Update on the Vera C. Rubin Observatory

Michele Bannister

S. Eggl, M. Jurić, A. Heinze, J. Moeyens, Z. Langford, R.L. Jones, N. Lust, M. Schwamb, D. Trilling, S. Greenstreet, Z. Ivezić, H. Hsieh, G. Sarid, C. Opitom, D. Ragozzine, L. Inno and SSSC Collaboration

RUTHERFORD FOUNDATION

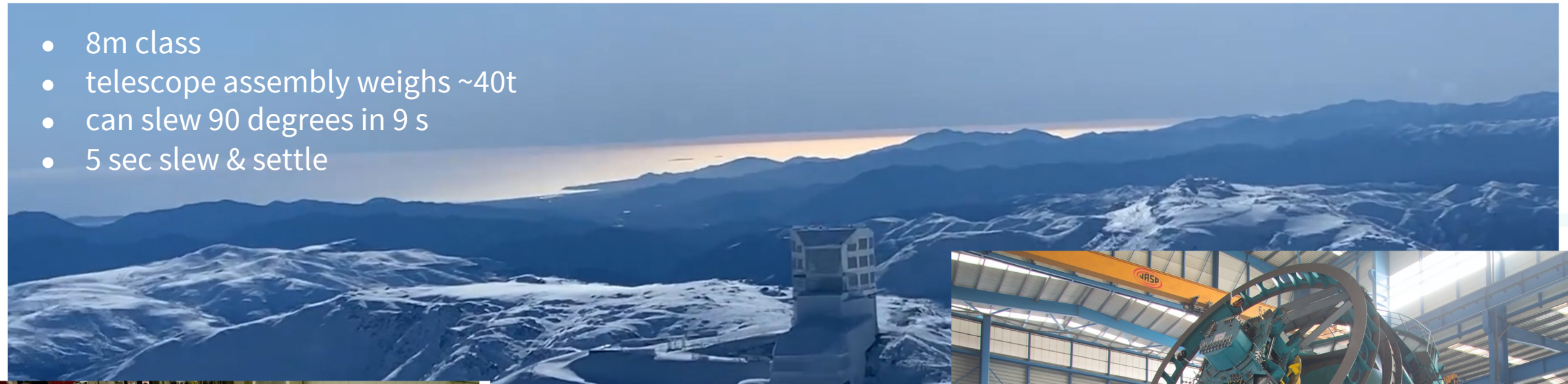
ROYAL SOCIETY TE APĀRANGI

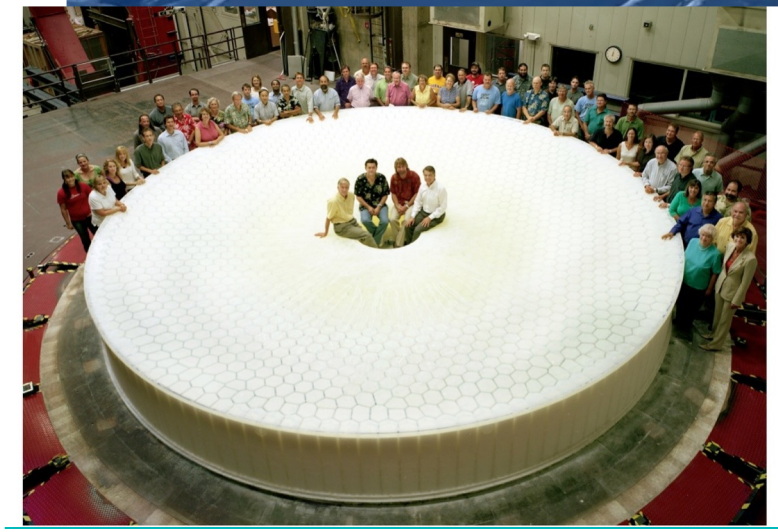
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

VERA C. RUBIN OBSERVATORY

The Vera C. Rubin Observatory

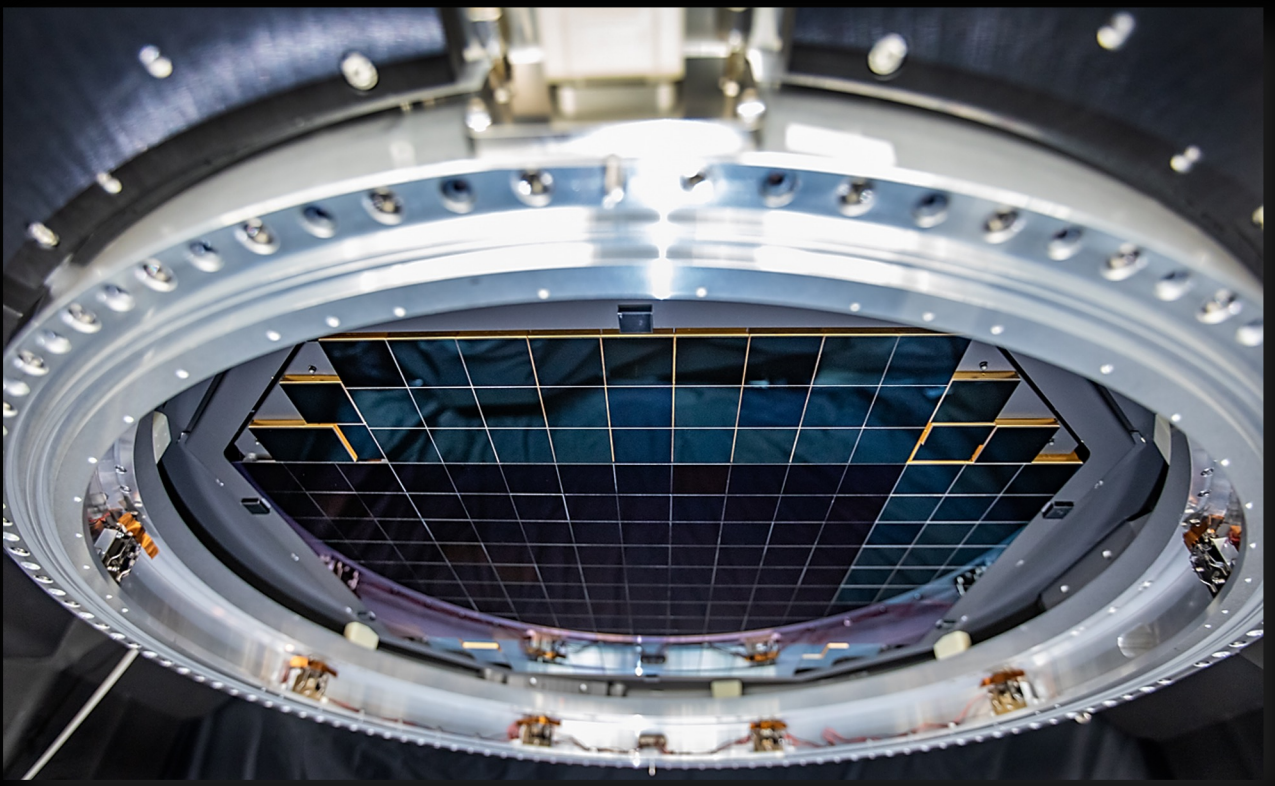
- 8m class
- telescope assembly weighs ~40t
- can slew 90 degrees in 9 s
- 5 sec slew & settle

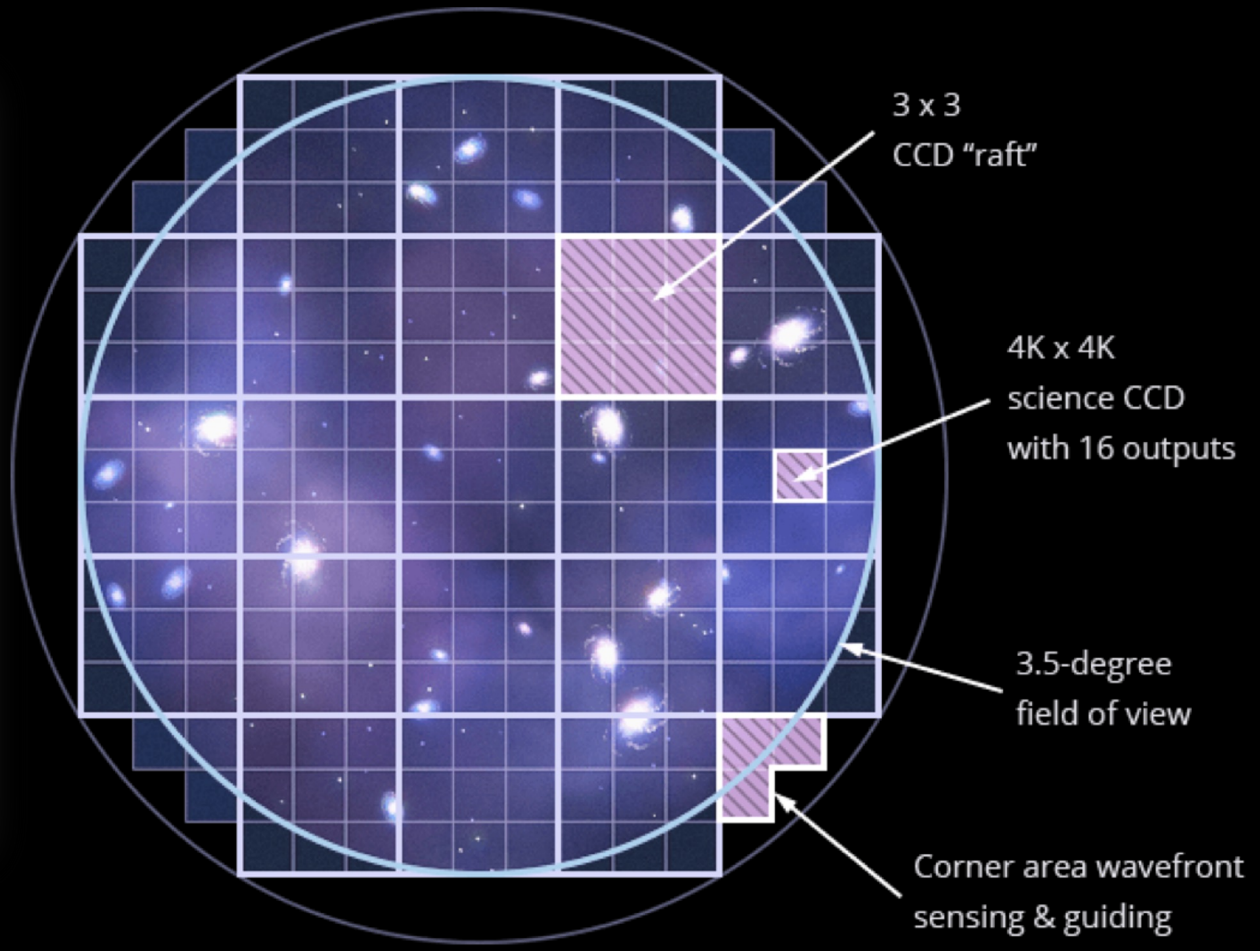


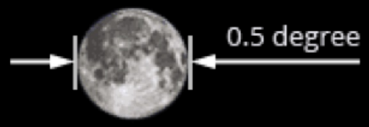


LSSTCam: the world's biggest wide-field camera

acquire a 20 Gb image every 40 s





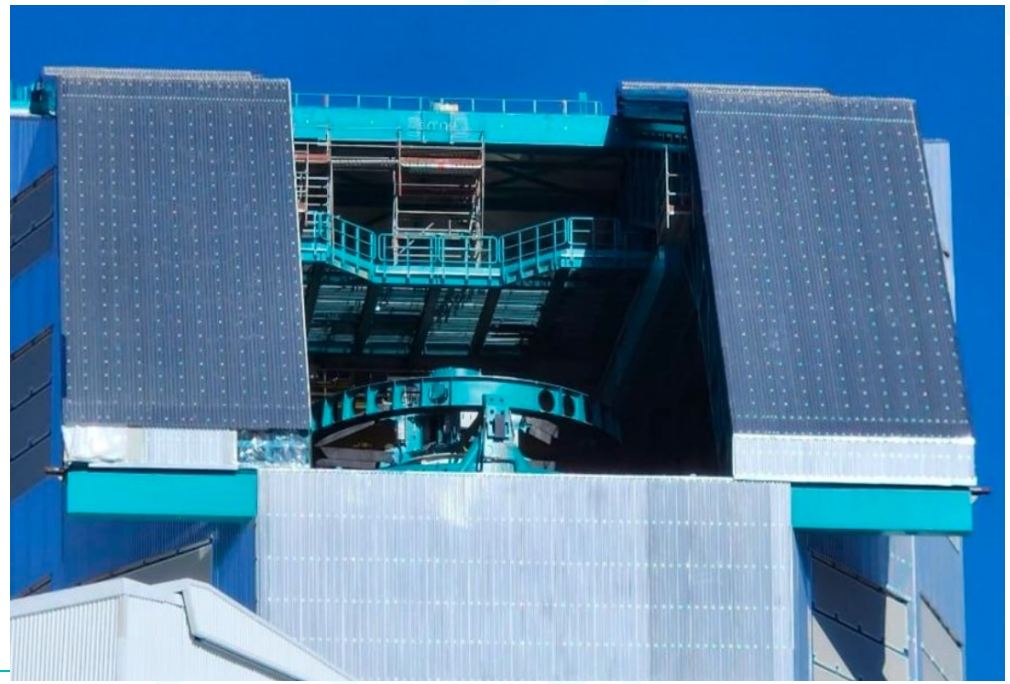


Angular size of the
moon in comparison

Laser Mirror (LM 4-8)
Assembly Station

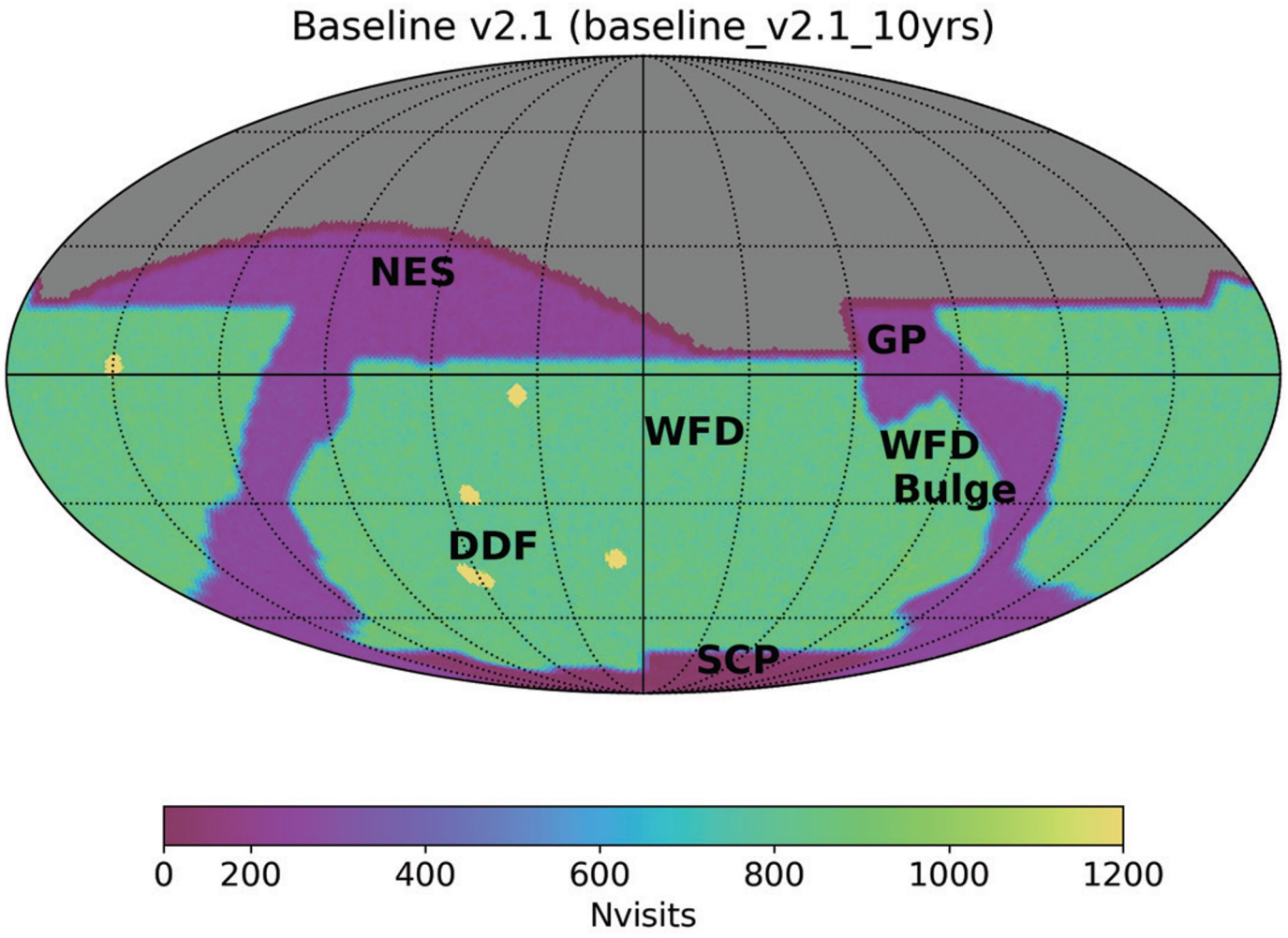
Construction status

- Telescope Mount Assembly is “99%” complete!
- The dome is progressing well (but work remains).
- LSSTCam is essentially ready to be shipped.
- Data Management: pipelines on schedule, new data facility (USDF) at SLAC, pipelines deployed for Subaru’s HSC and alert distribution for ZwickyTF
- System Integration and Commissioning is well under way (including data acquisition, transfer from the summit and processing at USDF).
- Education and Public Outreach (EPO) just passed their close-out review and the team has moved to Operations



slide credit: Zeljko Ivezic https://zenodo.org/record/7547772#.Y8gp9-zMJeh

The Legacy Survey of Space and Time



Duration: 10 yrs
Filters: ugrizy

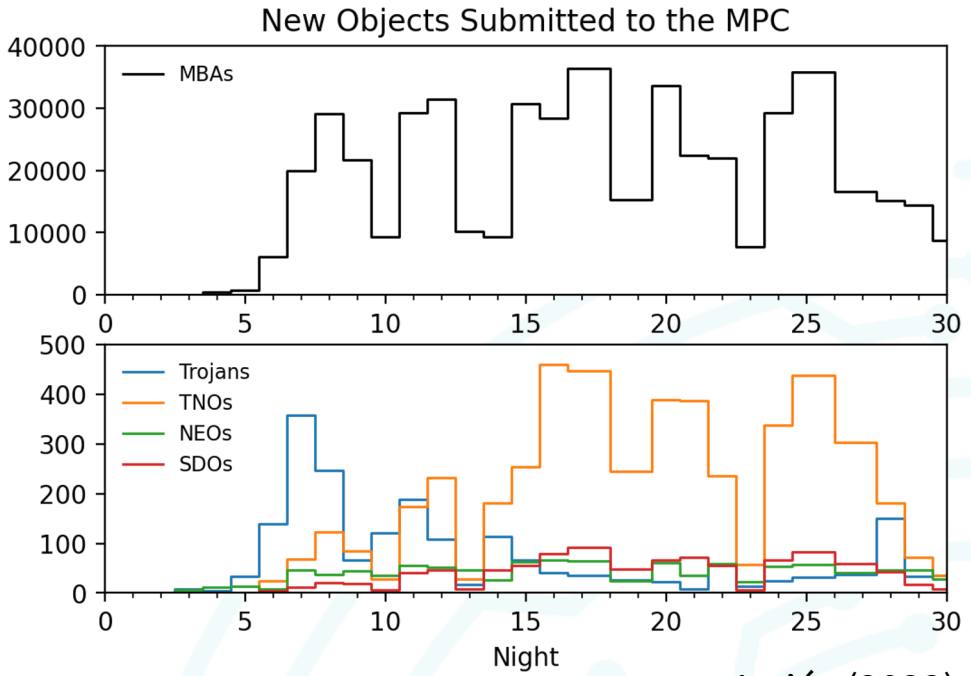
Wide Fast Deep (WDF)
North Ecliptic Spur (NES)
Galactic Plane (GP)
Deep Drilling Fields (DDF)
South Central Plane (SCP)

Major assessment by SSSC of cadence simulations V1.5-2.2 over the last 18 months

Schwamb+ (submitted to ApJS Special Issue)
https://iopscience.iop.org/journal/0067-0049/page/rubin_cadence

The Legacy Survey of Space and Time

	Currently Known	LSST expected Discoveries
near-Earth Objects (NEOs)	~ 28,000	60,000
Main Belt Asteroids (MBAs)	~ 1,000,000	5,000,000
Jupiter Trojans	~ 10,000	200,000
Trans-Neptunian Objects (TNOs)	~ 4,000	40,000
Comets	~ 4,000	10,000
Interstellar Objects	2	>10 (??)



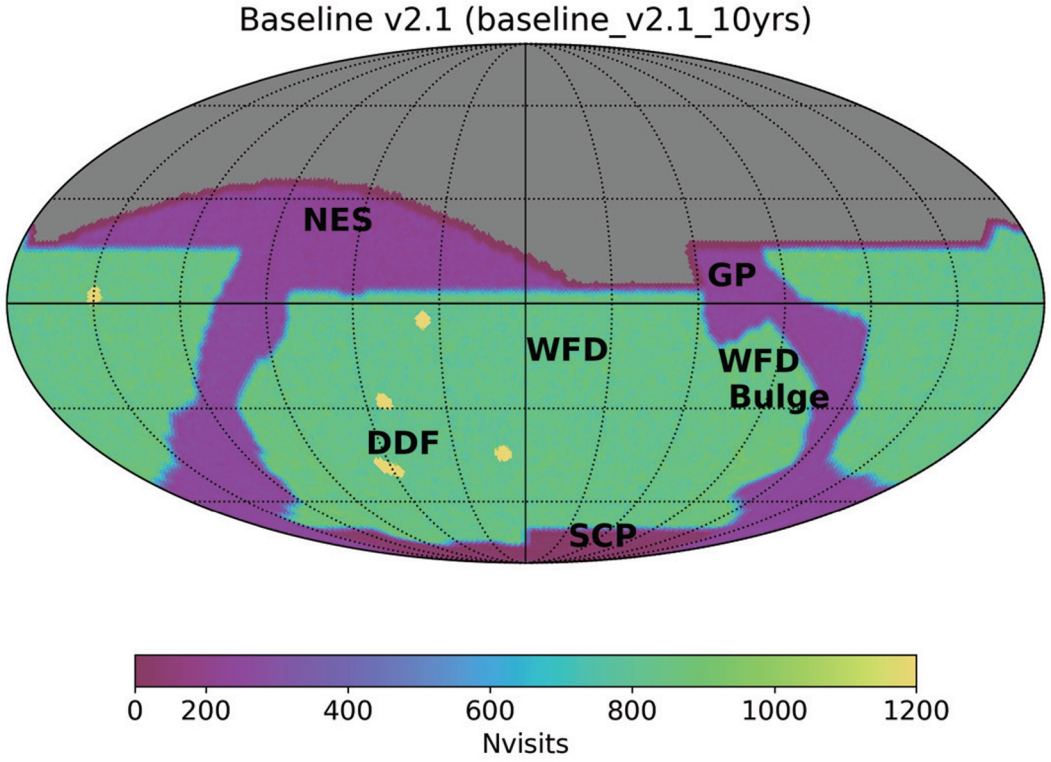
Jurić+ (2022)

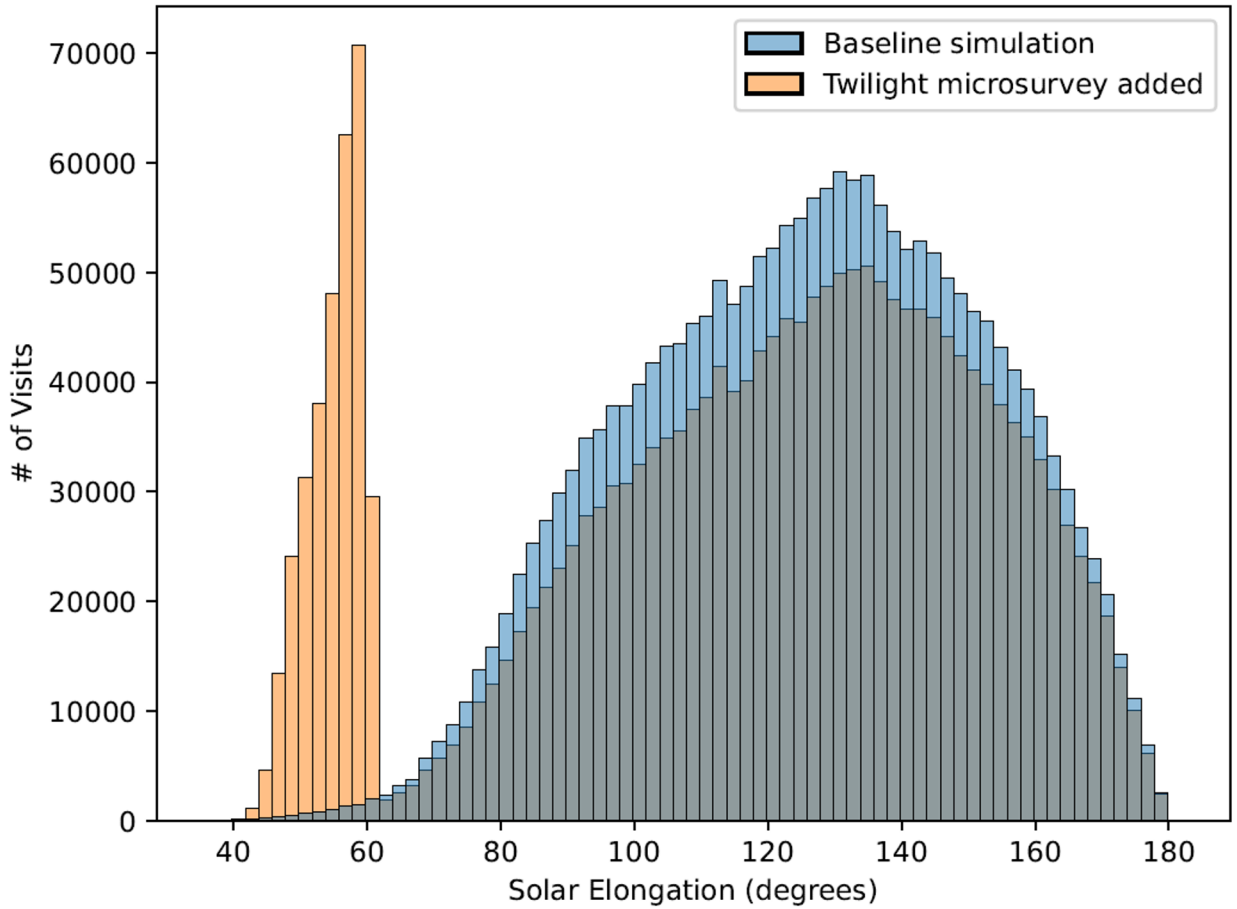
Most discoveries will happen early in the survey , except NEOs, ISOs and some comets.

The Legacy Survey of Space and Time

Baseline survey

Micro/Nanosurveys





Schwamb+ (submitted to ApJS)

Survey strategy: an iterative ongoing process

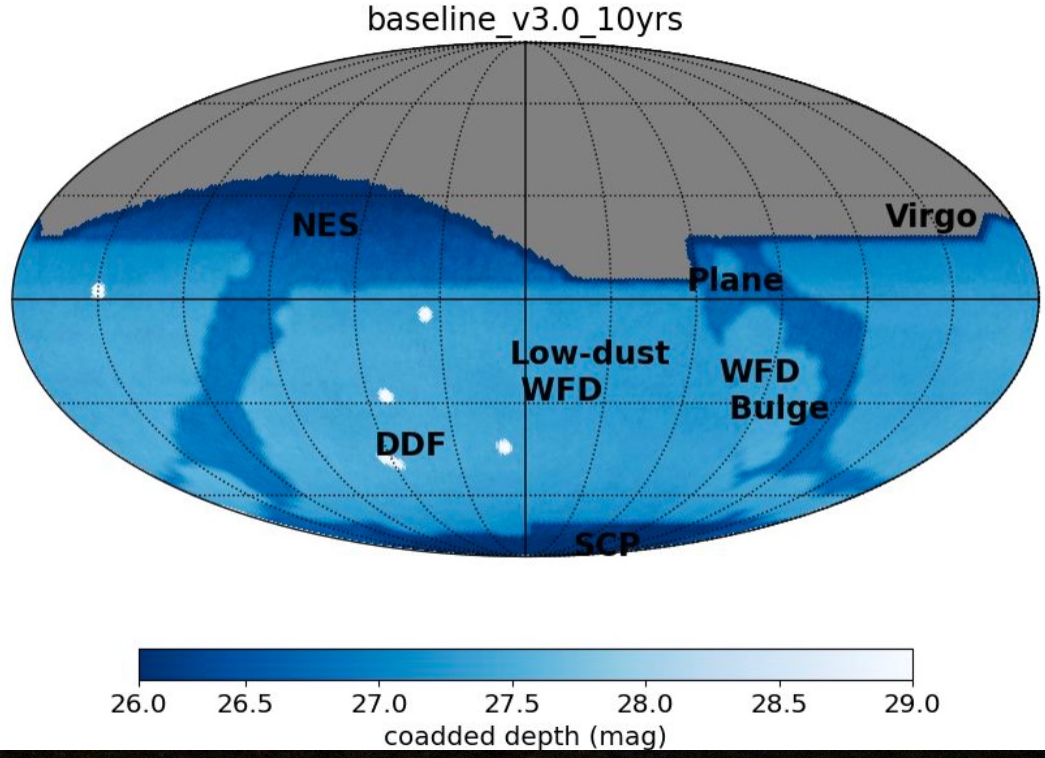
- Cadence selection is in progress
  - So many decisions: year 1 cadence, nightly visit pair/triplet, filter distribution, footprint, rolling cadence, deep drilling fields, twilight survey, 2 x 15 s or 1 x 30 s exposure (8% boost in on-sky visits)… Schwamb+ (submitted to ApJS)
- Phase 2 recommendation made!

- Filter Balance & Footprint refinements
- Intranight Cadence recommendations
- Finalized DDF Selection
- Recommends twilight NEO microsurvey and Northern Stripe microsurvey to start in year 1
- Recommending ½ sky Rolling Cadence
- Recommending a ToO program to <=3% of the LSST time

pstn-055.lsst.io

To be defined:

- Details of the observing strategy for DDFs
- Details of the observing strategy for ToOs
- Details of Galactic sky footprint and strategy
- Year 1 observations (work with Early science Ops team)



I. Real-Time Alerts within 60 sec

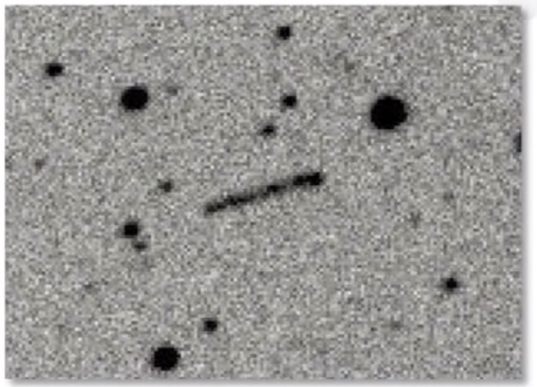
A. Real-time Alerts (>=2M SSO observations/night)	
Astrometry	±10 mas (bright; ±140 faint)
PSF flux	±10 mmag (bright end)
Aperture flux	±10 mmag (bright end)
Trailed source fit	Flux and on-sky motion for fast-moving (trailed) objects
Appearance characterization	Moments and extendedness of the object's image
Spuriousness score	Probability that the detection is an artifact
Nearby static objects	Information on adjacent objects (up to three)
MPC designation	Given for known objects
Predicted position and magnitude	Given for known objects

Details: DIASource tables in http://ls.st/oug

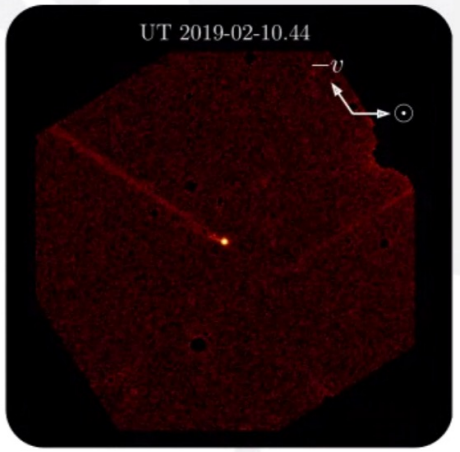
Measurements of all detections on difference images, including known and unknown SSOs.

Suitable for real-time discovery of trailed objects, and activity of known objects.

Allows us to monitoring ~0.5-1M small bodies for activity, each night.

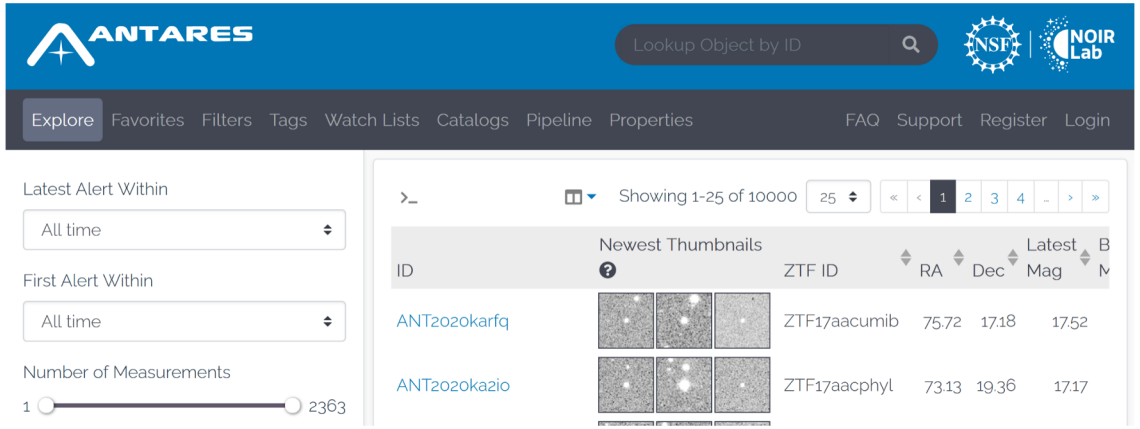


2014 MF6 (PHA), 60sec exposure, MPC Q62 (Guido, Howes & Nicolini)

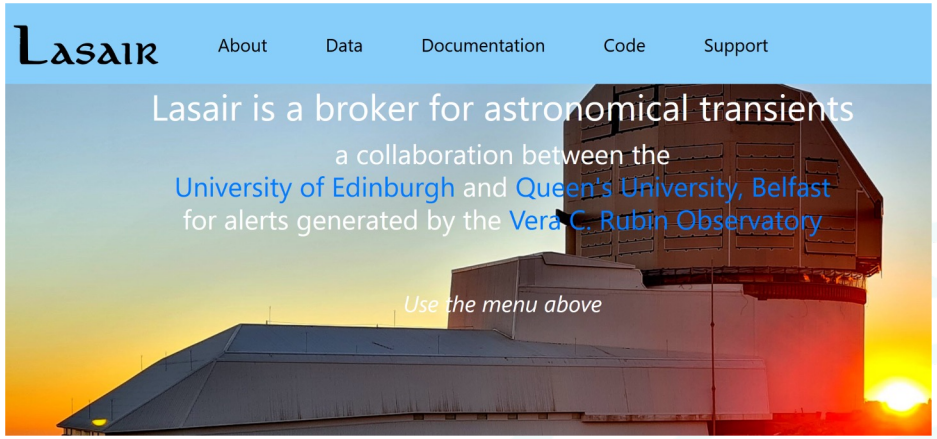


(6478) Gault outburst
(Ye et al, for the ZTF Collaboration)

Community can retrieve events from Alert Brokers



https://antares.noirlab.edu/



https://lasair-ztf.lsst.ac.uk/

The Solar System Notification Alert Processing System (SNAPS, D. Trilling)

FINK

https://fink-broker.org/

II. Daily Catalog

B. Daily Solar System Products (>= 5.5M objects)	
Orbits	Computed by the MPC
Light-curve characterization	Period, light curve shape, other features
Absolute magnitude estimates	Estimates of (H, G12) in u,g,r,i,z,y bands
MOID	Minimum Orbit Intersection Distance (Earth)
Extendedness indicators	Is/was the object comet-like in its appearance?

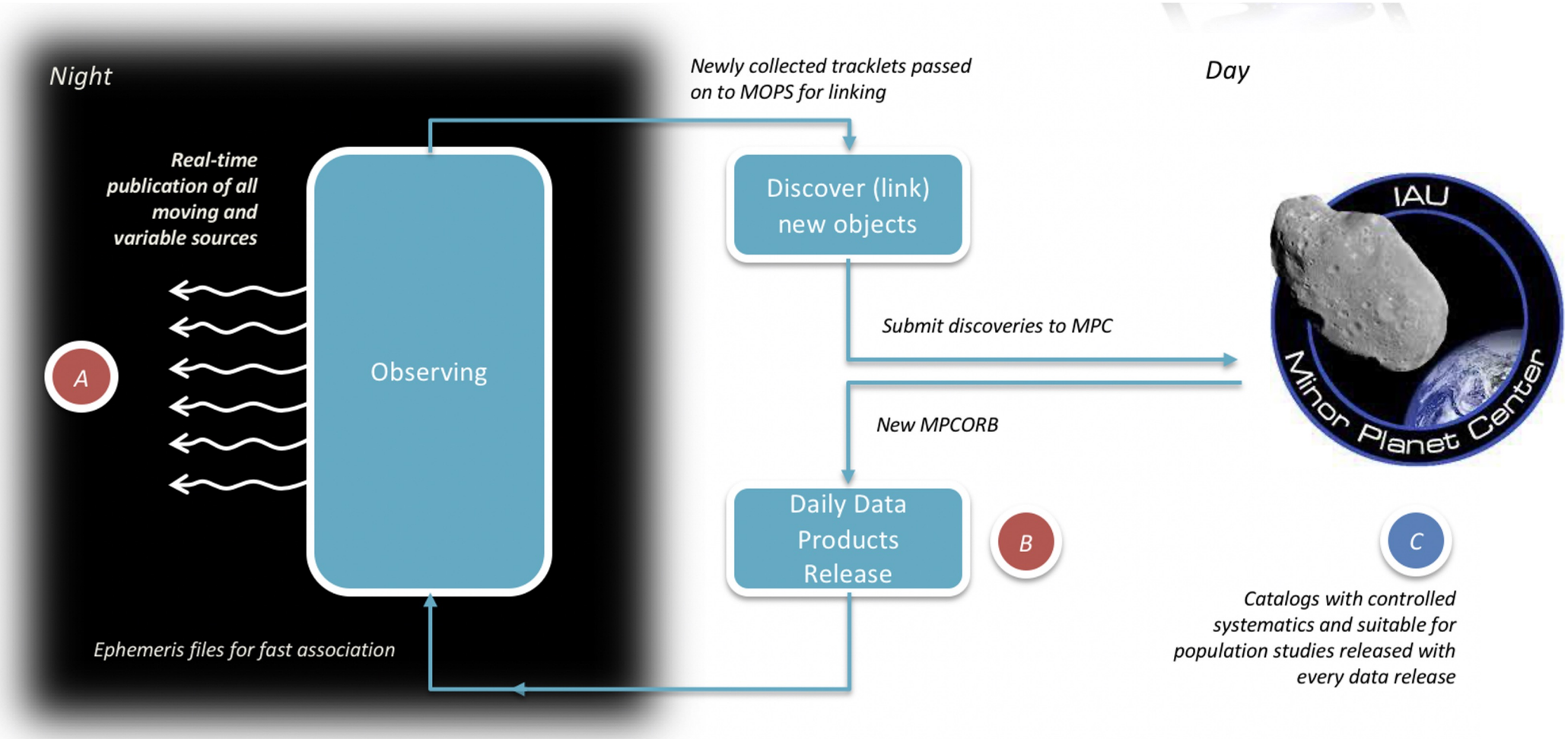
A catalog of orbits and physical properties, recomputed daily. The orbit solutions and designations will be obtained from the MPC.

The physical properties (absolute magnitudes, light curves, extendedness characterization) will be computed from LSST data.

The most up-to-date catalog of physically well-characterized small bodies in the Solar System.

Details: SSObject and SSSource tables in http://ls.st/oug

LSST Solar System Processing



See the handout at http://ls.st/Document-29545 for a one-page summary!

The state of things Rubin: minor planet detection

- Moving-object pipeline (HelioLinC+) is operational 🥳
  - 95.6% completeness of recovery of ISOs with H=18-23 (1I had H=22)
  - Asteroids (some NEOs, full main belt, some Jupiter Trojans) even better
- Minor Planet Center has stress-tested with Rubin, and can handle LSST nightly input 🤩 (as per F. Soto, SBAG June '22)
- Precovery integrated into LSST pipelines

III. High-Quality Data Release Catalogs

C. Solar System Data Release Products (every year)	
High-fidelity reprocessing	Catalogs derived from re-reductions of all survey data using improved calibrations and a single, well-characterized, software release. **A "gold" version of the daily catalog.**
The LSST Catalog of Solar System Objects	**A catalog, suitable for population studies**, of objects detected by LSST with orbits estimated using only LSST data.

Details: SSObject and SSSource tables in http://ls.st/oug

LSST will reprocess all data once a year, publishing well-characterized and manually QA-ed data releases (DR).

The Solar System aspects of a data release include a "gold" version of the daily catalog (improved astrometry and photometry), and a special "LSST-only" catalog of Solar System objects, suitable for population studies.

We will also deliver the linking software, information about the selection functions, and metadata necessary to enable debiasing of the population.

The state of things Rubin: data and support

So once LSST begins:

- Same-night alert reporting; MPC discovery reporting the next day
- First Solar System catalogue with survey characterization with DR1, 1-1.5 years after LSST start
- more details at: lsst-sssc.github.io

- In 2021-22 Rubin community support scaled up: seed grants, PhD student schools, postdoc fellowships, funded software incubators
- Much of this *is not continuing* in the coming year
  - no postdocs, no seed funding
- How best to support the community?

When is LSST data going to be available?

- forecast **System First Light** is now **July 2024**.
  - System First Light is expected about 3 months after First Photon,
  - Scheduler-driven LSST data acquisition will start about 4 months after System First Light.
- There will be no engineering first light with the single-raft ComCam (originally expected in 2023).
  - *Less clear what the first data preview release will contain*
- 2023: **shipping LSSTCam from SLAC to Chile, dome completion**, full system integration
  - Solar System data products may not be in data preview from commissioning data

- Anticipate **a start to the LSST of February 2025**

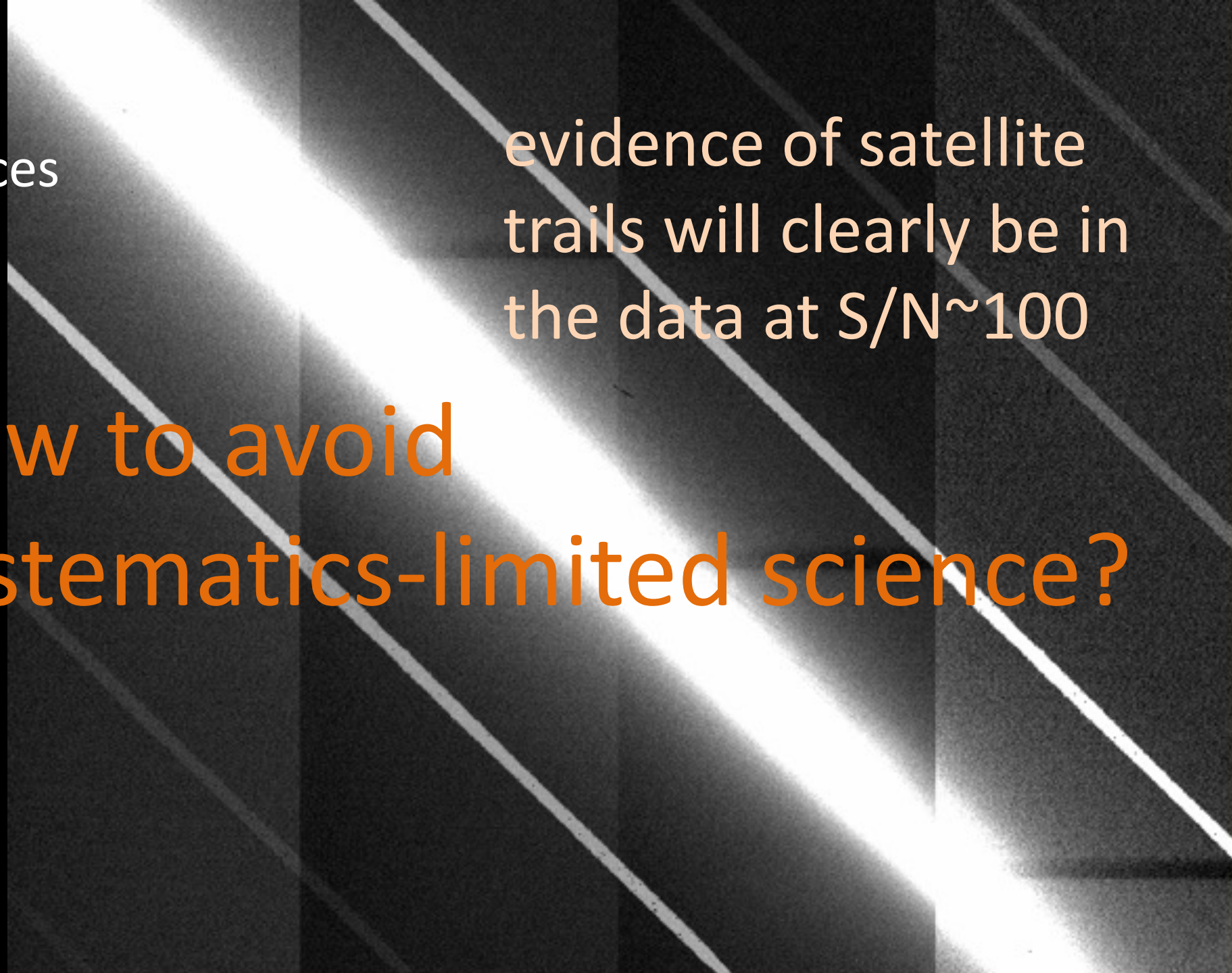
Your LSST Early Science Plan:
2023: Develop analysis against simulated data on the Rubin Science Platform (data previews, DPs)
2024: Preparation for real data; First Light; data preview release and analysis
2025: Survey starts, first Alerts; significant data preview release and analysis
2026: Data release 1 and analysis (first 6 months of Legacy Survey of Space and Time)

cf. https://zenodo.org/record/7547772#.Y8gp9-zMJeh

Rubin will look into
a hyper-industrialized sky
currently 0.5 million artificial satellites planned for launch by 2035
Joshua Rozells

Satellite trail induces image artifacts

Tyson et al. 2020



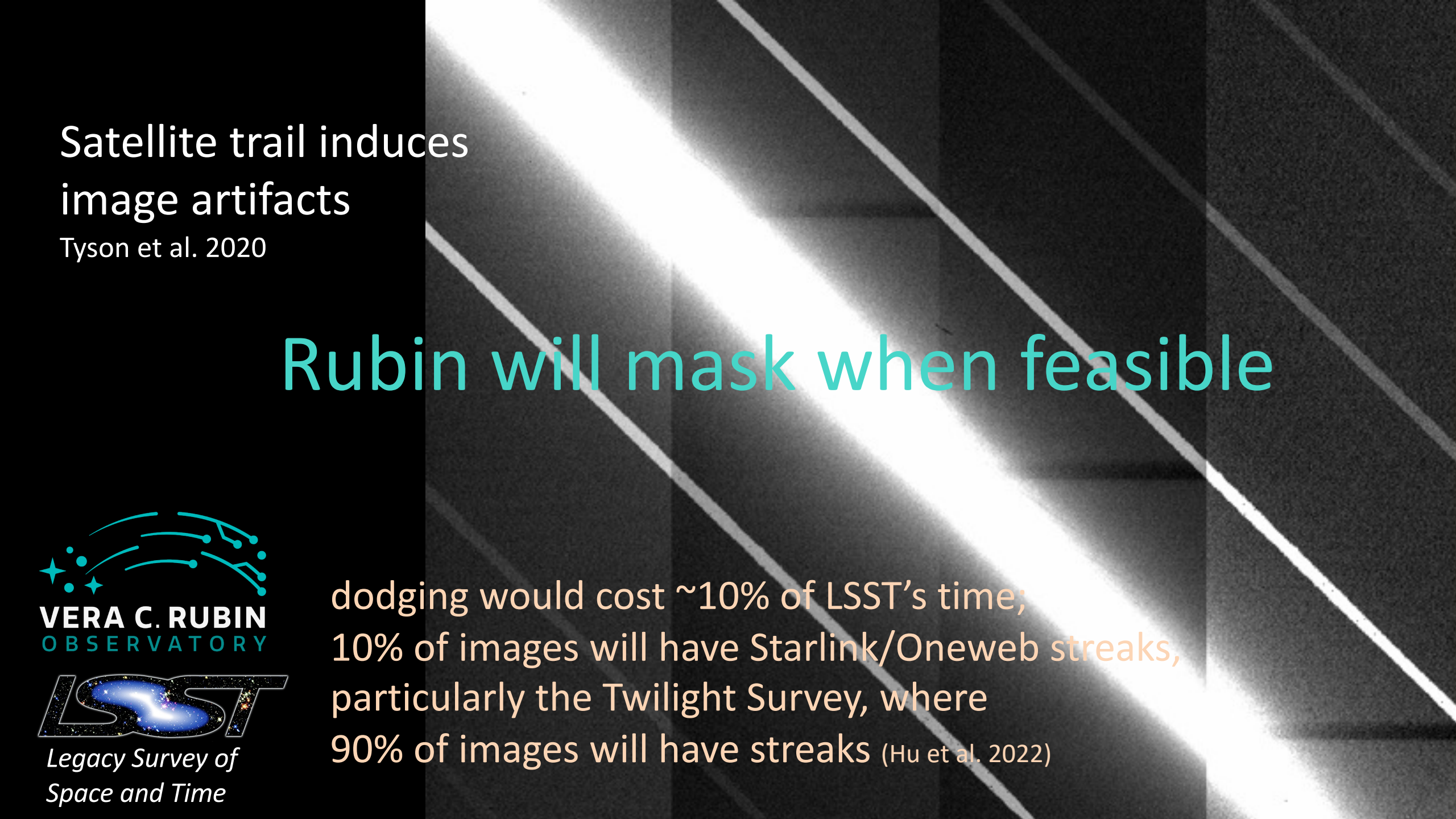
evidence of satellite trails will clearly be in the data at S/N~100

how to avoid systematics-limited science?

VERA C. RUBIN OBSERVATORY

LSST

Legacy Survey of Space and Time



Satellite trail induces image artifacts

Tyson et al. 2020

Rubin will mask when feasible

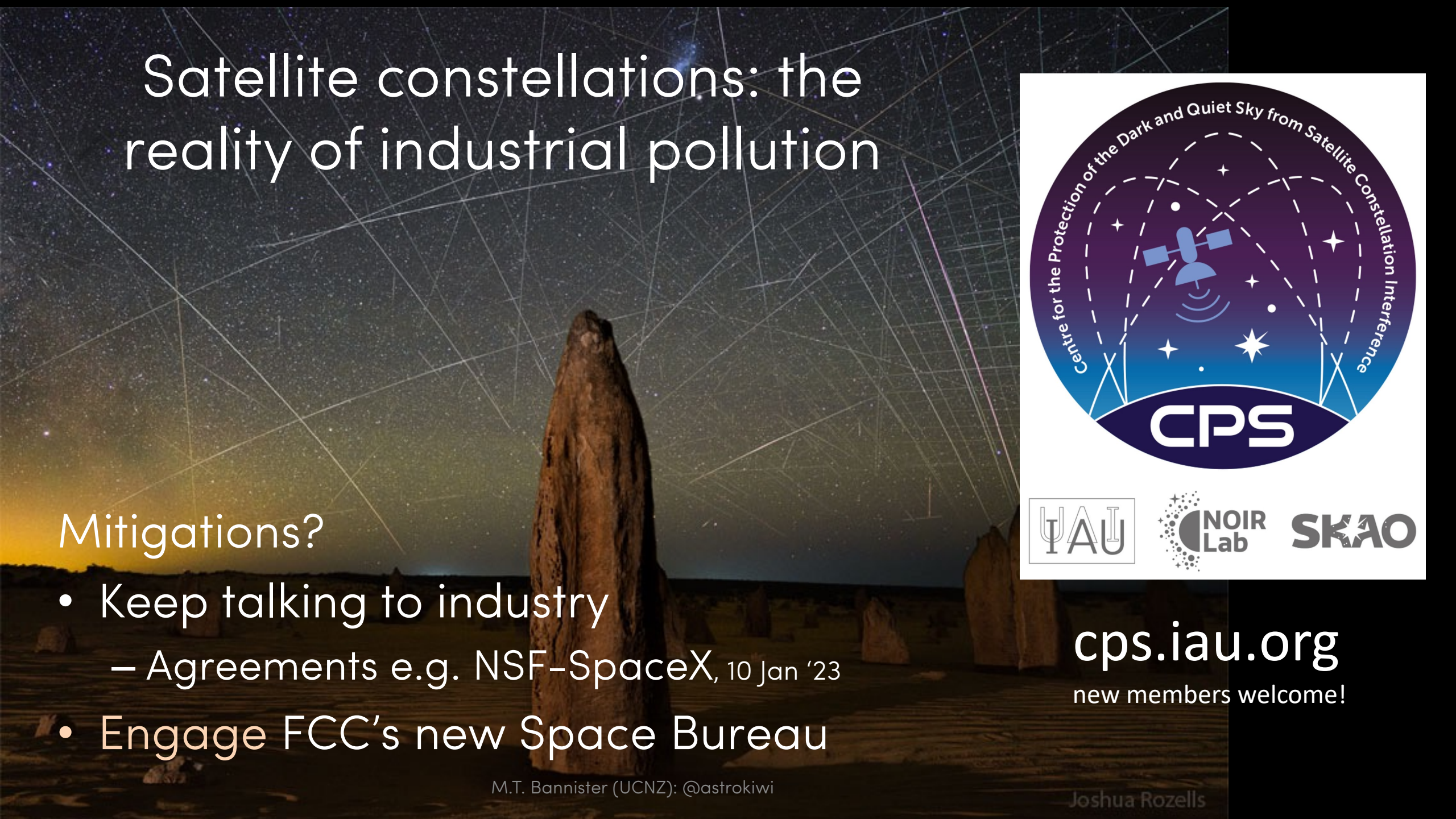
VERA C. RUBIN OBSERVATORY

LSST

Legacy Survey of Space and Time

dodging would cost ~10% of LSST's time;
10% of images will have Starlink/Oneweb streaks,
particularly the Twilight Survey, where
90% of images will have streaks (Hu et al. 2022)

Satellite constellations: the reality of industrial pollution



Mitigations?

- Keep talking to industry
  - Agreements e.g. NSF–SpaceX, 10 Jan '23
- Engage FCC's new Space Bureau

cps.iau.org

new members welcome!

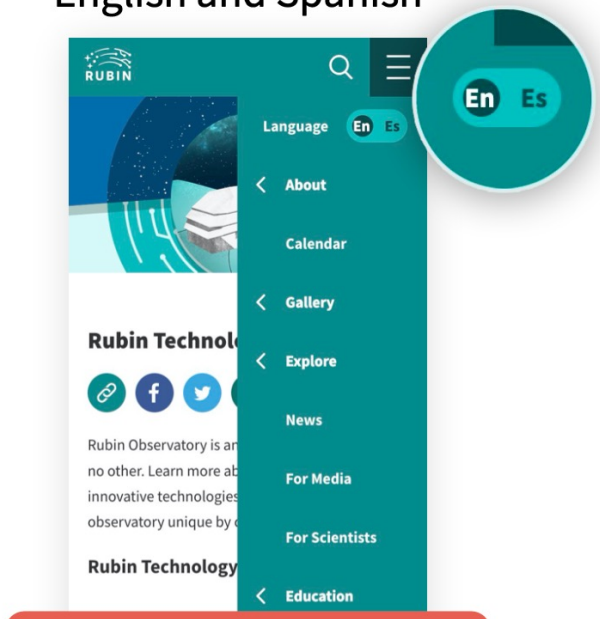
M.T. Bannister (UCNZ): @astrokiwi

Joshua Rozells

Rubin Education & Public Outreach program is built

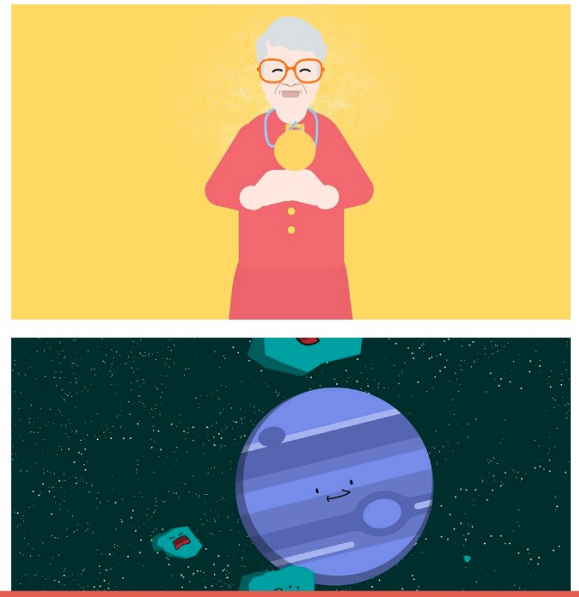
- Launching Jan/Feb at **rubinobservatory.org**

A new mobile-first, accessible website with engaging, conversational content in English and Spanish



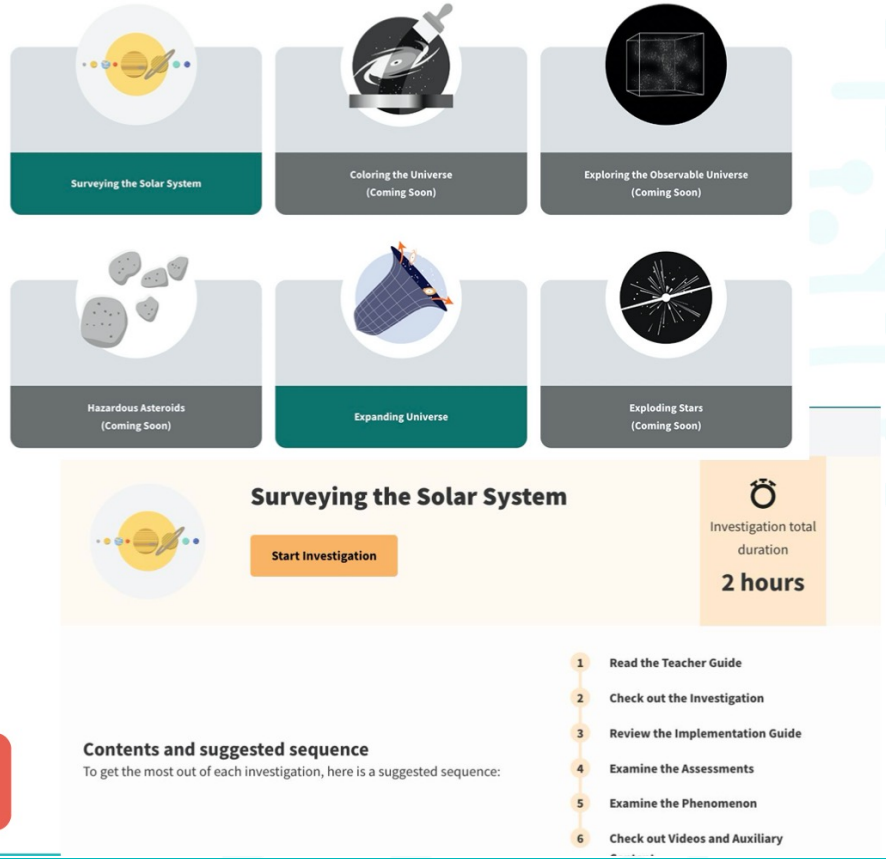
rubinobs.org
(soon to be rubinobservatory.org)

Animated videos about Rubin and its science, on Youtube in English and Spanish



youtube.com/RubinObservatory

Formal education investigations with resources for teachers

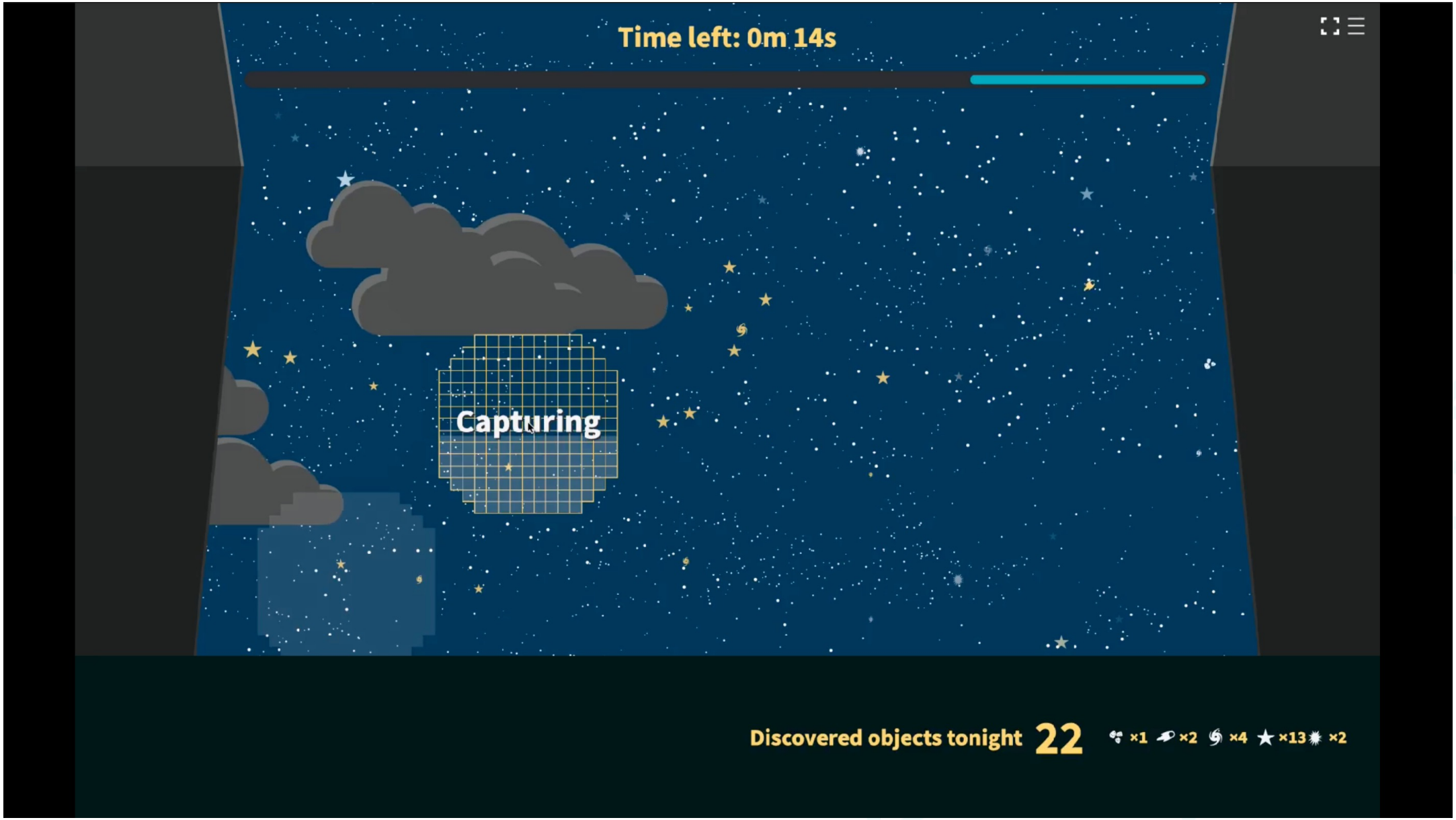


slide credit: Stephanie Deppe

Rubin Education & Public Outreach program is built

spacesurveyors.app

slide credit: Stephanie Deppe


Time left: 0m 14s
Capturing
Discovered objects tonight 22
×1 ×2 ×4 ×13 ×2

Rubin offers a vast new set of targets
— future missions will have plenty to choose from…

Outstanding issues:
—community funding support for preparatory work
—Engage FCC's new Space Bureau on satcon impacts

lsst-sssc.github.io

new members welcome!

VERA C. RUBIN
OBSERVATORY