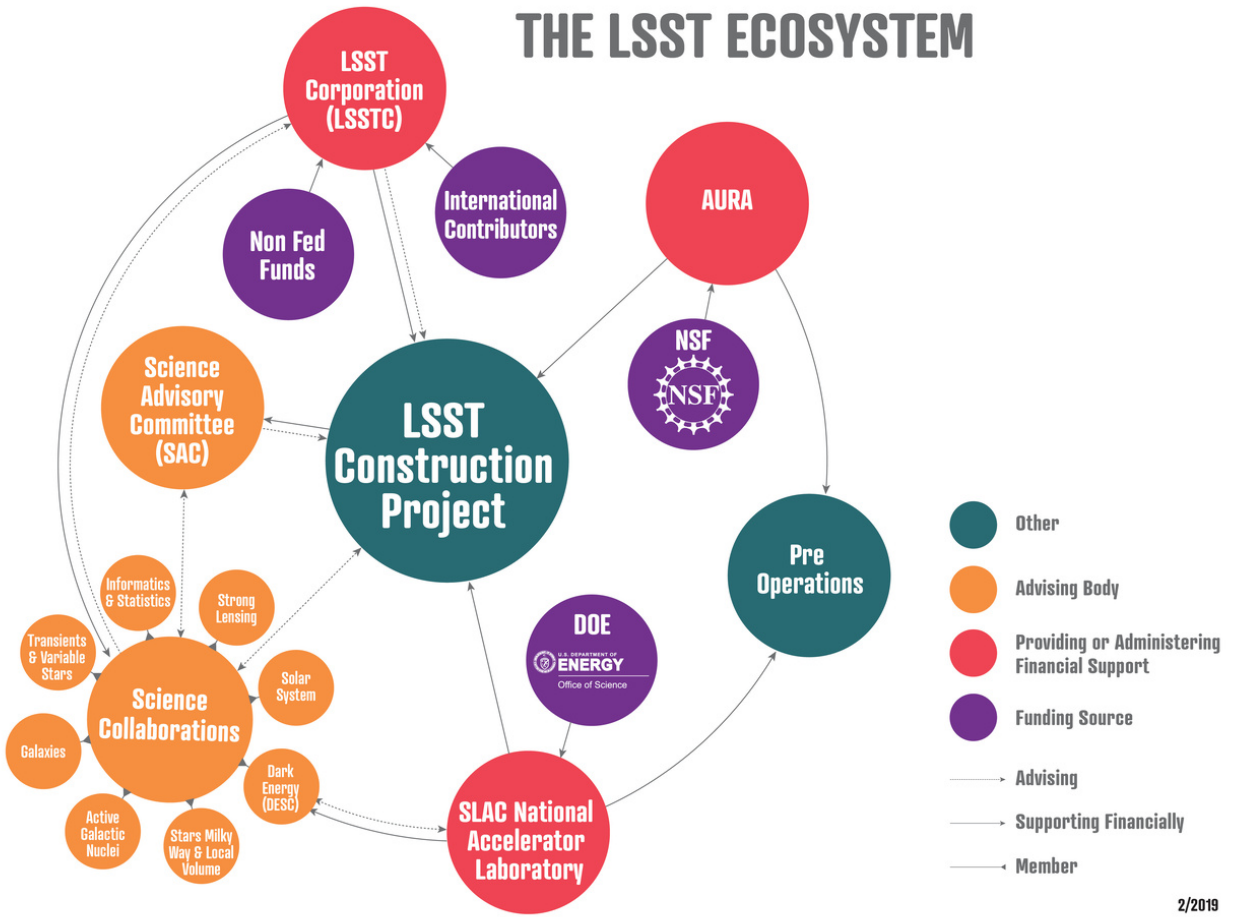
10M alerts every night shared with the world

60 seconds after observation

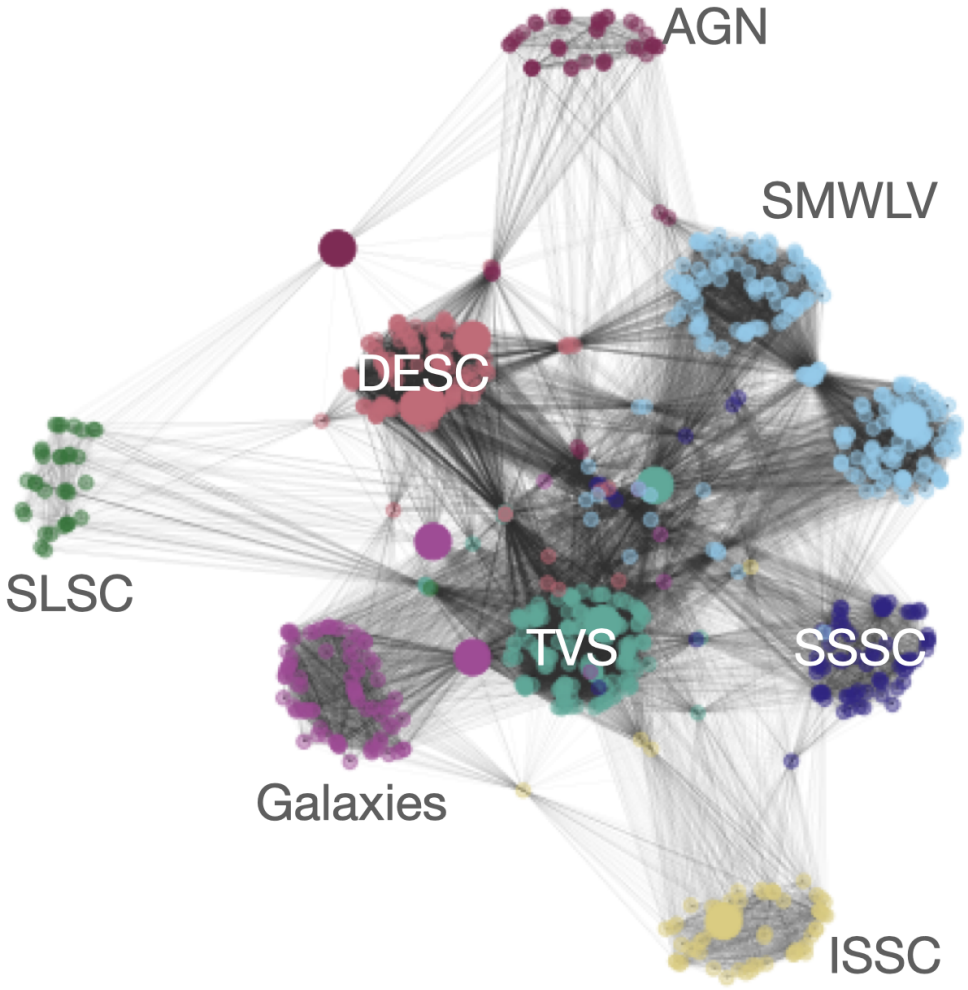
LSST Science Drivers

image credit: ESA–Justyn R. Maund

The Rubin Organization is almost as complex as the Universe it will explore!



Rubin LSST Science Collaborations



8 teams

>1500 members

>2000 affiliations

5 continents

federica bianco - fbianco@udel.edu

@fedhere

Rubin LSST Science Collaborations

Active Galactic Nuclei SC

Dark Energy SC

Informatics and Statistics SC

Galaxies SC

Strong Lensing SC

Stars Milky Way Local Volume SC

Solar System SC

Transients and Variable Stars SC

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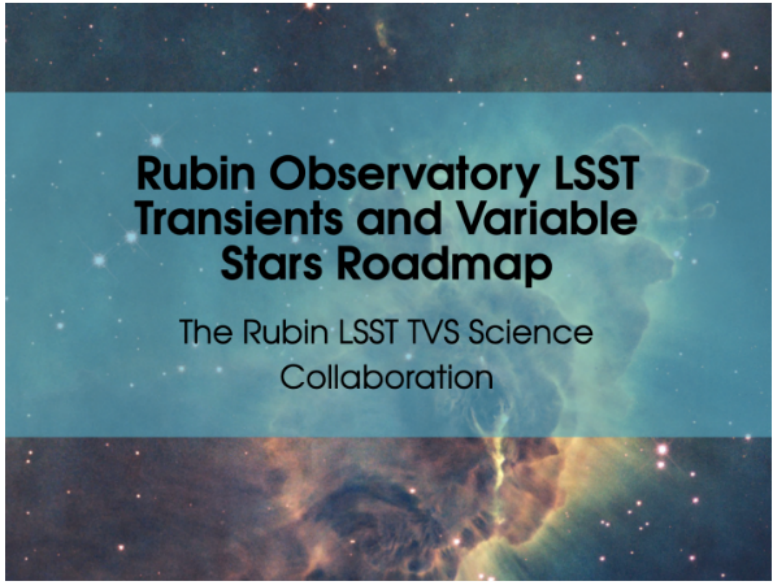
Rubin LSST Science Collaborations

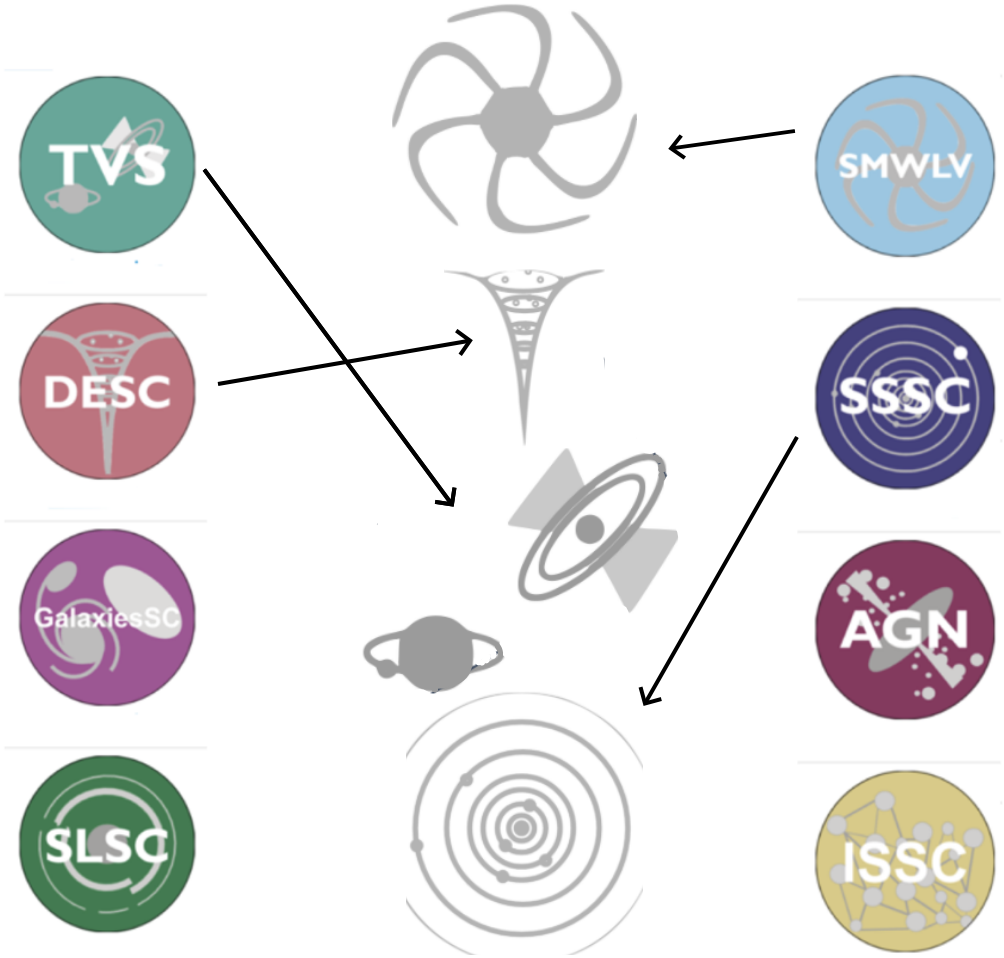
TVS ROADMAP TO SCIENCE

EXPLORE THE OUTLINE OF OUR ROADMAP BELOW AND DOWNLOAD THE FULL DOCUMENT

DOWNLOAD OUR ROADMAP



https://arxiv.org/abs/2208.04499 (to be published in PASP)



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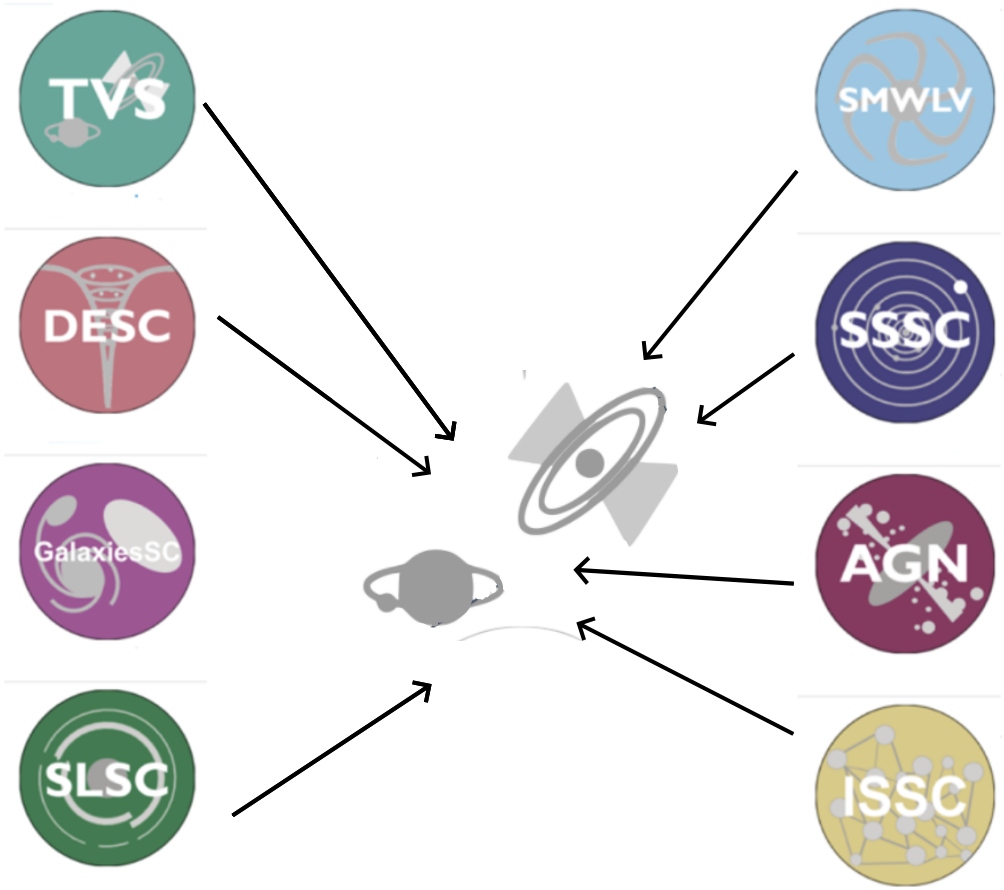
Rubin LSST Science Collaborations



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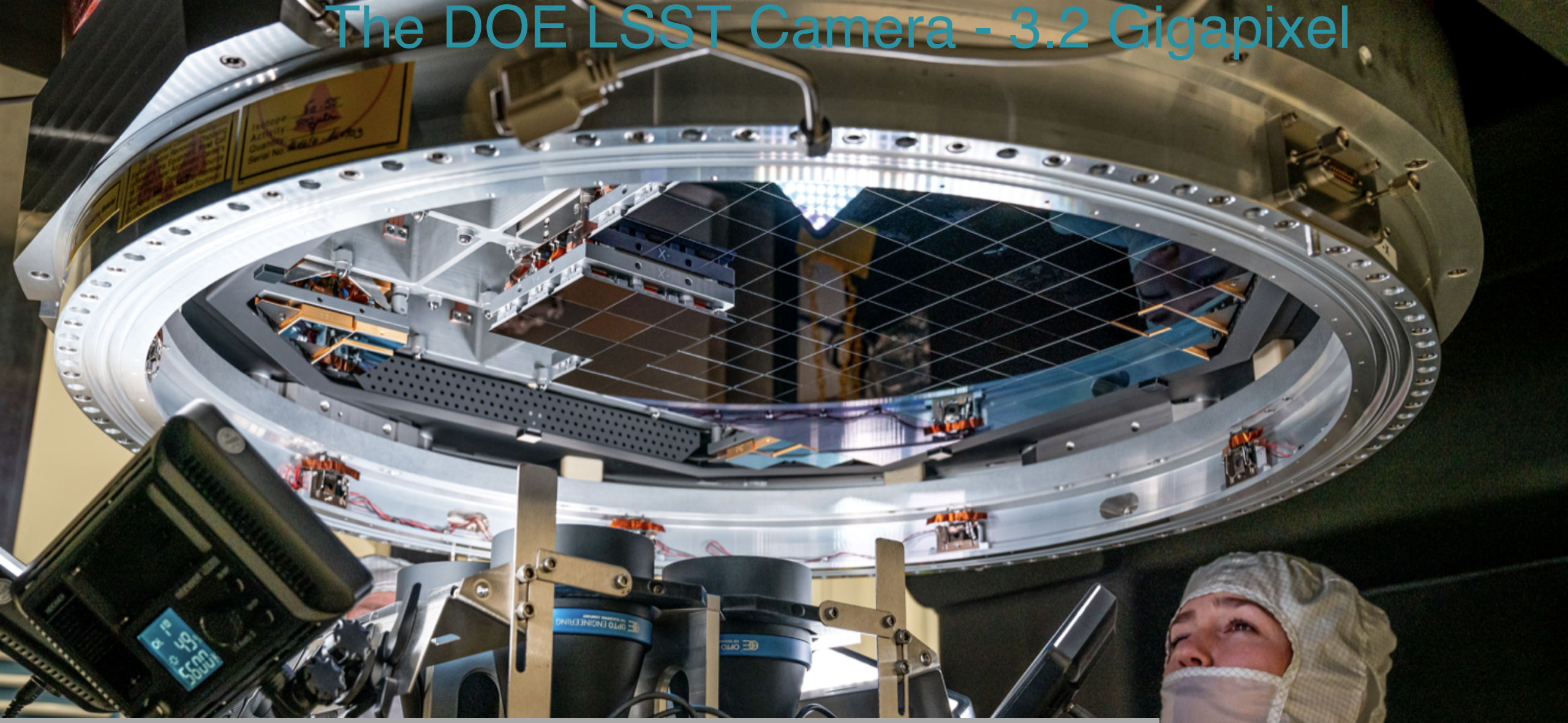
Vera C. Rubin Observatory

May 2022 - Telescope Mount Assembly

The DOE LSST Camera - 3.2 Gigapixel

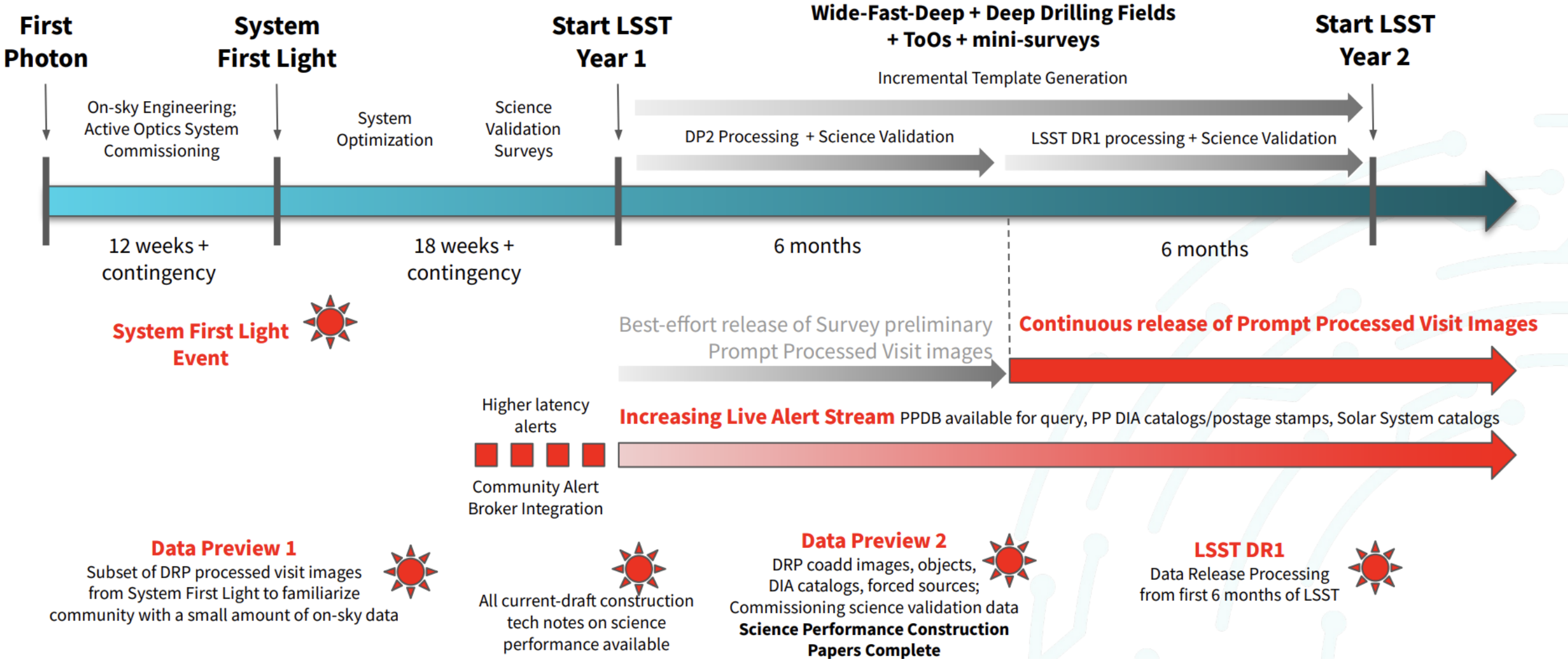


Camera and Cryostat integration completed at SLAC in May 2022,

Shutter and filter auto-changer integrated into camera body

Pre-Ship Review ongoing at SLAC

Early Science Timeline Overview



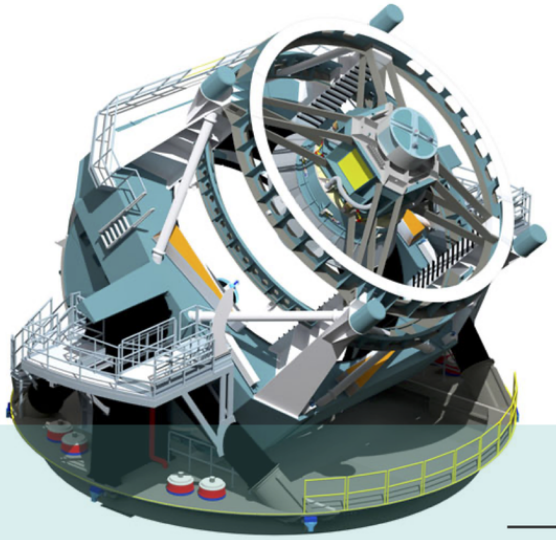
ls.st/dates First Photon forecasted for July 2024 (+ contingency)

LSST time domain data products

Data Products

Raw Data: 20TB/night

Sequential 30s images covering the entire visible sky every few days

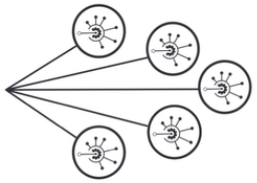


LSST SCIENCE PIPELINES

Prompt Data Products

Alerts: up to 10 million per night

60s via nightly alert streams



Community Brokers

Raw & Processed Visit Images, Difference Images, Templates

Transient and variable sources from Difference Image Analysis

Solar System Objects: ~ 6 million

24h via Prompt Products DB

Data Release Data Products

Final 10yr Data Release:

- Images: 5.5 million x 3.2 Gpixels
- Catalog: 15PB, 37 billion objects

via Data Releases

Rubin Data Access Centres (DACs)

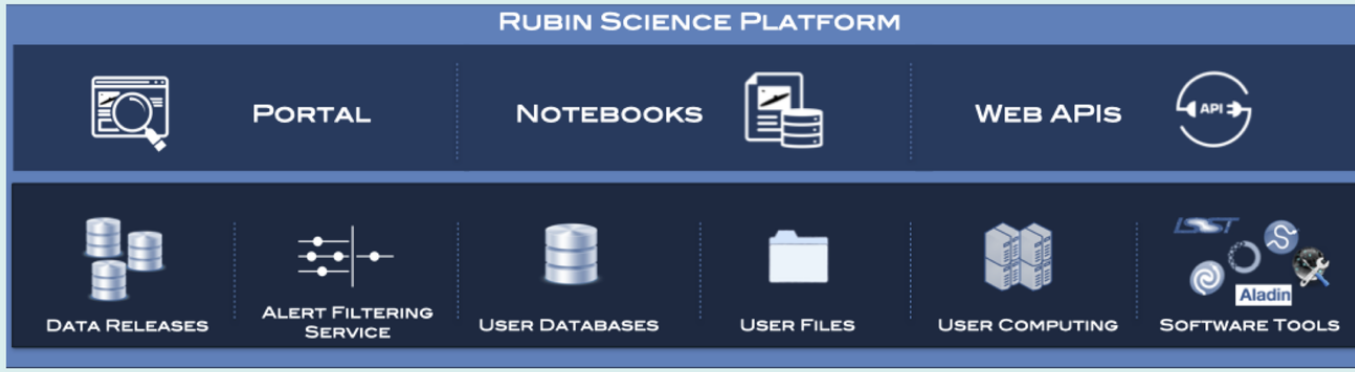
USA (USDF)
Chile (CLDF)
France (FRDF)
Uniter Kingdom (UKDF)

Independent Data Access Centers (IDACs)

Access to proprietary data and the Science Platform require Rubin data rights

LSST Science Platform

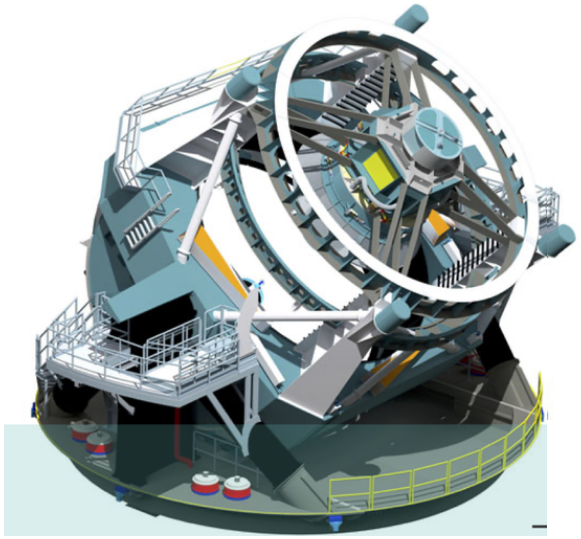
Provides access to LSST Data Products and services for all science users and project staff



Credit: Leanne Guy

Raw Data: 20TB/night

Sequential 30s images covering the entire visible sky every few days



Prompt Data Products

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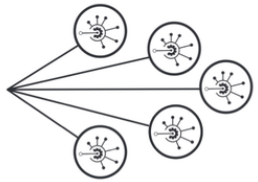
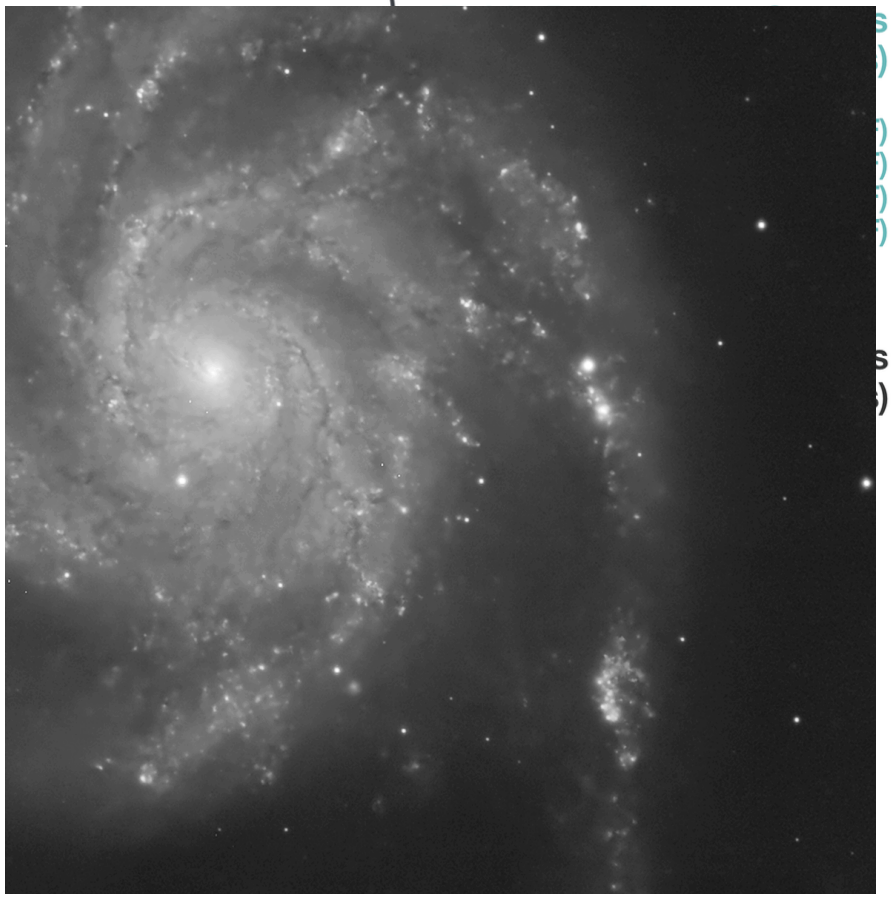
← world public!

60s via nightly alert streams



Community Brokers



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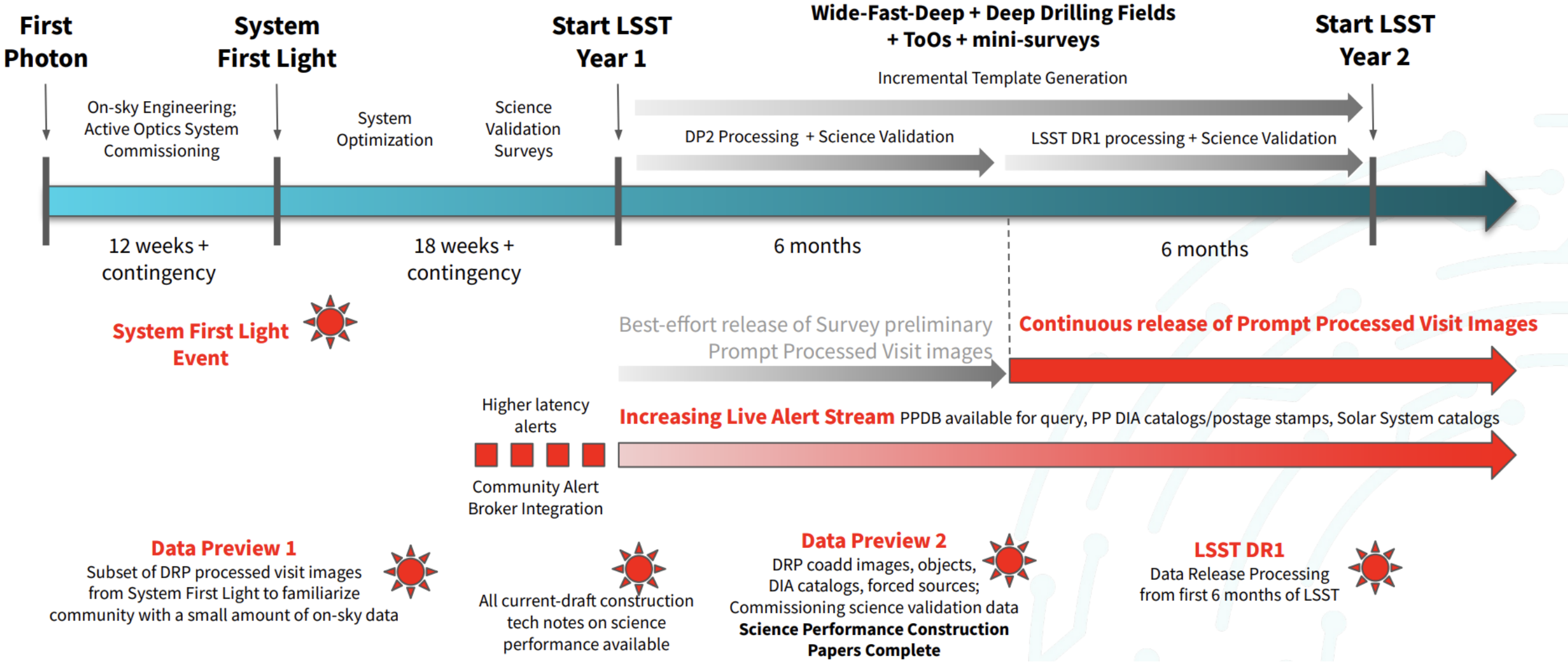
Early Science Timeline Overview



ls.st/dates First Photon forecasted for July 2024

LSST Data Volume:

from novelty to statistical samples

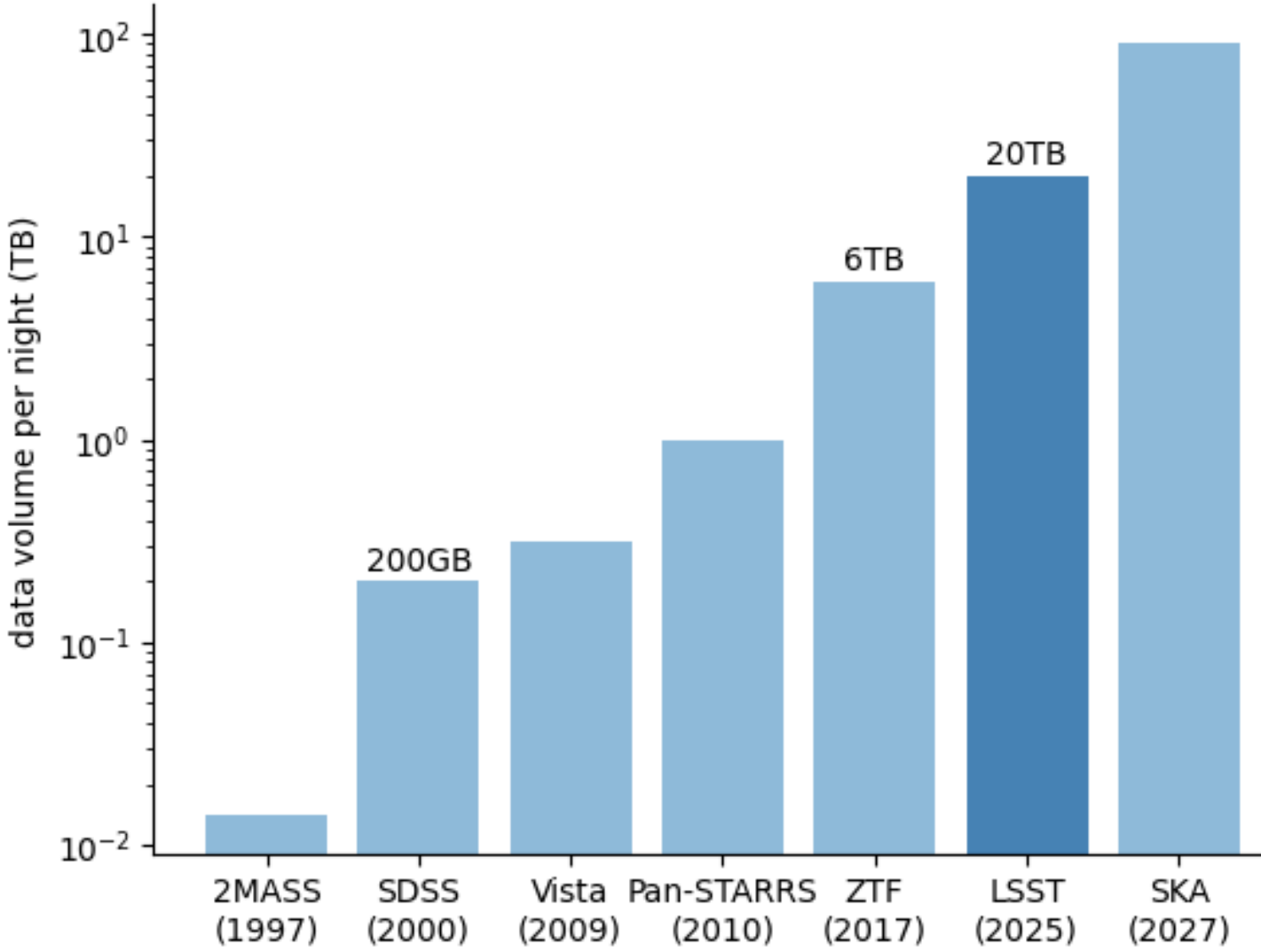
from unknown to discovered

Rubin Transients by the numbers

~1000 images per night

10M alerts per night (5sigma changes)

17B stars 30B galaxies Ivezic+19



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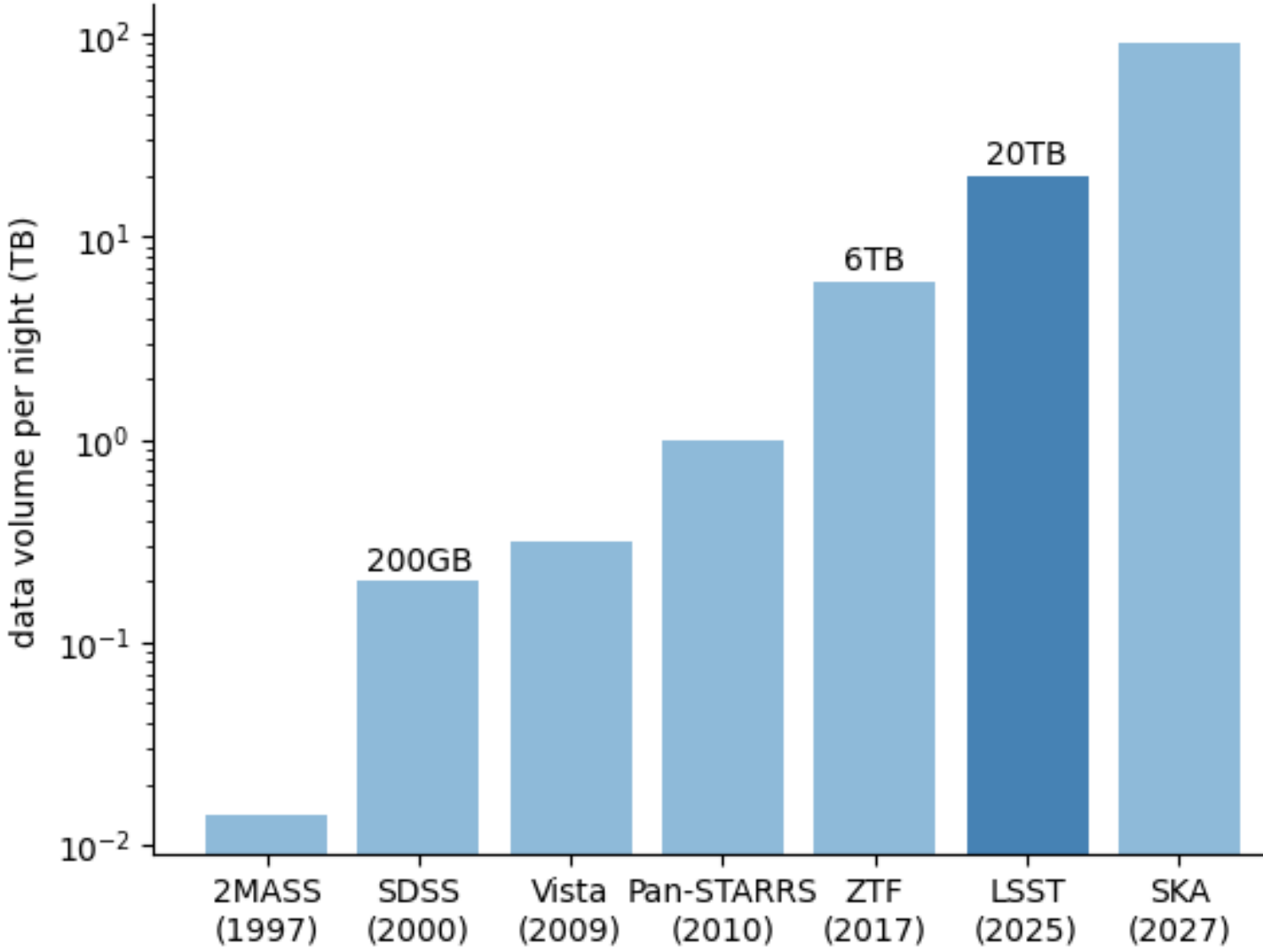
17B stars 30B galaxies Ivezic+19

~200 quadruply-lensed quasars Minghao+19

~50 kilonovae Setzer+19, Andreoni+19 (+ ToO)

>10 interstellar objects



Rubin Transients by the numbers

New stress on the infrastructure

~1000 images per night

10M alerts per night (5sigma changes)

17B stars 30B galaxies Ivezic+19

~200 quadruply-lensed quasars Minghao+19

~50 kilonovae Setzer+19, Andreoni+19 (+ ToO)

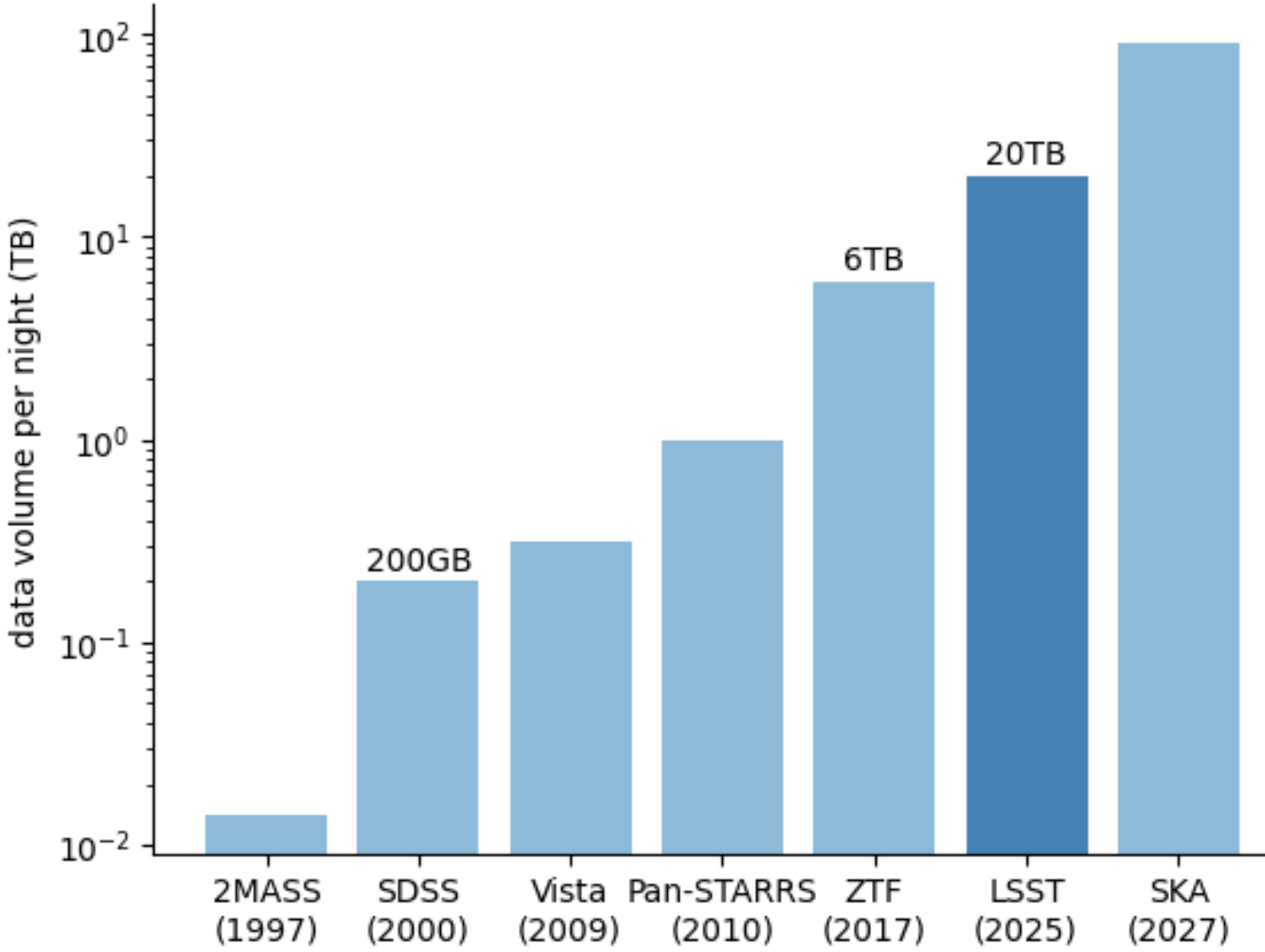
>10 interstellar objects

~10k SuperLuminous Supernovae Villar+ 2018

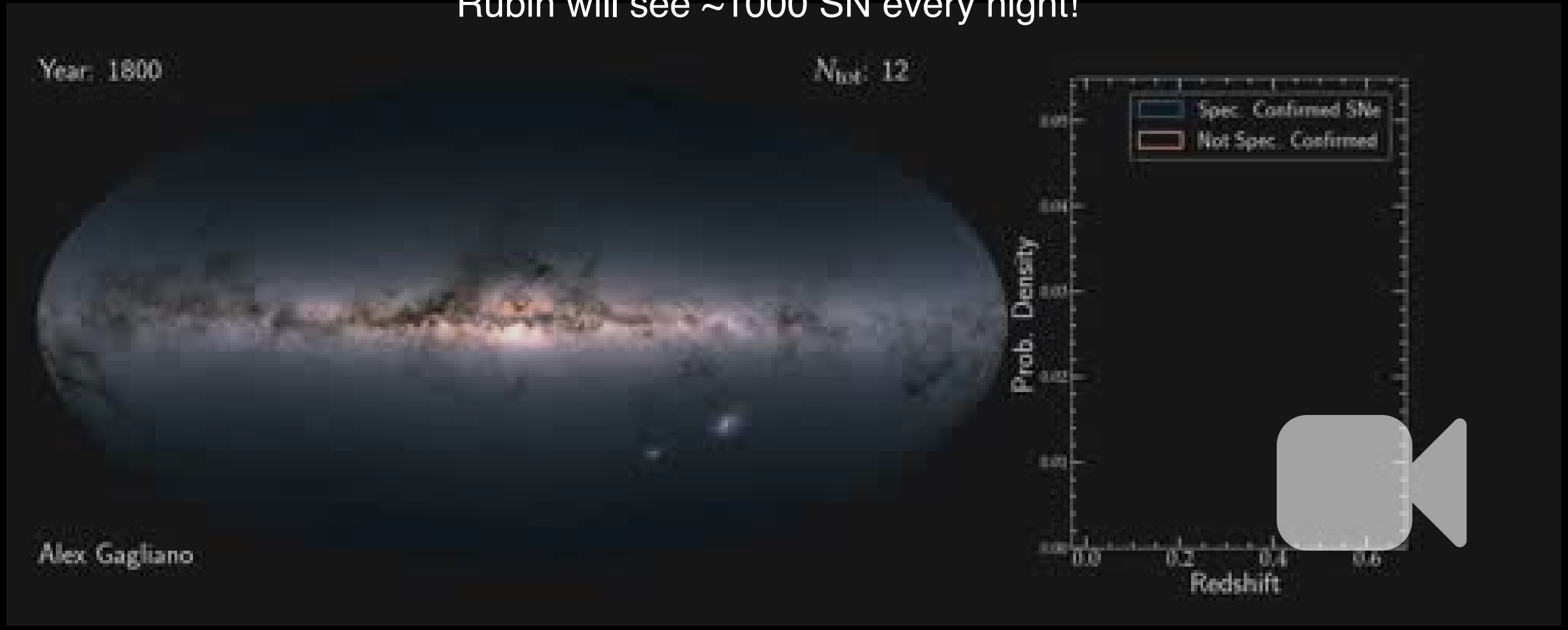
~ 50k Tidal Disruption Events Brickman+ 2020

~10 million QSO Mary Loli+21

~1000 SNe every night in the LSST sky



Rubin will see ~1000 SN every night!



Credit: Alex Gagliano University of Illinois,
IAIFI fellow 2023

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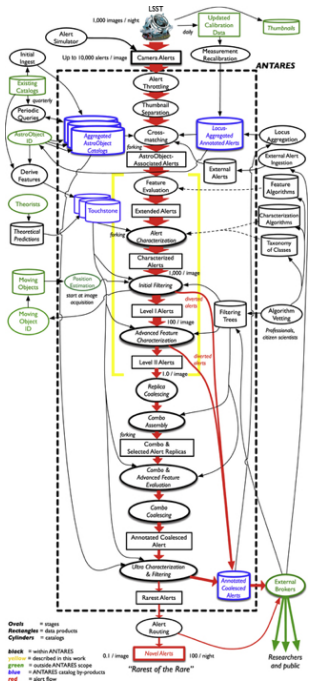
LSST has profoundly changed the TDA infrastructure

the astronomy discovery chain

Discovery Engine

10M alerts/night



ALeRCE

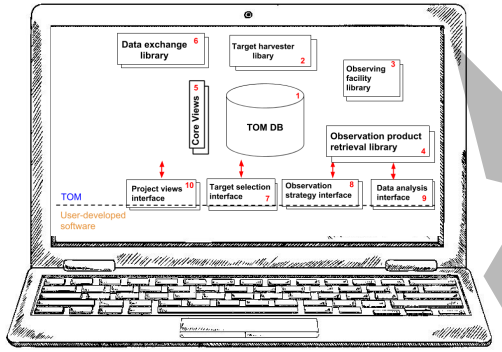
ANTARES beta

Lasair

FINK

Pitt-Google Broker

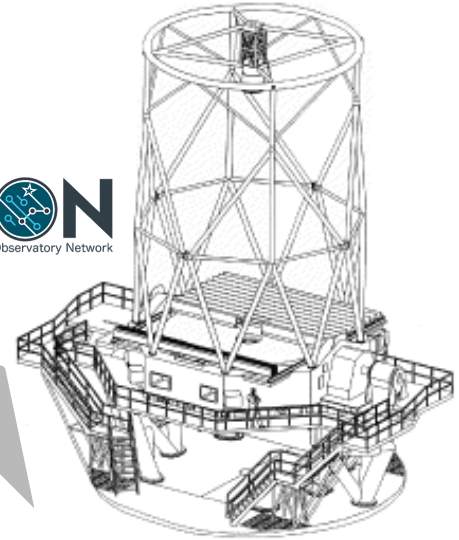
BABAMUL

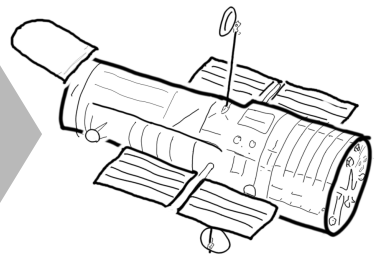


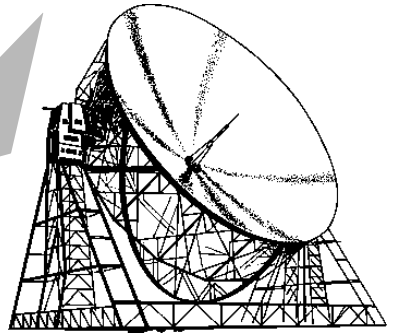
target observation managers

TOM TOOLKIT

AEON
Astronomical Event Observatory Network







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Photometric Classification

Featured Prediction Competition

PLAsTiCC Astronomical Classification

Can you help make sense of the Universe?

$25,000
Prize Money

LSST Project · 1,094 teams · 2 years ago

Overview | Data | Notebooks | Discussion | Leaderboard | Rules | Join Competition

Overview

- Description
- Evaluation
- Prizes
- Timeline
- PLAsTiCC's Team

Help some of the world's leading astronomers grasp the deepest properties of the universe.

The human eye has been the arbiter for the classification of astronomical sources in the night sky for hundreds of years. But a new facility -- the Large Synoptic Survey Telescope (LSST) -- is about to revolutionize the field, discovering 10 to 100 times more astronomical sources that vary in the night sky than we've ever known. Some of these sources will be completely unprecedented!

LSST DESC
Dark Energy Science Collaboration

Dark Energy Science Collaboration (DESC)

+

Transients and Variable Star Science Collaboration (TVS SC)

TVSSC

LSST: Science Collaborations

LSST CORPORATION

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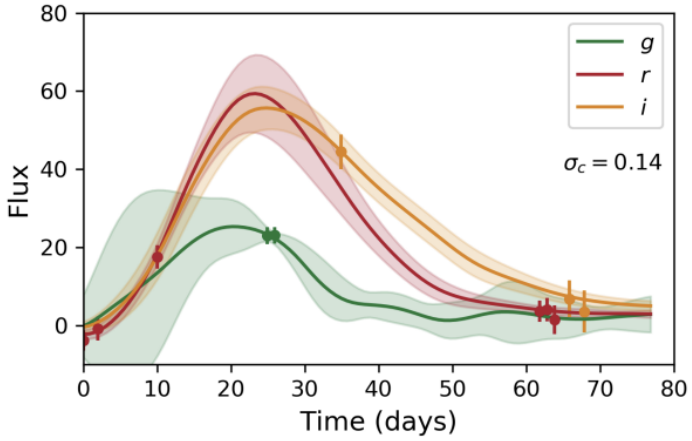
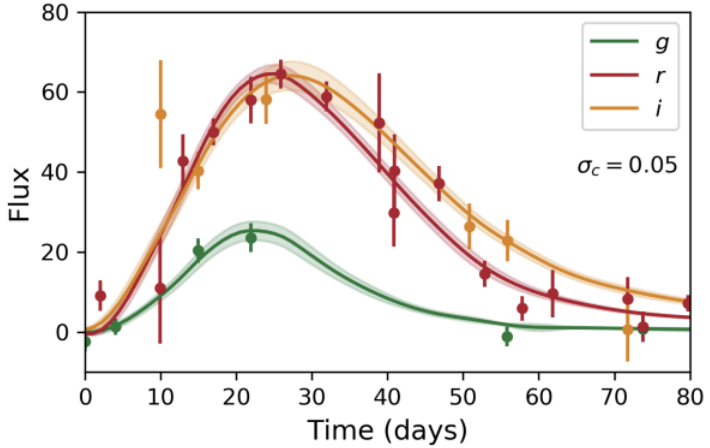
Wide Fast Deep



Deep Drilling Fields Data



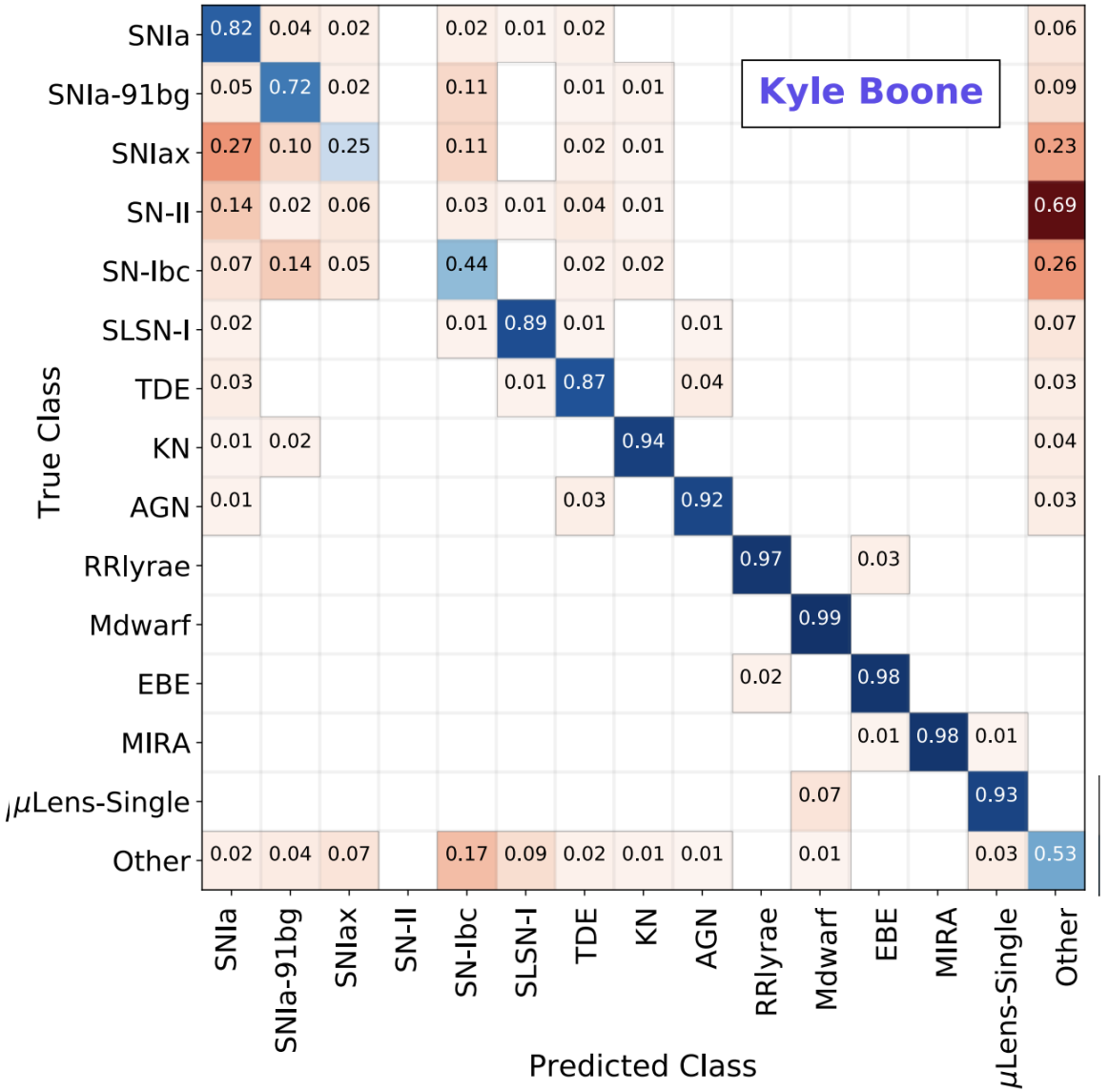
Lochner et al 2018

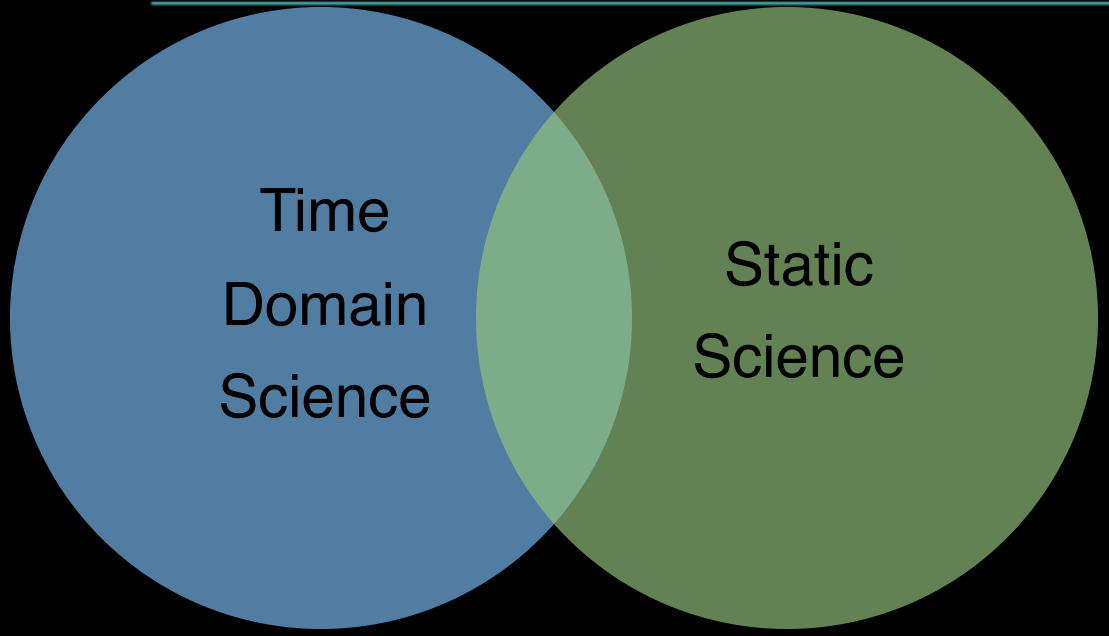
https://arxiv.org/pdf/1812.00515.pdf

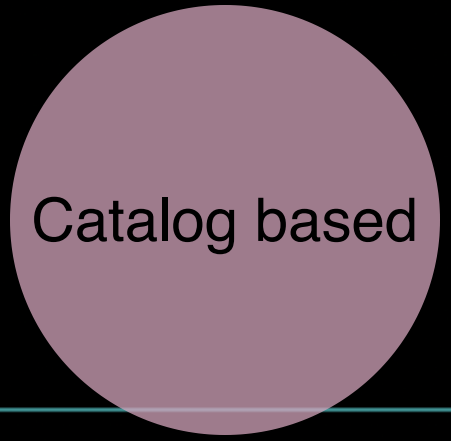
Kaggle PLAsTiCC challenge

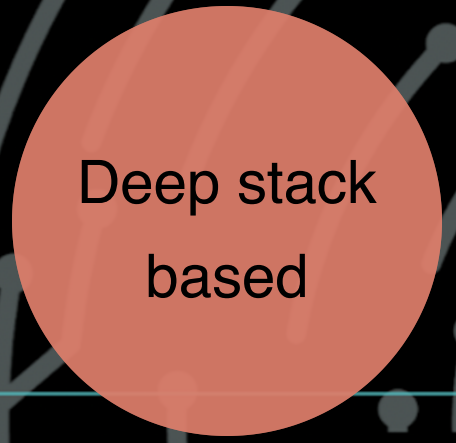
AVOCADO classifier

https://arxiv.org/abs/1907.04690









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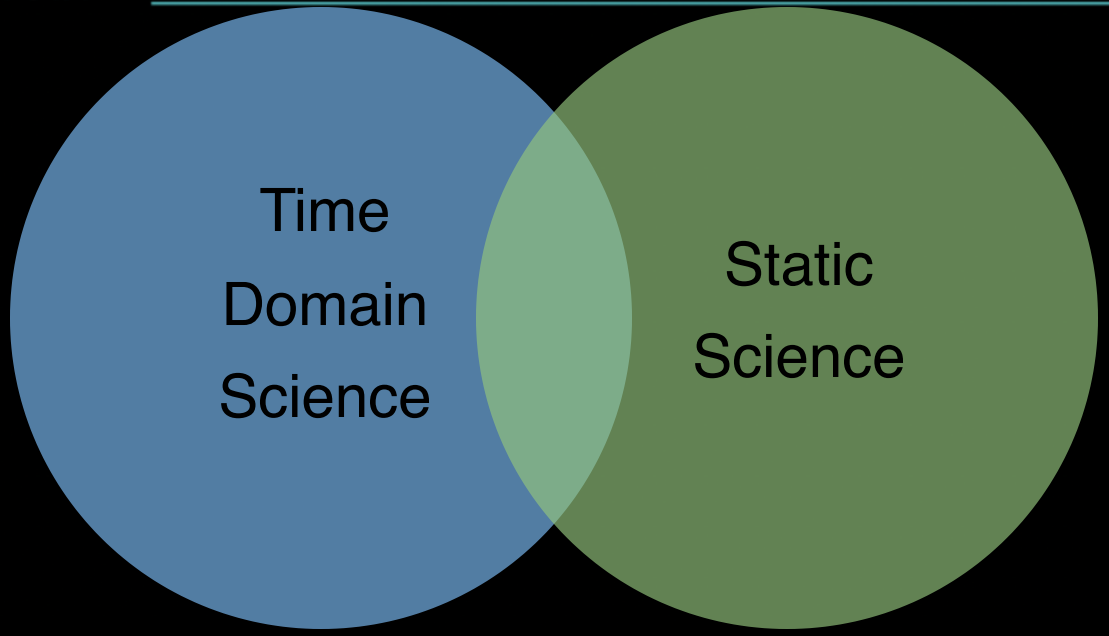

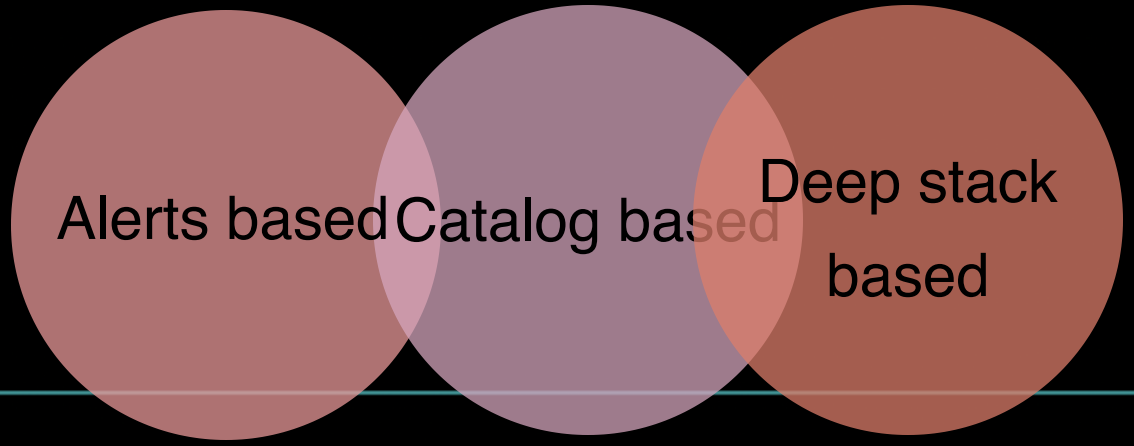

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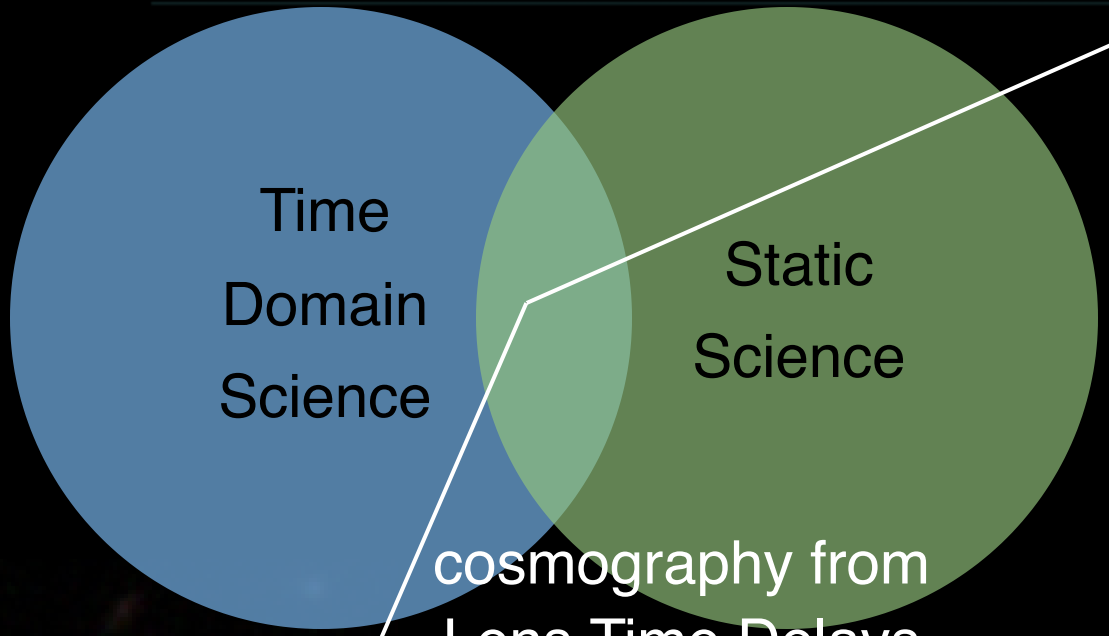


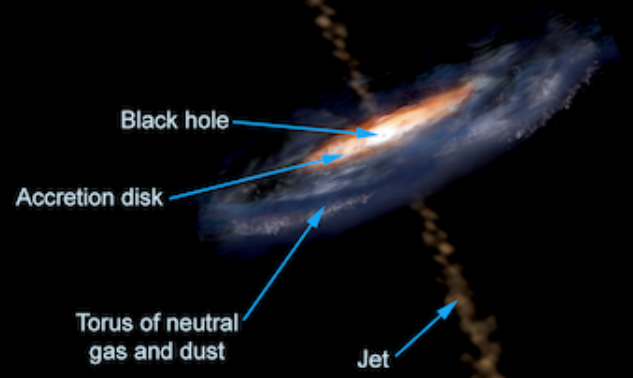
cosmography from
Lens Time Delays

resolved high z
galaxy properties

calibration of cluster
mass function with
with S+W Lensing

STRONG
LENSING

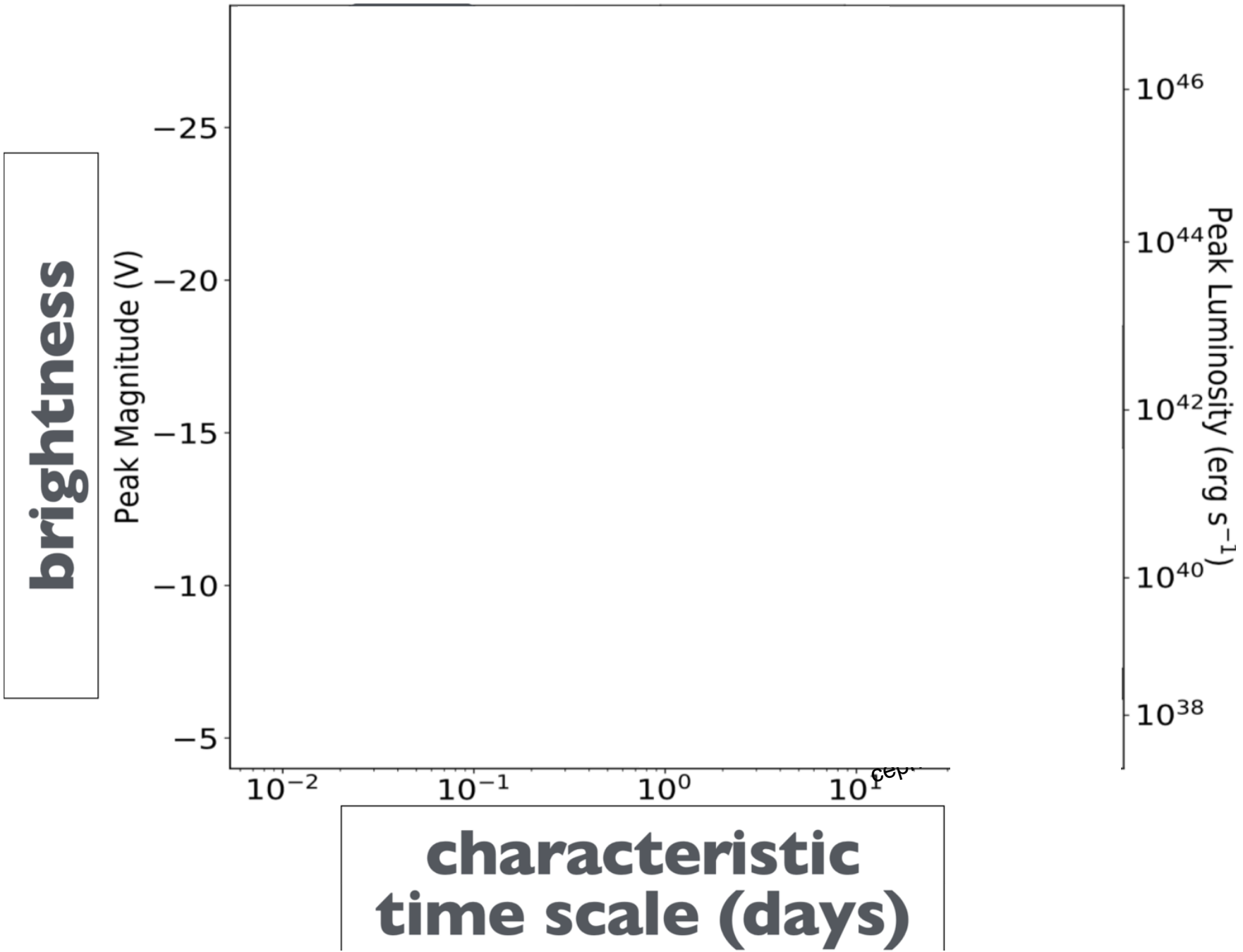
AGN



50M+ AGNs to z~7.5

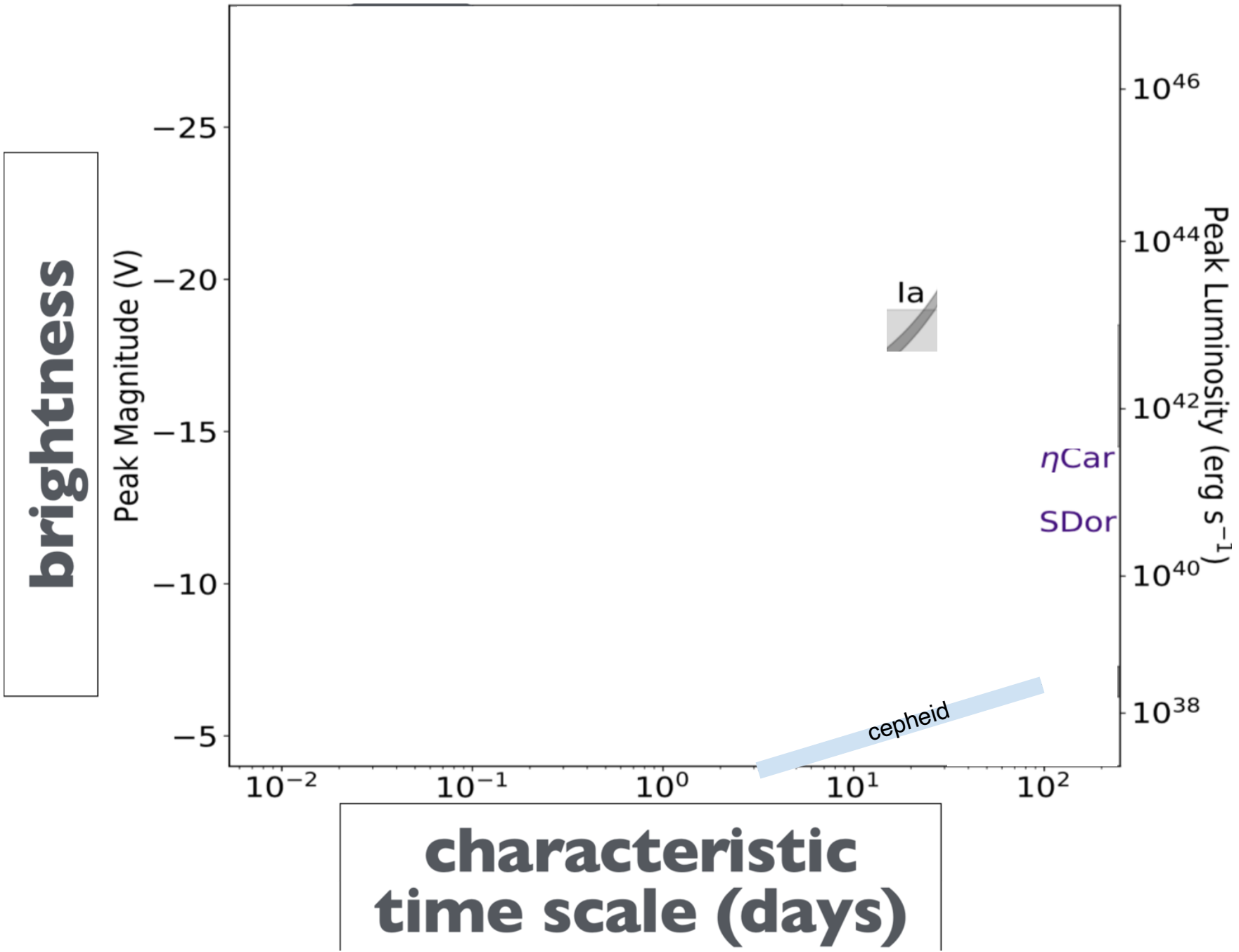
variability,
microlensing,
binaries

What time scales can LSST address

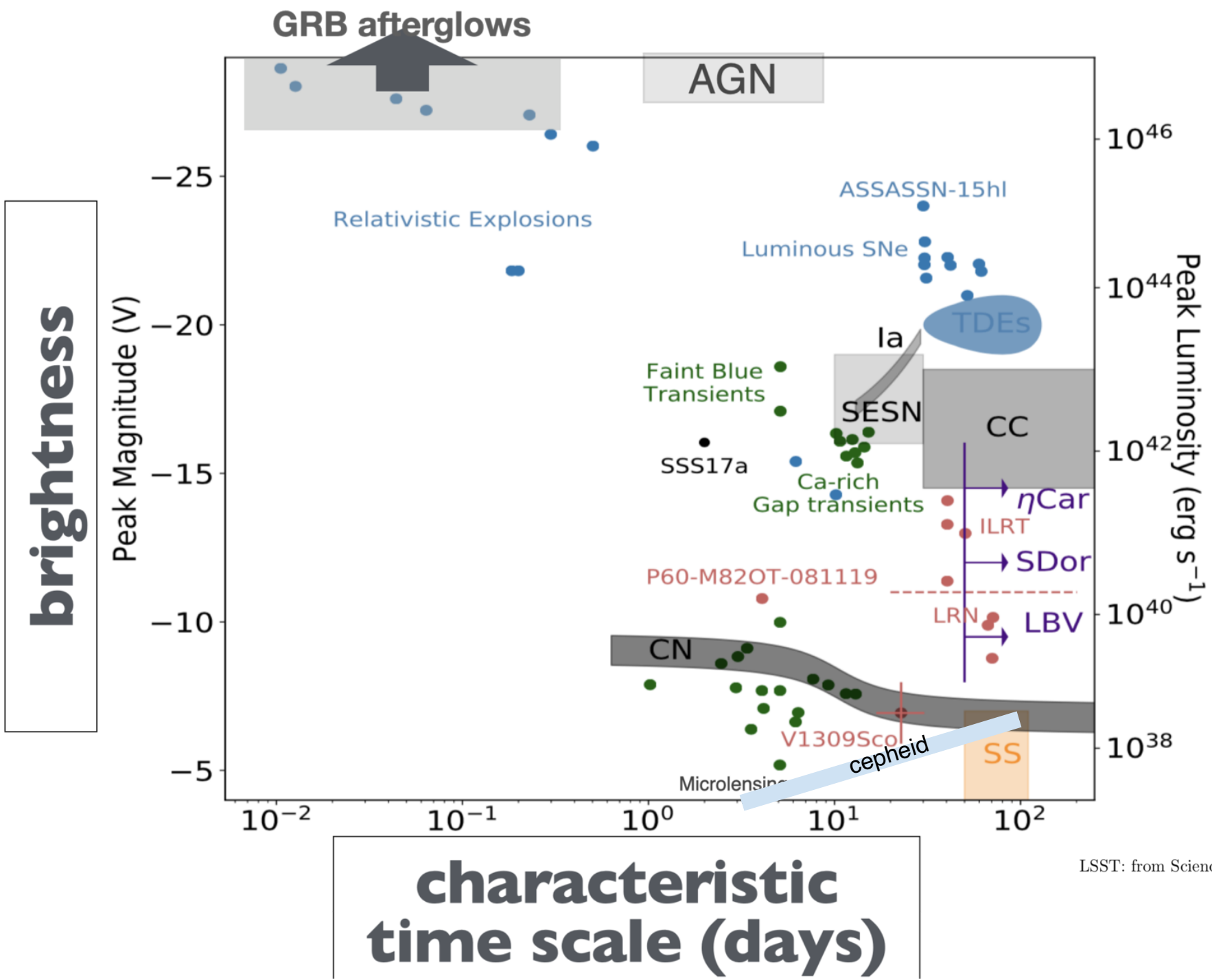


most of human history

a never changing sky

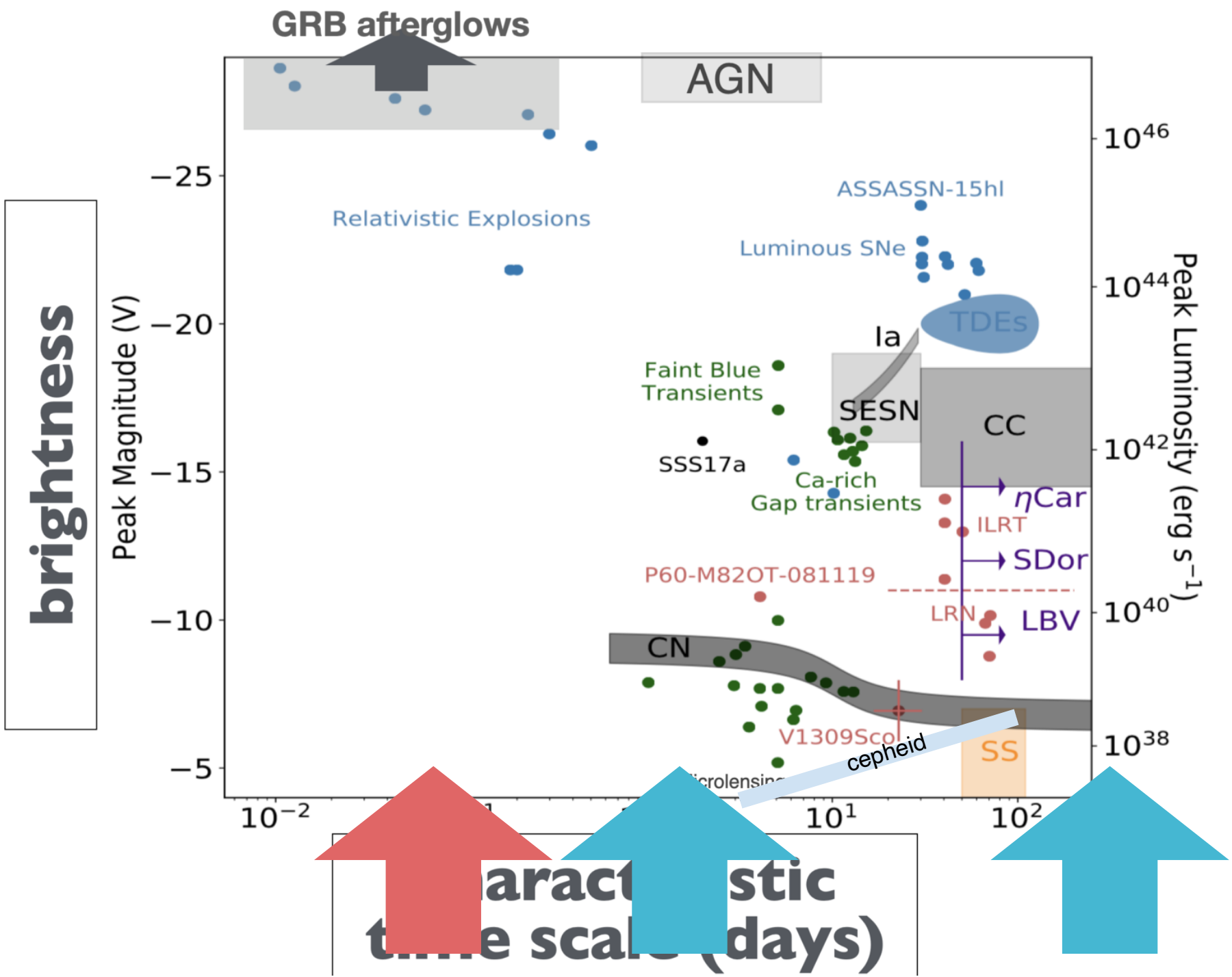

brightness
Peak Magnitude (V)
−25
−20
−15
−10
−5
Peak Luminosity (erg s^{-1})
10^{46}
10^{44}
10^{42}
10^{40}
10^{38}
Ia
ηCar
SDor
cepheid
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
characteristic time scale (days)

circa 1900



LSST: from Science Drivers to Reference Design and Anticipated Data Products

Ivezić et al 2019


GRB afterglows
AGN
Relativistic Explosions
ASSASSN-15hl
Luminous SNe
TDEs
Ia
Faint Blue Transients
SESN
CC
SSS17a
Ca-rich Gap transients
ηCar
ILRT
SDor
P60-M82OT-081119
LRN
LBV
CN
V1309Sco
SS
cepheid
Peak Magnitude (V)
Peak Luminosity (erg s^{-1})
−25
−20
−15
−10
−5
10^{46}
10^{44}
10^{42}
10^{40}
10^{38}
10^{-2}
10^{1}
10^{2}
brightness
aract stic
e scal (days)

Science-Driven Optimization of the LSST Observing Strategy

Prepared by the LSST Science Collaborations, with support from the LSST Project.

Marshall et al 2017

5 Variable Objects

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6 Eruptive and Explosive Transients

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7 The Magellanic Clouds

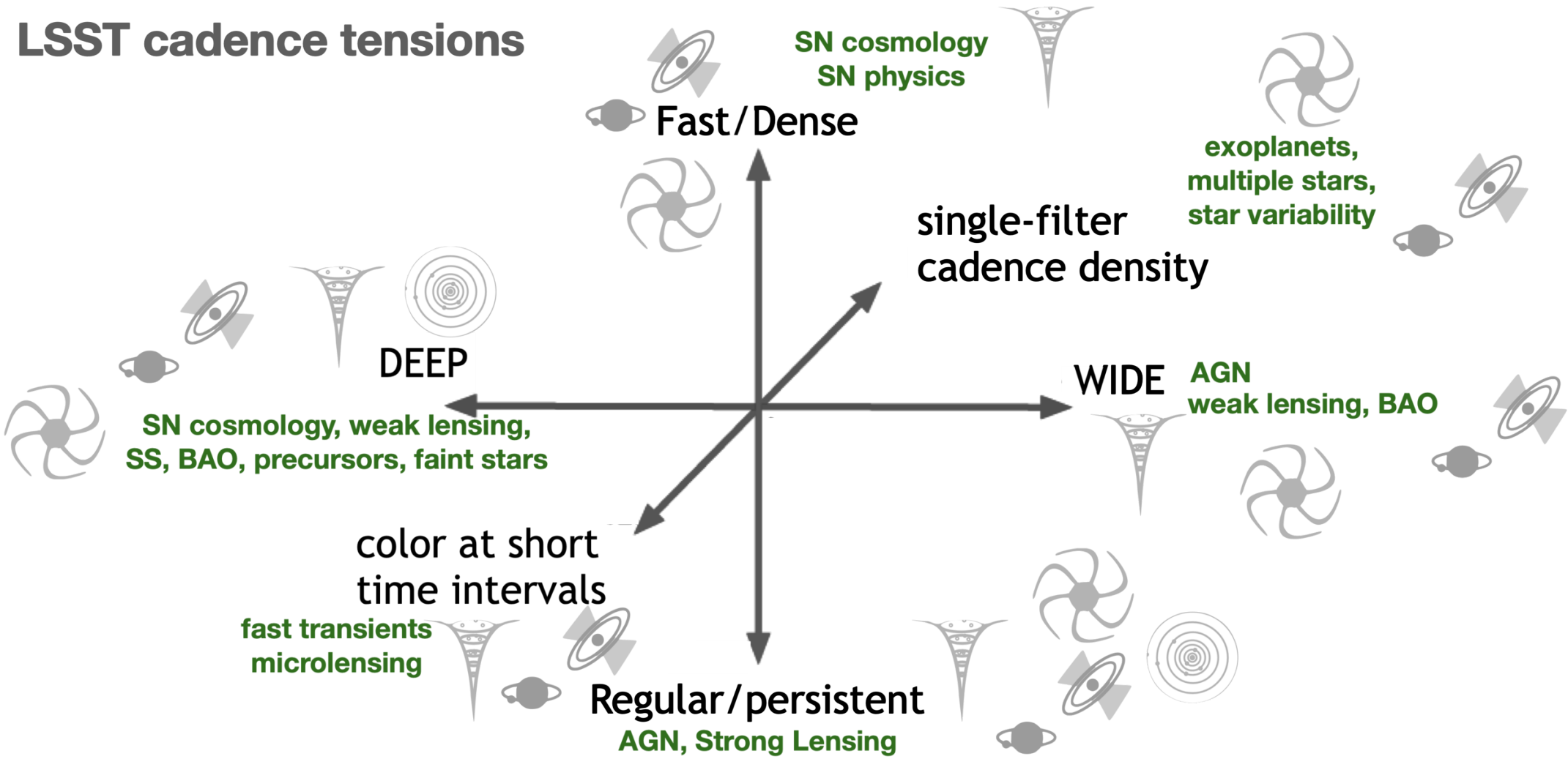
Chapter Editors: *David Nidever*, *Knut Olsen*

Periodic Variable Type	Examples of target science	Amplitude	Timescale
RR Lyrae	Galactic structure, distance ladder, RR Lyrae properties	large	day
Cepheids	Distance ladder, cepheid properties	large	day
Long Period Variables	Distance ladder, LPV properties	large	weeks
Short period pulsators	Instability strip, white dwarf interior properties, evolution	small	min
Periodic binaries	Eclipses, physical properties of stars, distances, ages, evolution, apsidal precession, mass transfer induced period changes, Applegate effect	small	hr-day
Rotational Modulation	Gyrochronology, stellar activity	small	days
Young stellar populations	Star and planet formation, accretion physics	small	min-days

Transient Type	Science drivers	Amplitude	Time Scale	Event Rate
Flare stars	Flare frequency, energy, stellar age, space weather	large	min	very common
X-ray Novae	Interacting binaries, stellar evolution, SN progenitors, nuclear physics	large	weeks	rare
Cataclysmic variables (6.6.3)	Interacting binaries, stellar evolution, compact objects	large	min - days	common
LBV variability (6.6.5)	Late stages stellar evolution, Mass loss, SN progenitors	large	weeks-years	rare

LSST survey strategy optimization

Rubin LSST survey design



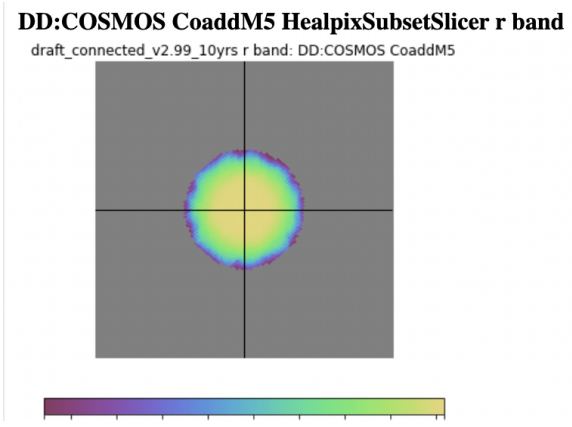
Rubin LSST survey design

(current plan)

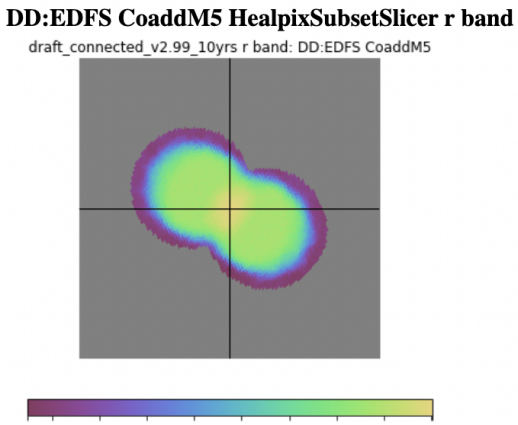
Rubin LSST survey design

(current plan)

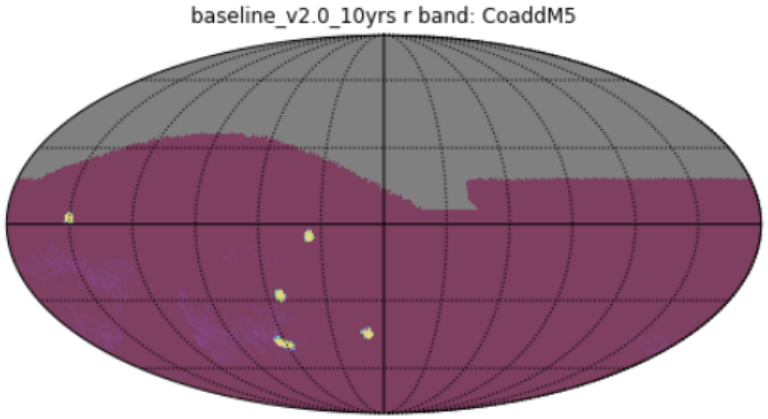
Group: *Basics*; Subgroup: *Coadd M5*; Slicer: *HealpixSubsetSlicer*						
	DD:COSMOS CoaddM5	**DD:ECDFS CoaddM5**	**DD:EDFS CoaddM5**	**DD:ELAISS1 CoaddM5**	**DD:WFD CoaddM5**	**DD:XMM_LSS CoaddM5**
g band	28.64	28.30	28.07	28.25	26.74	28.16
i band	28.20	27.83	27.59	27.79	26.36	27.70
r band	28.63	28.25	28.06	28.25	26.91	28.16
u band	27.41	27.01	26.83	26.98	25.78	26.93
y band	26.72	26.37	26.13	26.34	24.81	26.28
z band	27.30	27.03	26.78	26.99	25.61	26.94



26.8 29.05



26.8 28.6



26.9 coadd 5σ depth 28.1

source http://astro-lsst-01.astro.washington.edu:8080/?runId=2

Rubin LSST survey design

(current plan: 3% of the LSST time devoted to ToO)

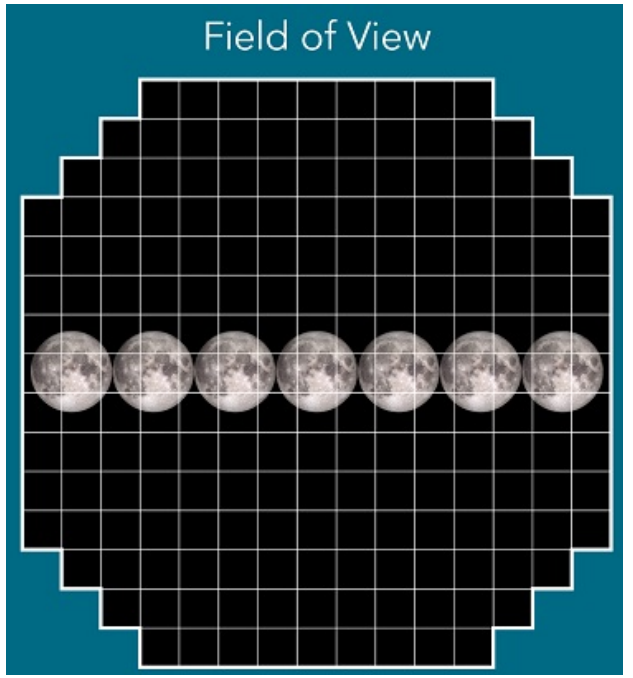
LIGO/VIRGO area of localization ~100deg square

Ursa Minor contains 255.86 square degrees

S190425z 18% of the sky localization

Rubin can find the electromagnetic counterpart of Gravitational Wave and Neutrino discoveries better than any survey

Rubin FoV 10 deg



2024 workshop organized by Andreoni + Margutti

Rubin LSST survey design

Rubin has involved the community to an unprecedented level in survey design this is a uniquely "democratic" process!

https://iopscience.iop.org/article/10.3847/1538-4365/ac3e72

Survey Cadence Optimization Committee

The SCOC is advisory to the Rubin Observatory Operations Director (currently Bob Blum). It will begin its work in 2020, and will be a standing committee throughout the life of Rubin Observatory operations.

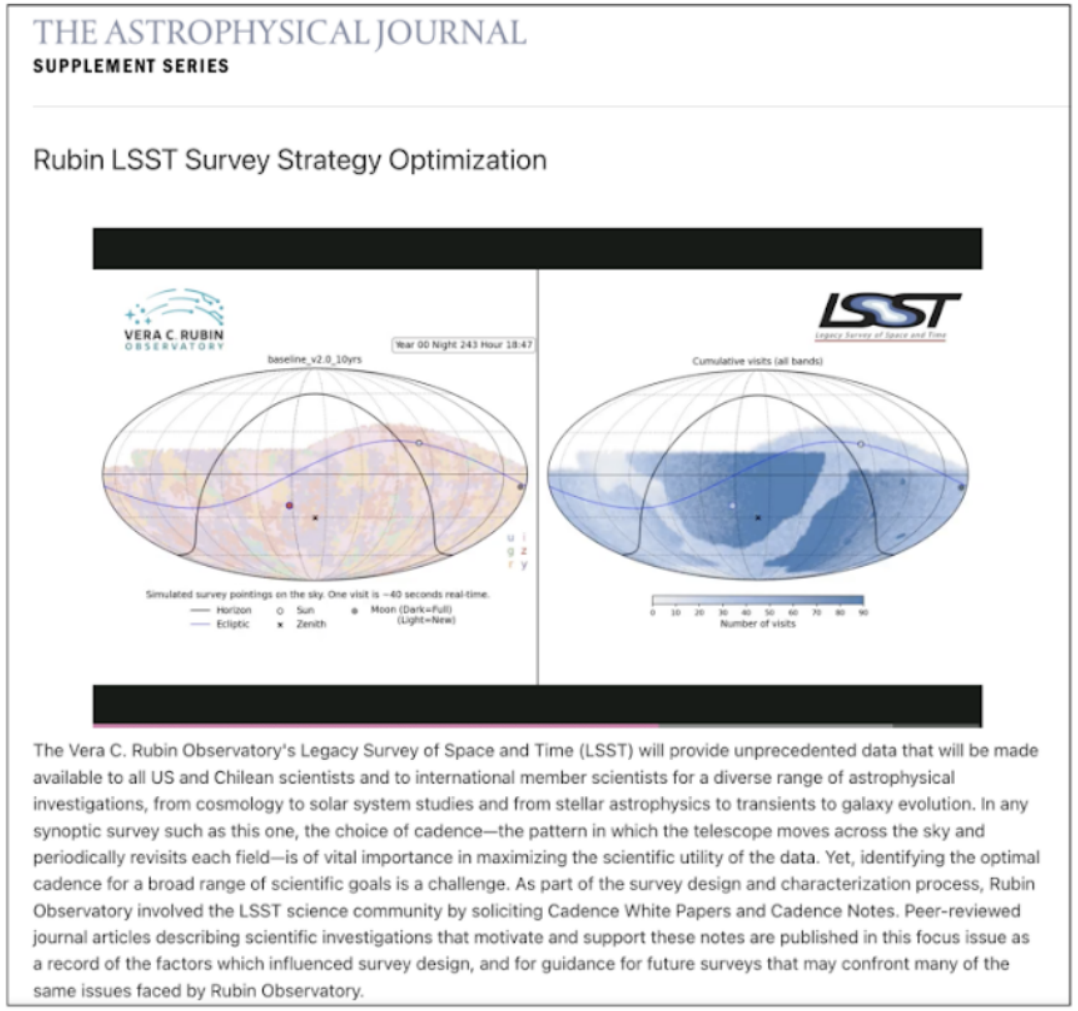
https://www.lsst.org/content/charge-survey-cadence-optimization-committee-scoc

The community received indispensable support from
- LSSTCorporation Enabling Science Program
(supporting small projects and fellowships)
- Heising-Simons Fundation
($1M to the SCs + smaller grants to support workshops over time)

2015-17	*Community Observing Strategy Evaluation Paper* (COSEP, Marshall et al. 2017) 9 chapters 25 science cases 14 LSST simulations
2018	Call for white papers -> 46 community submissions **467 unique authors** I +16 simulations
2021	Call for "cadence notes" -> 46 community submissions **218 unique authors I** 173 simulations

Rubin LSST survey design

An ApJ Supplements focus issue dedicated to community contribution to the Survey Strategy Optimization



https://iopscience.iop.org/journal/0067-0049/page/rubin_cadence

20 peer review papers accepted

several more under review and in preparation

- Supernovae
- Kilonovae
- Blazars
- AGN
- Variable stars
- YoungStellarObjects
- PulsatingStars
- TidalDisruptionEvents
- TD anomalies+unknowns
- ...

Key development needs (my opinion)

TDA is resource intense

Equitable Access Needs Resources

support training a diverse workforce

recognize technical contributions

enable access to tool (open science)

support preparatory work

Rubin DEI activities

https://www.lsst.org/about/dei

Thomas, S. J., et al. (2022), Observatory Operations: Strategies, Processes, and Systems IX, 12186, 1218607.

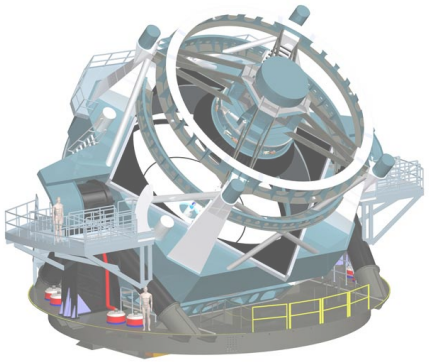
Science Collaborations activities (e.g.)

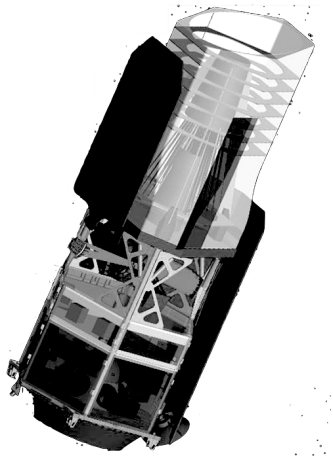
Heising-Simons Foundation Grant Will Fund Equity and Excellence in Science

The Heising-Simons Foundation is investing in the future of astronomy with a grant of just under $900,000 over the next 18 months that will provide researchers around the world with the opportunity to kickstart scientific research programs in time for the opening of the Vera C. Rubin Observatory. Under the title "Leveling the Playing Field", this project will enable all astronomers to explore the potential of Rubin Observatory for Galactic, stellar, and Solar System science, through the work of Science Collaborations that are dedicated to these topics. The award will be managed by the Las Cumbres Observatory, a global robotic telescope network dedicated to time domain astronomy.

Survey coordination

(one example)



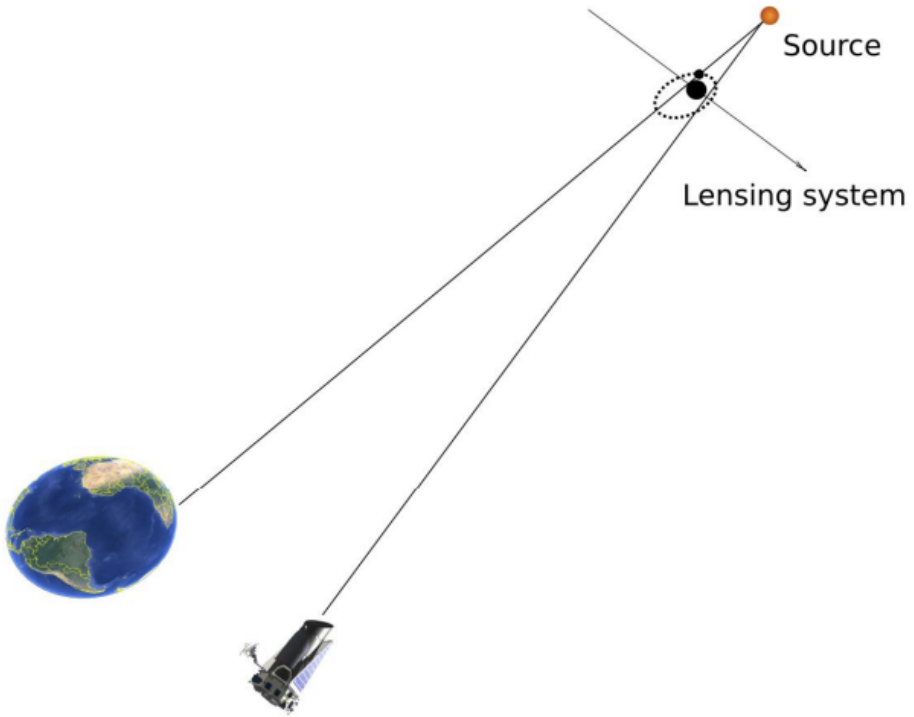


Rubin + *Roman*

Micro- and meso-lensing for stellar physics

- detect microlensing events where both the lens and source lie in the Magellanic Clouds, and explore stellar and stellar remnant populations in another galaxy.
- LSST will investigate the mass distribution offaint objects in the local neighborhood, such as low mass dwarfs, stellar remnants, andfree-floating planets.

Humbleton et al 2022 **TVS Roadmap**



Street + 2018, arxiv/1812.04445

thank you!

federica bianco

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