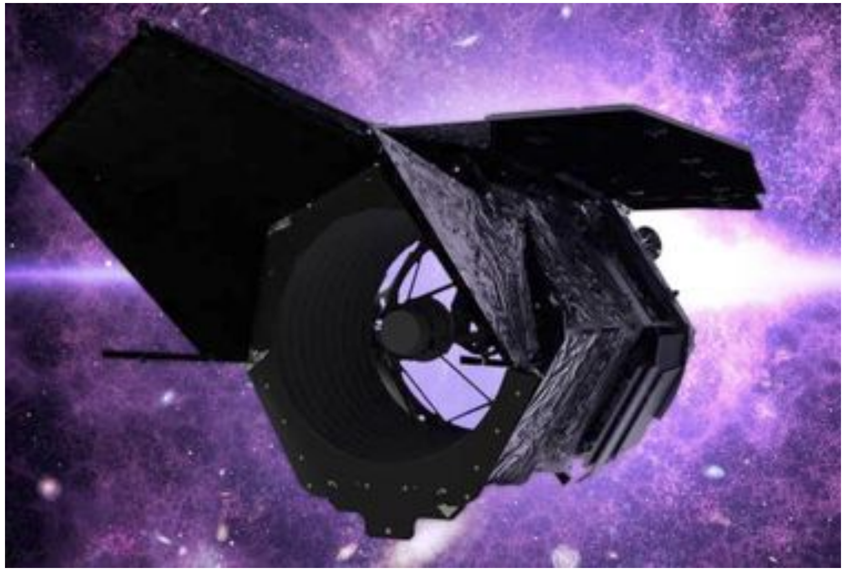
R2–D2: Roman and Rubin – from Data to Discovery

Aaron Meisner (NSF’s NOIRLab)

on behalf of the *AURA Roman-Rubin Synergies Working Group*

AAS 240 Exhibitor Theater, 6/13/22

Roman & Rubin: this decade's defining survey facilities in space and on the ground



Nancy Grace Roman Space Telescope

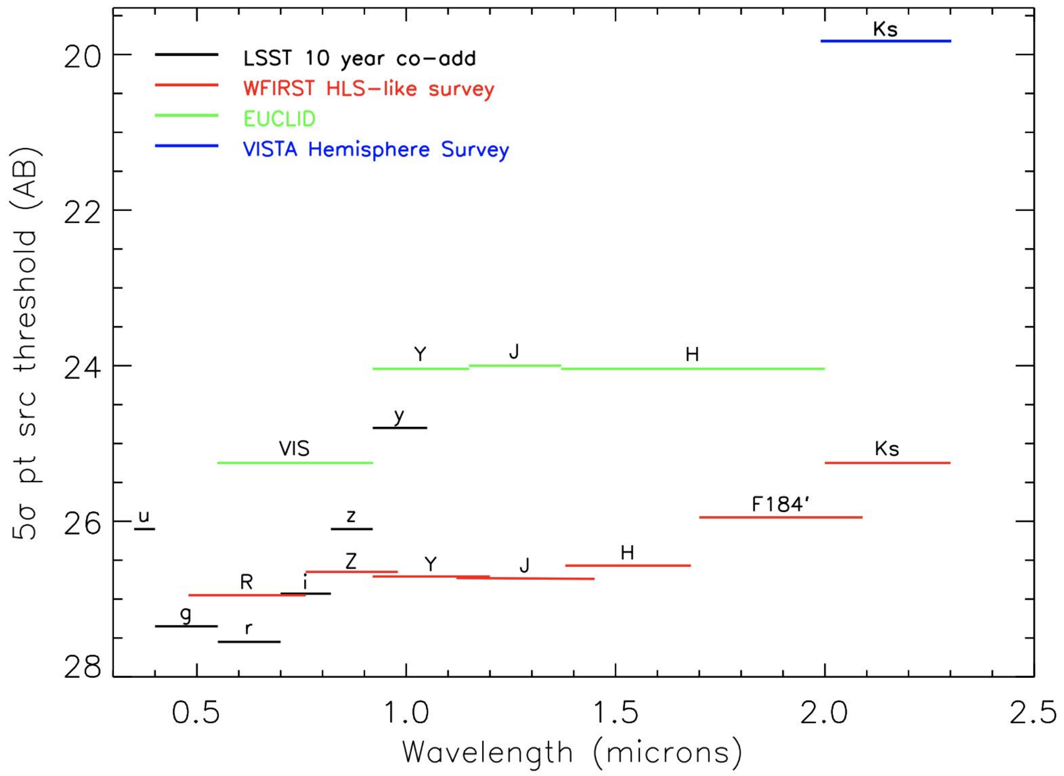
Hubble resolution with ~100x larger field of view

Vera C. Rubin Observatory

deep mapping of entire visible sky every ~3 nights

Roman & Rubin complementarity

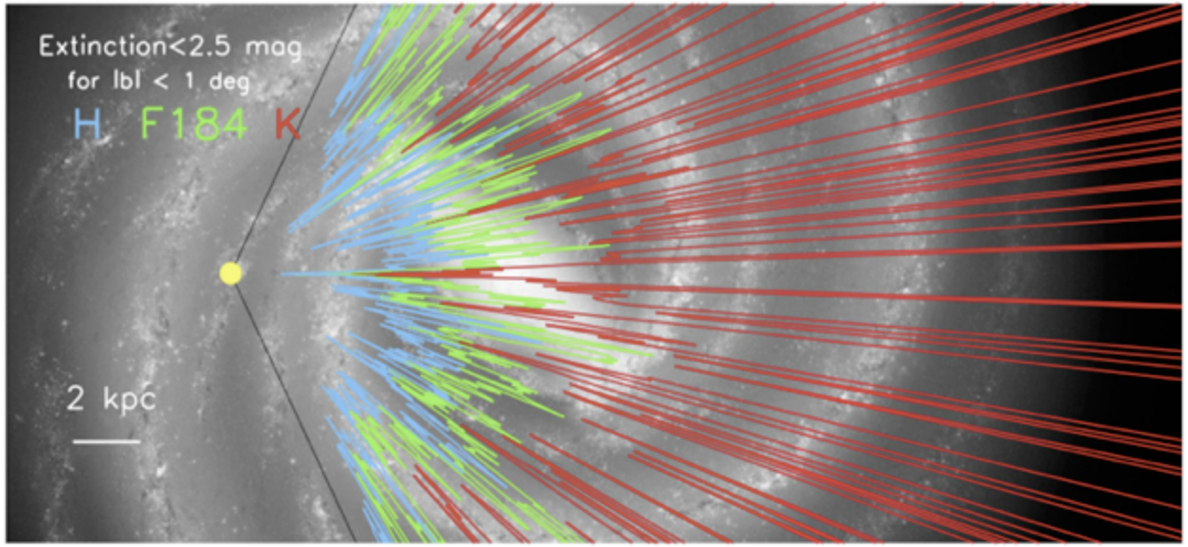
- Roman/HLS & Rubin/LSST deliver similar depths over complementary wavelength ranges
- Rubin: wide area in time-domain
- Roman: high spatial resolution, spectroscopy



Helou et al. 2019

AURA Roman-Rubin Synergies charge:

What are the frontier science questions in General Astrophysics that can be uniquely addressed through the combination of Roman and Rubin? How can the coordination of observations, data archiving, and data analysis best realize these synergies?



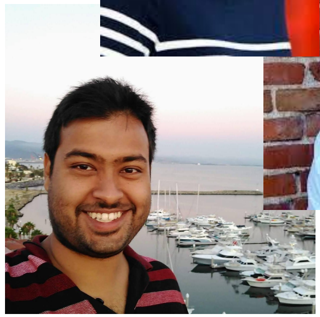
Helou et al. 2019

Working Group Members

Suvi Gezari **(chair)**	STScI	tidal disruption events, transients
Edo Berger	Harvard	gravitational waves [outside expert]
Misty Bentz	Georgia State	SMBHs
Kishalay De	MIT	Galactic transient
Decker French	University of Illinois	extragalactic transients hosts
Robert Jedicke	Hawaii IfA	asteroids
Aaron Meisner	NSF's NOIRLab	brown dwarfs
Michelle Ntampaka	STScI	large-scale structure simulations
Ekta Patel	Berkeley	galaxy dynamics
Dan Perley	Liverpool	supernovae
Robyn Sanderson	UPenn/Flatiron	near-field cosmology
Irene Shivaei	Arizona	galaxies [outside expert]

Željko Ivezic	(**ex-officio;** Rubin)
Harry Ferguson	(**ex-officio**; Roman)
Neill Reid	(**ex officio**; STScI)
Beth Willman	(**ex officio**; AURA, NSF's NOIRLab)







Collaborative & inclusive process: community 'science pitches'

- More than 60 pitches received from the community!
  - Roughly half from senior researchers
  - Other half mostly from postdocs and junior researchers

First Author	Title of Community Science Pitch
MILKY WAY AND SOLAR SYSTEM SCIENCE	
Abrams, Natasha	*Using microlensing distributions to perform Galactic population analysis.*
Busa, Innocenza	*Uncovering new sources of Galactic cosmic rays from coordinated optical and near-infrared monitoring of diffuse clouds in the Galactic Bulge.*
Chakrabarti, Sukanya	*Direct accelerations measurements of eclipsing binaries to probe dark matter in the Milky Way.*
Couperus, Andrew	*Rubin observations of the cycles of host stars of Roman detected exoplanets.*
De, Kishalay	*Accreting compact objects in the dynamic Galactic plane. What are the demographics of accreting compact objects in the Milky Way?*
Eggl, Siegfried	*Joint analysis of Solar System objects from Roman and Rubin observations of the ecliptic*
Fernández-Trincado, José G.	*Dusting-off the Ancient Relics from the heart of the Milky Way. What is the nature of the Milky Way's globular clusters?*
Ginsburg, Adam	*Roman and Rubin observations of young stellar object (YSO) outbursts, and the identification of obscured YSO populations.*

AURA Commissioned Whitepaper to STScI and NOIRLab Directors

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R2–D2: Roman and Rubin – from Data to Discovery

The AURA Roman–Rubin Synergy Working Group

Suvi Gezari (*chair, STScI/JHU*), Misty Bentz (*Georgia State*), Kishalay De (*MIT*), K. Decker French (*UIUC*), Aaron Meisner (*NOIRLab*), Michelle Ntampaka (*STScI/JHU*), Robert Jedicke (*Hawai'i*), Ekta Patel (*UC Berkeley*), Daniel Perley (*Liverpool*), Robyn Sanderson (*UPenn*),

+ 21 outside expert coauthors

We present frontier science questions uniquely addressed by Roman and Rubin synergies:

Milky Way and Solar System

i. *What is the composition, physical state, and morphology of the small bodies in the solar system?*
ii. *What are the demographics and formation histories of stars and substellar objects in the Milky Way?*
iii. *How do compact objects form and evolve in the Milky Way?*
iv. *Roman and Rubin synergies into the dark universe: isolated and accreting compact objects*
v. *What is the distribution of stars and dust in our Galaxy?*

Transient Discovery and Transient Hosts

i. *What are the electromagnetics properties of gravitational-wave events?*
ii. *Using gravitationally lensed SNe as a time machine and an independent measure of H_0.*
iii. *How do galaxies and black holes co-evolve through cosmic time?*
iv. *How do the rates and properties of all classes of transients depend on their host galaxy environments?*
v. *What end states of stars exist in nature that have yet to be discovered?*

Galaxies, Large Scale Structure, and Dark Matter

i. *What is the 3D distribution of small scale structure?*
ii. *Galaxy evolution and large-scale structure through cosmic time.*
iii. *Data-driven discoveries with Roman and Rubin: supporting simulations as parallel data sets.*

Table of Implementation Recommendations

- ❑ Observing Strategy
- ❑ Data Products
- ❑ Joint Analysis Methods
- ❑ Computing Infrastructure
- ❑ Community Engagement

Appendix of Community Science Pitches

60+ science pitches from the community for frontier areas of general astrophysics that would uniquely benefit from Roman-Rubin synergies.

Posted to arXiv on Feb 28, 2022!

arXiv:2202.12311

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Outside Experts

Christian Aganze (*UC San Diego*), Igor Andreoni (*Maryland/JSI*), Eric F. Bell (*Michigan*), Edo Berger (*Harvard*), Ian Dell'Antonio (*Brown*), Ryan Foley (*UC Santa Cruz*), Henry Hsieh (*Planetary Science Institute*), Mansi Kasliwal (*Caltech*), Joel Kastner (*Rochester Institute of Technology*), Charles D. Kilpatrick (*Northwestern/CIERA*), J. Davy Kirkpatrick (*IPAC*), Casey Lam (*UC Berkeley*), Karen Meech (*Hawai'i*), Dante Minniti (*Universidad Andrés Bello*), Ethan O. Nadler (*Carnegie/USC*), Daisuke Nagai (*Yale*), Justin Pierel (*STScI*), Irene Shivaei (*Arizona*), Rachel Street (*LCOGT*), Erik J. Tollerud (*STScI*) and Benjamin Williams(*University of Washington*)

1. EXECUTIVE SUMMARY

The NASA Nancy Grace Roman Space Telescope (*Roman*) and the Vera C. Rubin Observatory Legacy Survey of Space and Time (*Rubin*), will transform our view of the wide-field sky, with similar sensitivities, but complementary in wavelength, spatial resolution, and time domain coverage. Here we present findings from the AURA *Roman*+*Rubin* Synergy Working group[1], charged by the STScI and NOIRLab Directors to identify frontier science questions in General Astrophysics, beyond the well-covered areas of Dark Energy and Cosmology, that can be uniquely addressed with *Roman* and *Rubin* synergies in observing strategy, data products and archiving, joint analysis, and community engagement. This analysis was conducted with input from the community in the form of brief (1-2 paragraph) "science pitches" (see Appendix), and testimony from "outside experts" (included as co-authors).

Rubin will provide wide, deep, multi-band seeing-limited optical imaging with a regular cadence of observations. *Roman* will provide wide, deep, multi-band diffraction-limited near-infrared imaging with grism and prism low-resolution spectroscopic capabilities. The core science goals, and technical requirements to achieve these goals, have been defined separately for *Roman* [2] and *Rubin* [3]. However,

Some Examples of Frontier Science Questions in

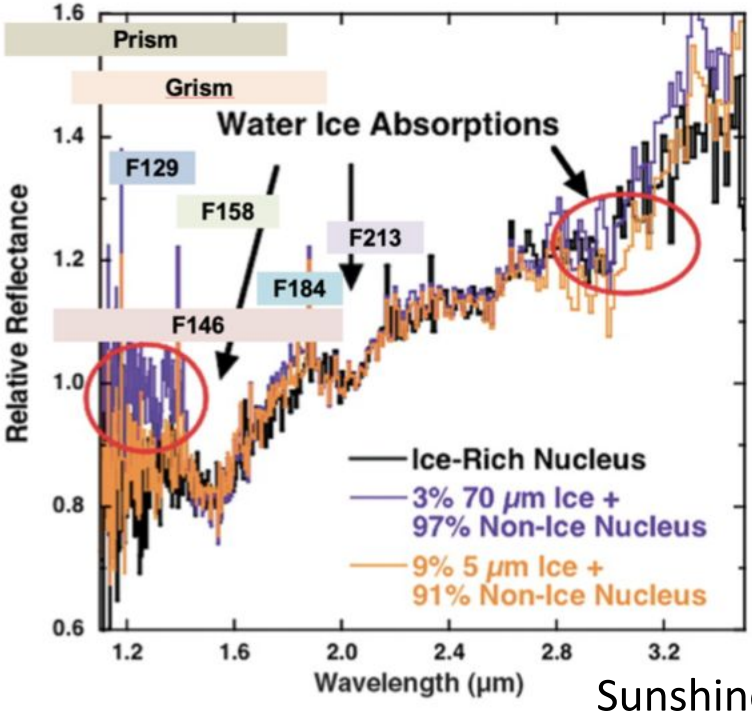
Milky Way and Solar System

Transient Discovery and Transient Hosts

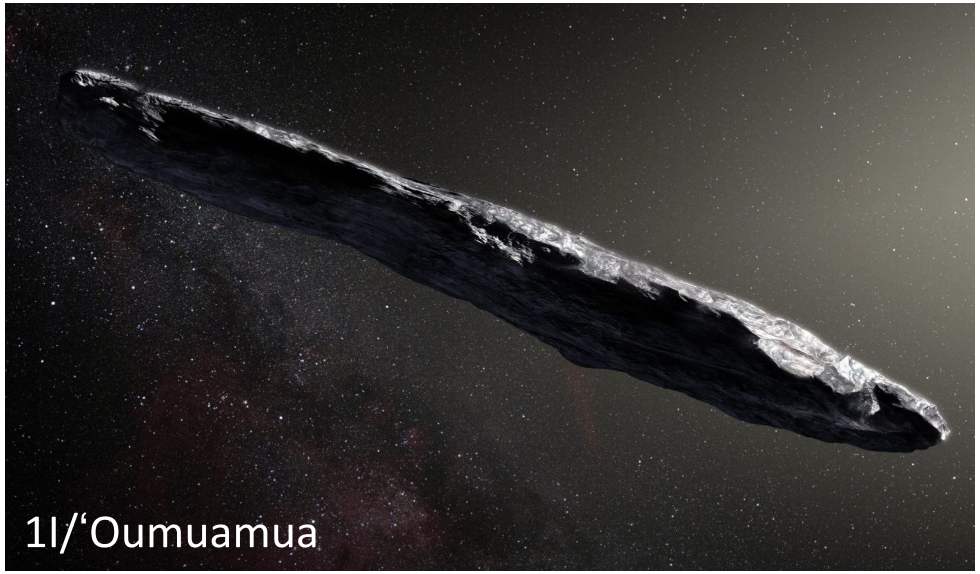
Galaxies, Large Scale Structure And Dark Matter

What is the composition, physical state, and morphology of the small bodies in the Solar System?

-- *Roman* deep imaging and follow-up spectroscopy of *Rubin* discovered small bodies, including hazardous near-Earth objects and interstellar asteroids, for characterization of orbits, measuring morphology, and identification of water ice features.



Sunshine et al. 2006



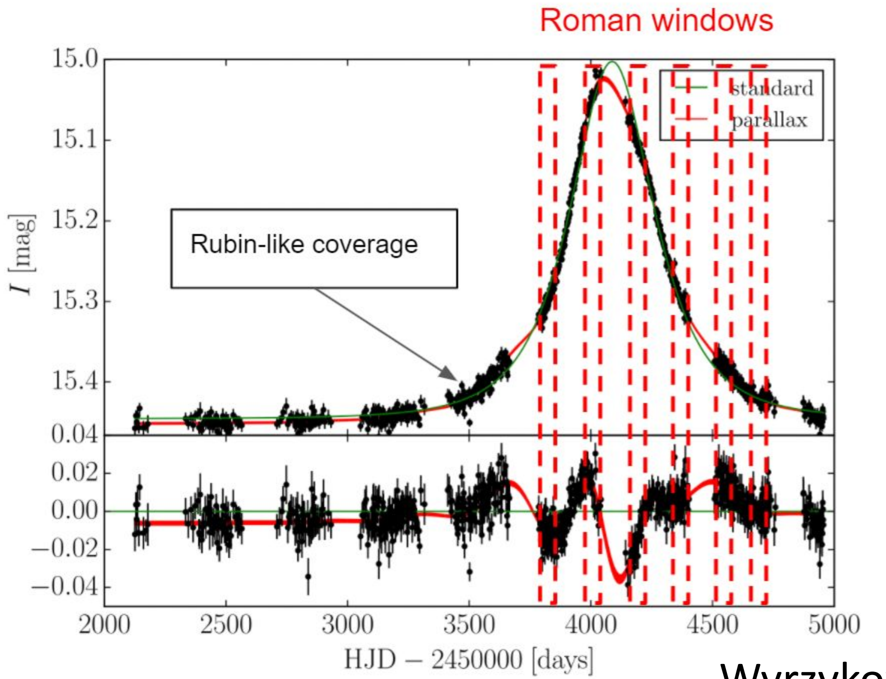
What are the demographics and formation histories of stars and substellar objects in the Milky Way?

-- *Roman* high resolution imaging follow-up of young stellar objects (YSOs) discovered in outburst by *Rubin.* Such outbursts may account for a significant fraction of accreted mass during star formation, and only a handful of erupting YSOs have high resolution imaging.

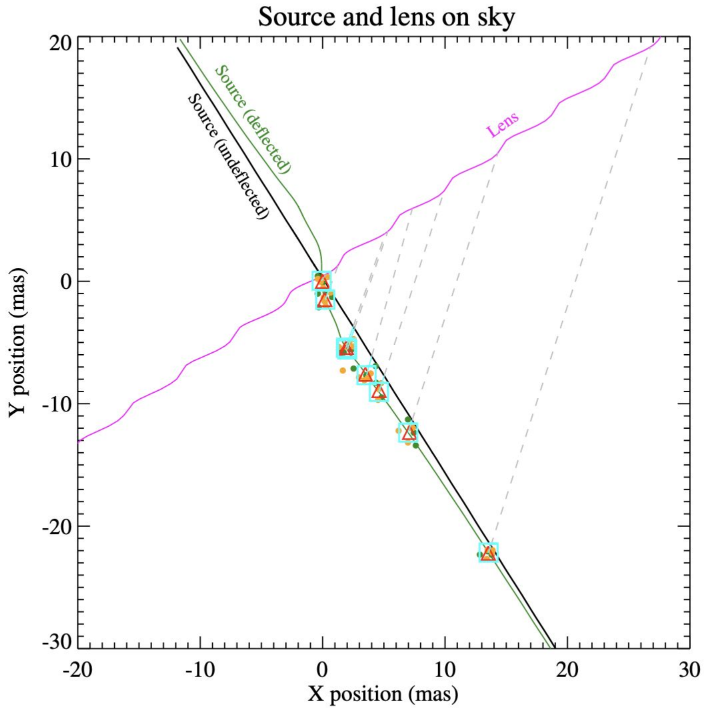
Hubble image of nearby YSO PV Cep in outburst.

Roman and Rubin synergies into the dark universe: Isolated compact objects

-- *Rubin* survey of the *Roman* bulge footprint to fill in gaps of Galactic Bulge Time Domain Survey, and extend photometric coverage to constrain long-lived microlensing events characterized by NS/BH systems, together with their astrometric deflection measured by Roman.



Wyrzykowski et al. 2016

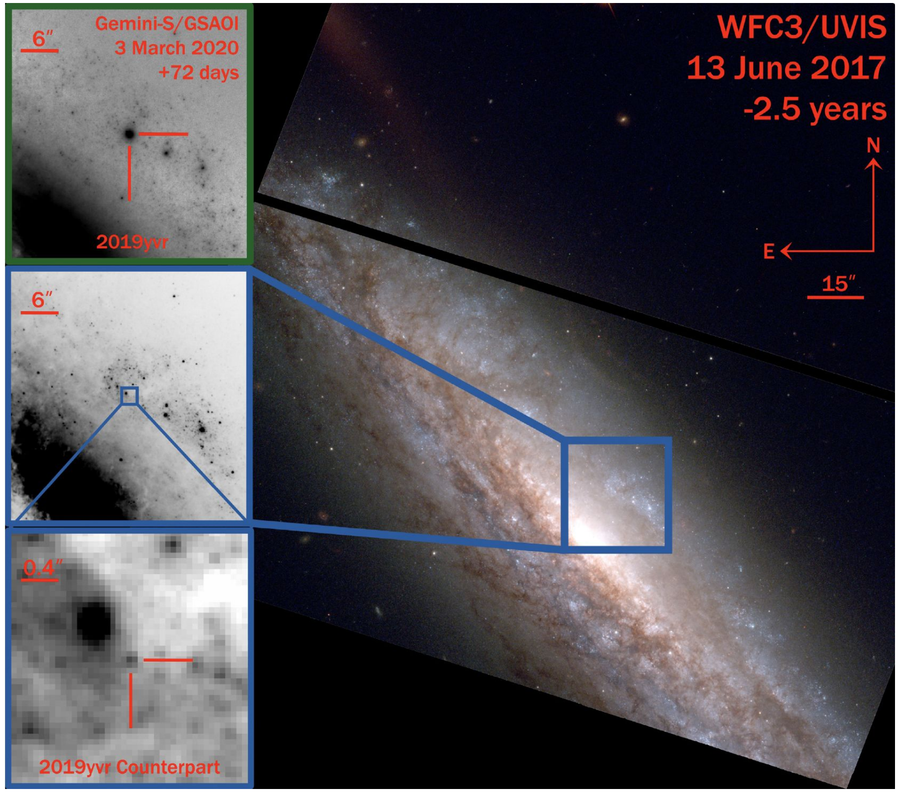


Astrometric microlensing detected by *Hubble* for a 7.1 M_{sun} black hole microlensing event discovered by OGLE.

Sahu et al. 2022

How do the rates and properties of all classes of transients depend on their host galaxy environments and stellar populations?

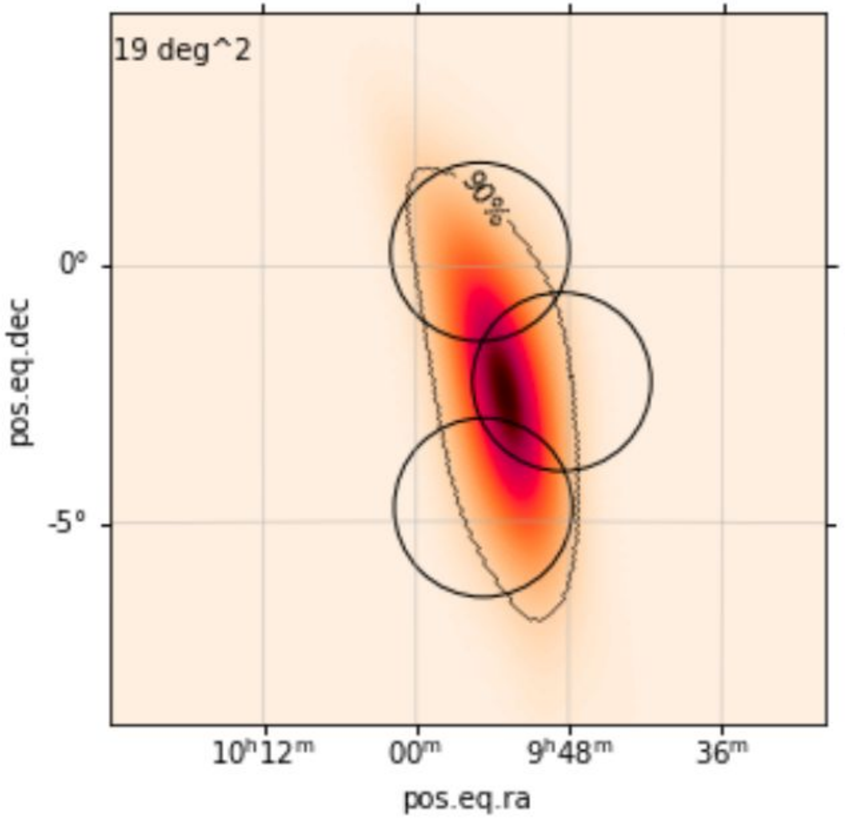
-- *Roman* pre-imaging of *Rubin* discovered transients to characterize their progenitor stars and local environments, potentially with an early survey of Virgo and Fornax clusters.

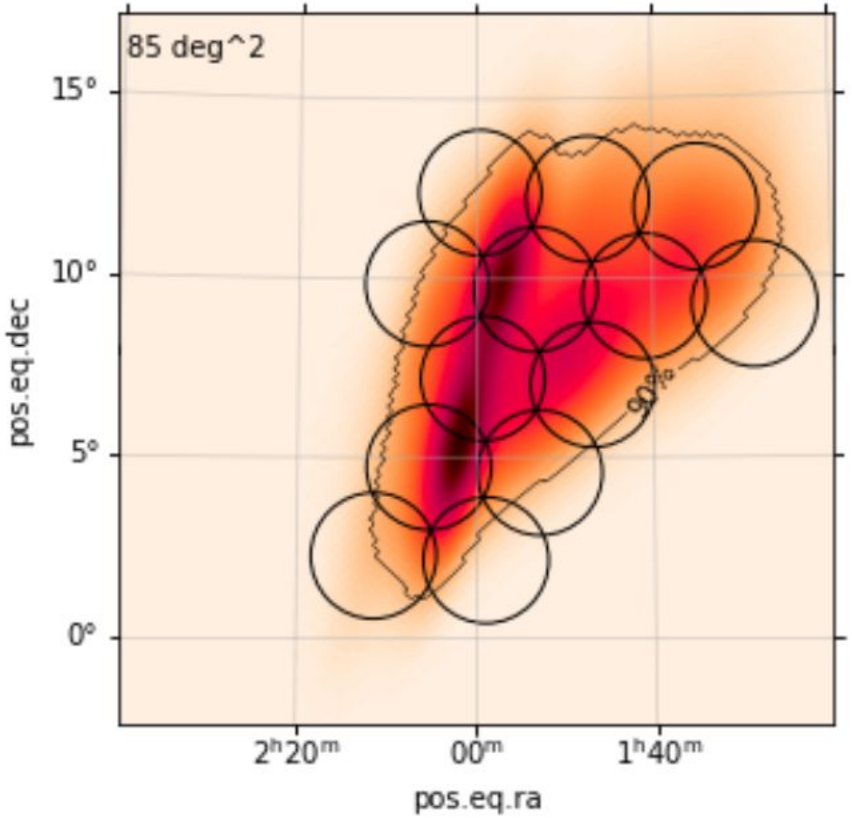


Kilpatrick et al. 2021

What are the electromagnetic properties of gravitational wave events, their relation to binary properties, and implications for r-process nucleosynthesis?

-- *Roman* and *Rubin* rapid coordinated TOO follow-up observations of the localization regions (up to tens of square degrees) of GW-detected events and SGRBs.

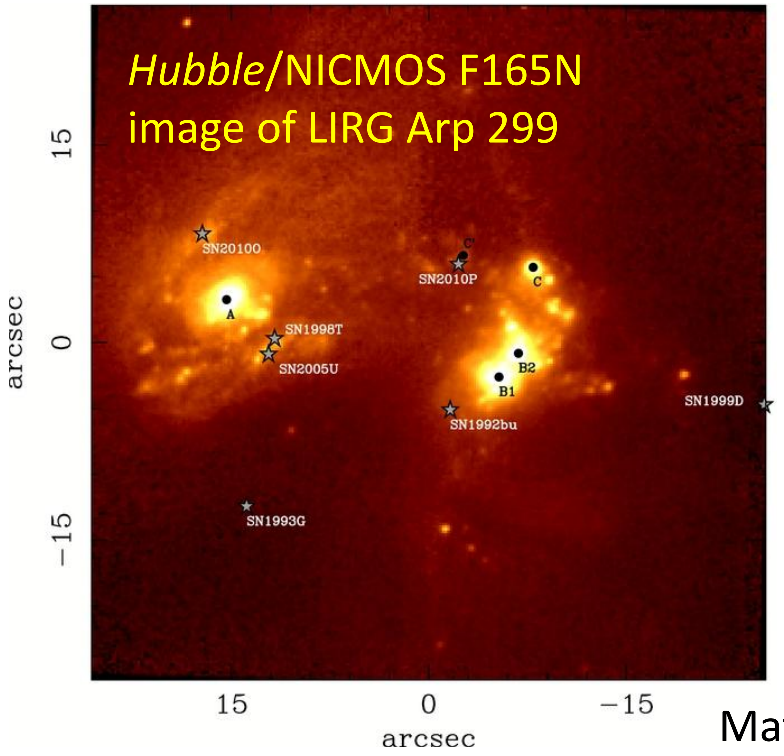




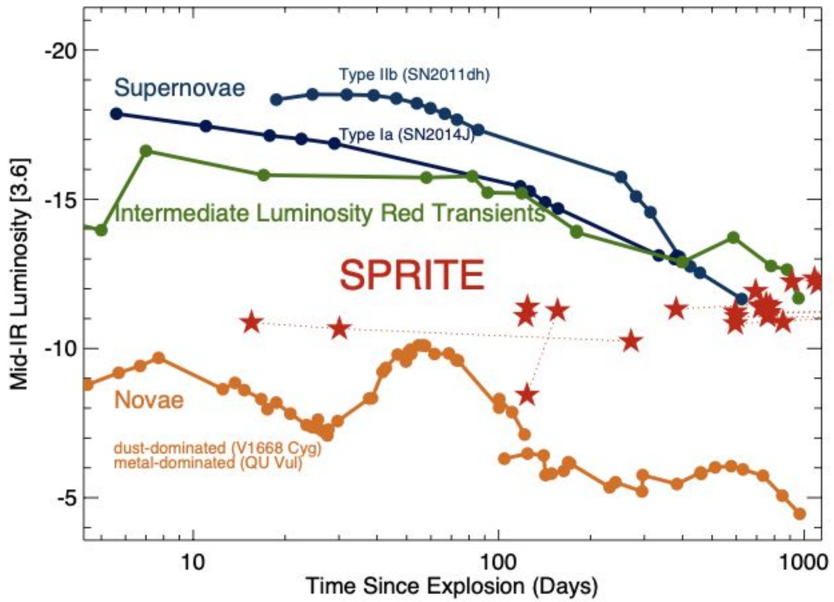
Andreoni et al. 2021

What end-states of stars exist in nature that have yet to be discovered?

-- *Roman* and *Rubin* together provide the ability to cover major "blind spots" of current surveys: dust-obscured (from dusty environment or newly synthesized dust), high-redshift, and intrinsically red transients.



Mattila et al. 2012

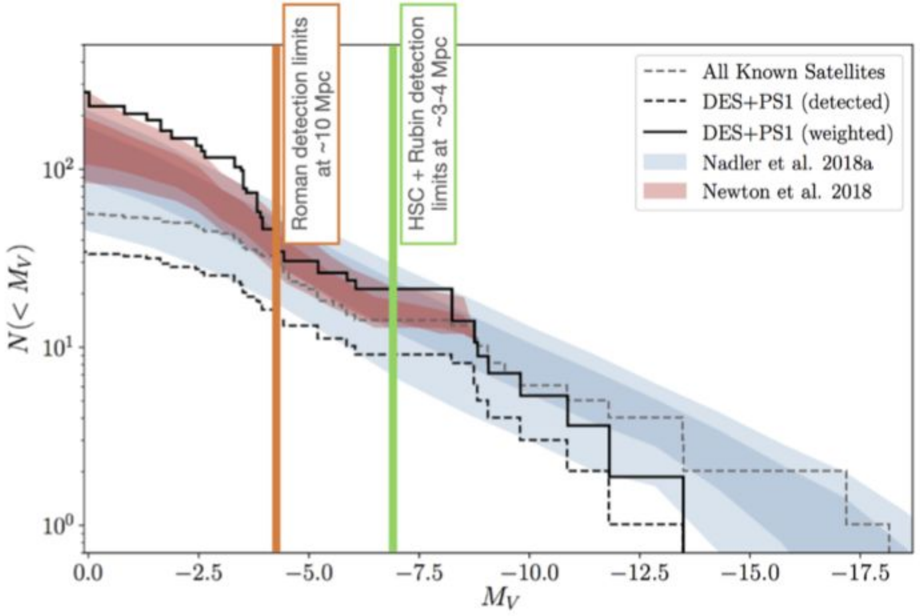


Spitzer Infrared Intensive Transients Survey (SPIRITS) discovery of eSPecially Red Intermediate-luminosity Transient Events (SPRITEs).

Kasliwal et al. 2017

What is the 3D distribution of small scale structure?

-- *Roman+Rubin* will allow us to draw the first statistical connections between the faintest known satellite populations and their hosts by doubling the number of known satellite galaxies around nearby galaxies (3-4 Mpc), to put them on roughly equal footing with our knowledge of M31's galaxy luminosity function.



adapted from Drlica-Wagner+ 2020

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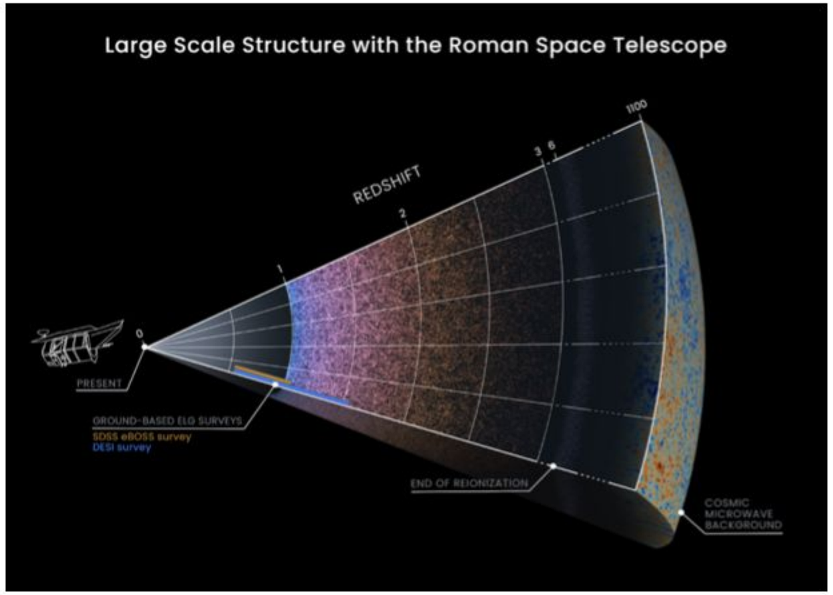
Galaxy evolution and large-scale structure through cosmic time.

-- *Roman+Rubin* will produce unprecedented, detailed maps of the sky. Photometric and spectroscopy galaxy surveys produced by these two observatories will offer new insights on cosmological models, the formation of large scale structure, galaxy evolution, and the epoch of reionization.



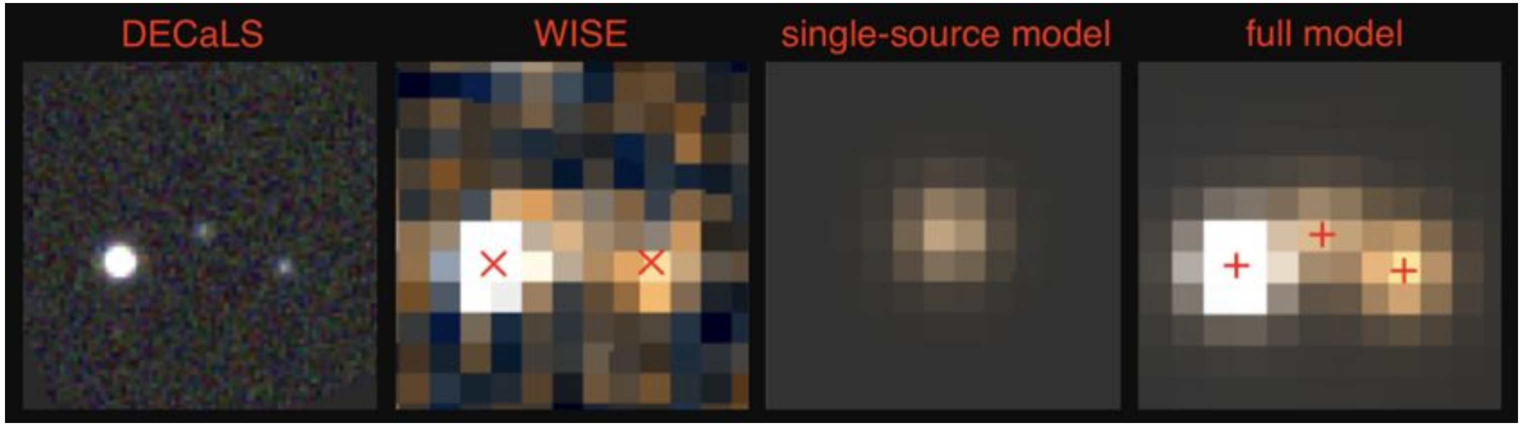
Implementation: 4 thematic areas

- (1/4) Observing strategy
  - Survey observations of the Galactic plane and bulge by Rubin in its Deep Wide Fast Survey
  - Roman target of opportunity observations of Rubin-discovered transients
- (2/4) Data products
  - Cross-matched Roman/Rubin catalogs (including moving objects)

See our R2-D2 white paper for the complete list of implementation strategies.

Implementation: 4 thematic areas

- (3/4) Joint analysis methods (see also Chary et al. 2019 JSP report)
  - Cross-survey forced photometry, Roman deblending of crowded Rubin fields, astrometric cross-calibration, …
- (4/4) Computing infrastructure
  - Libraries of cosmological simulations, simulated observations
  - Co-location of Roman and Rubin data in a common analysis environment



forced photometry schematic, adapted from Lang et al. 2016

Conclusion

- The combination of Roman & Rubin uniquely enables an ***extremely broad*** range of astrophysical investigations, beyond Dark Energy and cosmology.
- These frontier science questions span from our own solar system to the epoch of reionization.
- Coordinated Roman/Rubin observations, data products, joint processing, and data archiving would help realize the full combined potential of these two missions.