

# Nancy Grace Roman Space Telescope Research and Support Participation Opportunities

## Abstracts of Selected Proposals (NNH22ZDA001N-ROMAN)

This document provides the abstracts of proposals selected for funding within the *Roman* program. Principal Investigator (PI) name and institution, lead Co-I name and institution, proposal title, and category are also included. 91 proposals were received in response to this opportunity. On July 5, 2023, 30 proposals were selected for funding. For more information, please contact the *Roman* Program Scientist at NASA’s Headquarters, Dominic Benford ([Domini.Benford@nasa.gov](mailto:Domini.Benford@nasa.gov)).

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**Brett Andrews / University of Pittsburgh, PI**  
***Exploiting Deep Learning to Improve Roman Photometric Redshifts***  
**WIDE-FIELD SCIENCE – REGULAR**

Photometric redshifts (photo- $z$ s) will be a critical ingredient for studies of both galaxy evolution and cosmology with *Roman*. The *Roman* Science Operations Center will estimate photo- $z$ s, but these will only use integrated photometry in *Roman* bands, disregarding the key color information in *Rubin* bands and morphological information that recent deep learning methods have unlocked. At low redshift ( $z < 0.2$ ), algorithms that exploit resolved imaging of galaxies via deep learning methods have delivered much better photo- $z$  performance than those that rely on integrated photometry alone. However, at higher redshifts the potential constraining power of deep, multi-band resolved imaging has been inaccessible due to the comparatively small sizes of galaxies in comparison to ground-based seeing.

*Roman* will bypass this limitation by providing deep and well-resolved images of galaxies – even for those at  $z > 1$  – in multiple bands from the red-optical to the near-IR. We propose to apply bleeding-edge deep learning methods to existing *Roman*-like data sets with resolved imaging from Hubble to test how much improvement the incorporation of resolved imaging will yield for deep samples. This should be particularly effective for removing the degeneracies between low and high redshift that plague many photo- $z$  algorithms.

Specifically, we propose to train a state-of-the-art type of deep neural network – a masked autoencoder – to distill color and morphology information from *Roman*-like images from CANDELS and 3D-DASH HST imaging into low-dimensional encodings. We will then test our ability to predict the high-precision multi-band photo- $z$ s from COSMOS2020 and from spectroscopic redshifts using regression from the low-dimensional encodings and integrated *Roman* + *Rubin*-like broad-band photometry. We will compare the results to photo- $z$ s estimated with methods that only use integrated *Roman* + *Rubin*-like broad-band photometry.

The strikingly distinct morphologies of low- $z$  and high- $z$  galaxies, as well as the radically different resolved morphologies observed in bands above versus below the 4000Å break, should be instrumental in breaking the photo- $z$  degeneracies that beset photometry-only methods. Based upon the performance of deep learning-based photo- $z$  methods with resolved SDSS imaging in past work, we expect that the more modern techniques we plan to provide should produce the most accurate *Roman* photo- $z$ s across a broad range of magnitude-redshift-color space. We propose to develop and test the algorithms needed to realize that potential with existing HST optical and NIR imaging. Should our method prove valuable, additional time and effort (beyond the scope of this proposal) will be required to implement it at scale on *Roman* data (in coordination with the *Roman* Science Operations Center) early in the mission’s lifetime for maximum benefit, highlighting the urgency of our development effort.

We will share the resulting code, produce thorough documentation (including lessons learned), and release the new CANDELS photo- $z$  catalogs with the community. The resulting photometric redshift catalogs could significantly enhance the legacy value of the CANDELS data sets as a free byproduct of our work to develop new methodologies for *Roman*.

**Ruslan Belikov / NASA – Ames Research Center, PI**  
**Eduardo Bendek / Jet Propulsion Laboratory, Institutional PI**  
*Coronagraph Instrument testing and performance evaluation in single- and binary star modes*  
**CORONAGRAPH COMMUNITY PARTICIPATION PROGRAM**

We propose to assist the *Roman* Coronagraph Instrument team with laboratory testing, as well as performance predictions, in both single as well as multi-star modes. The main objectives of this proposal are to: (1) gain even greater confidence in reaching the Threshold Technology Requirement (TTR); (2) advance performance capability and identify opportunities beyond TTR, especially ones that are enabled by the multi-star contributed mode. In order to achieve these objectives, our work will consist of three inter-related parts: pure single-star mode; MSWC-assisted single star mode; and multi-star mode. We describe these in what follows.

(1) We will work with the *Roman* Coronagraph Instrument team to test and advance the performance of the pure single star mode (on the OMC test bench, or the new planned bench for the flight instrument). In particular, we will assist with testing and optimizing baseline single-star algorithms, finding limiting factors, and gaining a better overall understanding of technical subtleties of operating the Coronagraph Instrument. In addition, we will contribute computation efficiency improvements based on algorithms we've developed, such as semi-analytical approximations (e.g. small-star approximation), zoomFFT, etc. The exact details of this work are meant to be flexible and adapt to the needs of the *Roman* Coronagraph Instrument test program. We will leverage our experience working with the OMC test bench over the past 2 years, both in HLC single-star mode, as well as SPC single- and multi-star modes.

(2) We will take advantage of synergies with our MSWC project to maximally benefit standard Coronagraph Instrument single-star modes. In particular, the Coronagraph Instrument models we developed for binary star sources are also useful for analyzing background sources contaminating single-star targets. This is valuable because the Coronagraph Instrument observation time is limited, so we cannot afford to spend time on targets that turn out to be contaminated by off-axis sources. The same models are also useful to more accurately assess the viability of binary stars as single-star mode targets. In addition, we will study several techniques that enhance single-star mode operation by using information or metrology provided by the MSWC mask. The basic idea is to test certain aspects of MSWC which happen to be applicable to single-star modes. This reduces the risk of TTR, supports several Coronagraph Instrument Technology Objectives, and helps enable performance beyond TTR.

(3) Finally, we will further develop and test the multi-star mode for flight observations, leveraging and complementing the work we are doing as part of the ISFM program, and in particular bring MSWC is as close to flight-ready as possible, not only in terms of performance, but also in terms of compatibility with flight software. We will coordinate with the *Roman* Coronagraph Instrument flight software team to develop MSWC code to flight-readiness. Also, in case the Coronagraph Instrument allows ground testing of

instrument modes other than HLC, we plan to be ready to perform a test with flight hardware. We will also incorporate our findings and characterizations of flight components into MSWC mode performance estimates.

The primary significance of this work lies in gaining further confidence in achieving the Coronagraph Instrument TTR and Technology Objectives, which is of critical importance to ensure the Coronagraph Instrument success as a technology demo. In addition, the performance enhancements we described above have the potential to make the Coronagraph Instrument a powerhouse of exoplanet science in its own right.

**Jonathan Blazek / Northeastern University, PI**  
***Galaxy Intrinsic Alignments for Cosmology with the Roman Space Telescope***  
**WIDE-FIELD SCIENCE – REGULAR**

The Nancy Grace Roman Space Telescope brings exciting new capabilities for cosmology. The High-Latitude Wide-Area Survey on the Wide-Field Instrument will provide the positions and shapes of hundreds of millions of galaxies, and over ten million galaxy spectra, from which analysis of weak gravitational lensing and galaxy clustering will form a main pillar of cosmology studies.

Despite its tremendous statistical power, the ultimate success of *Roman* will depend on our understanding of a range of astrophysical, observational, and instrumental effects. With current cosmology projects, we have already reached the point where cosmological constraints are determined by these systematic uncertainties. While observing from space reduces several challenges induced by the atmosphere, the impact of astrophysical effects is unavoidable. Of particular interest to this proposal are galaxy “intrinsic alignments” (IA), correlations in the true shapes of galaxies as influenced by their local environment and formation. Galaxy IA induces observed correlations between galaxy shapes that mimic the weak lensing signal we are trying to measure. IA is one of the most significant astrophysical systematics for *Roman* and other future cosmology projects – without properly accounting for it, analyses can be significantly biased. Conversely, if sufficiently understood, IA can provide a new probe of cosmology and astrophysics.

The constraining power of *Roman* makes it critical that IA and other astrophysical effects are understood to a high degree of accuracy. At the same time, *Roman*’s depth means that we are probing galaxies that are fainter and more distant than those reached in current surveys, and we are thus more reliant on other approaches to predict their behavior. This proposal aims to address this challenge, using a combination of observational data, simulations, and analytic modeling to achieve three key objectives. First, we will combine current measurements to predict the plausible range of IA scenarios and the impact on *Roman* cosmology. These results will allow us to determine optimal modeling strategies. Second, we will provide simulation tools and proof-of-concept simulated *Roman* galaxy catalogs with realistic IA, to be used for pipeline validation and as an input for community-wide simulation efforts. Third, we will determine how to utilize IA as a new physical probe with *Roman* data.

The methods employed in this proposed research include analyzing existing observational data, processing numerical simulations, and analytic modeling. Forecasts will be done as realistic analysis of synthetic *Roman* data vectors. The simulation component will utilize “gravity-only” simulations, avoiding several challenges that arise when using hydrodynamics. We will refine and employ a method that is able to populate simulated dark matter structure with realistic galaxies, including alignments. These simulated galaxies will improve our understanding of galaxy IA and their impact on *Roman* analyses. We will also use them to develop a simulation-based model of IA and to improve and test analytic modeling in the context of *Roman*. Finally, these simulation and modeling tools will be used to develop new analyses for *Roman* that will utilize

observed galaxy shapes to probe both astrophysics (e.g. galaxy formation) and fundamental physics (e.g. inflation and dark matter interactions).

This proposal is highly responsive to the criteria of this WFS opportunity and to NASA science goals more broadly. It will enable core *Roman* cosmology analyses through better understanding and treatment of IA, including guidance to the relevant Project Infrastructure Team(s). It will expand the potential scientific impact of WFI data, including opportunities to learn about both astrophysics and fundamental physics of the Universe. It will provide simulation products and software that enable projects and collaboration across the *Roman* science community.

**Tzu-Ching Chang / Jet Propulsion Laboratory, PI**  
*Detecting Microhertz Gravitational Waves with the Nancy Grace Roman Space Telescope*

**WIDE-FIELD SCIENCE – REGULAR**

Gravitational waves (GWs) are a new avenue of observing our Universe. So far, we have seen them in the  $\sim 10$ -100 Hz range, and there are hints that we might soon detect them in the nanohertz regime. Multiple efforts are underway to access GWs across the frequency spectrum; however, parts of the frequency space are currently not covered by any planned or future observatories. Our recent work has shown that photometric surveys can bridge the microhertz gap in the spectrum between LISA and Pulsar Timing Arrays (PTAs) through relative astrometric measurements. Similar to PTA measurements, these astrometric measurements rely on the correlated spacetime distortions produced by gravitational waves at Earth, which induce coherent, apparent stellar position changes on the sky. To detect the microhertz GWs with an imaging survey, a combination of high relative astrometric precision, a large number of observed stars, and a high cadence of exposures are needed. The *Roman* Galactic Bulge Time Domain Survey (RGBTDS) would have all of these components. Our program seeks to simulate relevant data and explore survey designs for the *Roman* mission to better estimate the sensitivity of *Roman* to gravitational waves from supermassive black holes in the microhertz regime.

Using analytic estimates, we calculated that the RGBTDS is sensitive to GWs with frequencies ranging from  $7.7 \times 10^{-8}$  Hz to  $5.6 \times 10^{-4}$  Hz, which opens up a unique GW observing window for supermassive black hole binaries and their waveform evolution. While the detection threshold assuming the currently expected performance proves too high for detecting individual GWs given the expected supermassive black hole binary population distribution, we showed that *Roman* would still be sensitive to the stochastic GWB with an estimated signal-to-noise (SNR)  $\sim 1$  and set interesting limits to SMBH population and evolution. If the mean astrometric deflection, which is normally lost due to the use of guiding stars as reference for spacecraft pointing solution, could be recovered, a factor of 100 in sensitivity improvement could be expected. We will investigate this exciting prospect, which would allow confident detection of SMBH with a chirp mass  $M_c > 10^7 M_\odot$  out to 50 Mpc, and detection of stochastic GWB with an estimated SNR  $\sim 70$ .

In this proposal, working with mission and RGBTDS experts, we propose to study and simulate several key aspects of the RGBTDS, including the recovery of the mean astrometric deflection, as well as studying how modifications to the RGBTDS design could improve the sensitivity to GWs. Relying on these estimates, we will also develop an optimal statistic tailored to *Roman* to detect spatially and temporally coherent modulations and stochastic gravitational wave background modulations (e.g., from the superposition of many SMBHBs) in the RGBTDS data. Our program will guide the future development of the full simulation and analysis pipeline that will be required to make *Roman* a space based GW detector.



**Tansu Daylan / Washington University, PI**

***Preparing for a leap: Precursor Strong Lensing Science with Roman Towards Precision Cosmology***

**WIDE-FIELD SCIENCE – REGULAR**

The *Roman* Telescope will offer a unique opportunity to study strong lenses across cosmic time, enabling thorough investigations of the substructure and microphysics of dark matter. For the first time, the discovery images will have the required depth and resolution to perform high-precision measurements. What the Hubble Space Telescope could do on a limited selected sample, *Roman* will be able to achieve over the entirety of planned surveys. There is currently no realistic set of simulations of strong lenses with *Roman*, which can undermine the progress towards achieving maximal cosmology from *Roman*. Therefore, a set of realistic strong lens simulations must be performed in time in order to train and test the strong lensing pipelines that will process the *Roman* data.

We propose to generate a comprehensive suite of simulated *Roman* images of realistic strong lenses with substructure, organize a data challenge for the research community to test their detection and characterization pipelines on these data, and develop robust retrieval pipelines to determine the selection functions on the population-level properties of dark matter substructure indicative of its microphysics.

We will produce a detailed and realistic lens population over cosmic time and then generate synthetic *Roman* data that can be used for training, validation, or survey planning. We will include in our simulations both galaxy-galaxy-type lenses that are optimal for inferring substructure and quasar lenses that can enable other science cases such as time-delay tomography. Using our multiband simulations, we will enable precise determinations of the expected yields of static galaxy-galaxy strong-lenses, strongly-lensed quasars, and supernovae, as well as their population properties. Toward this goal, we will develop a simulation pipeline that accurately incorporates up-to-date detector characteristics of the Wide Field Instrument (WFI) on *Roman* and a population model for strong lenses informed by the Hubble Space Telescope and DES. Thus, we will help prepare *Roman* for the operational phase of the mission and enhance the science return of the WFI. Our work will be a Regular Wide Field Science (WFS) effort over two years, from September 2023 to September 2025.

The primary merit of our proposed effort is to facilitate the timely simulation and survey planning to enable optimal detection and characterization of the strong lenses following the launch of *Roman*. In particular, the early timing of our precursor effort is crucial to deliver a strong-lens simulation pipeline for *Roman* on time so that subsequent efforts from 2025 to launch can use the simulation pipeline for yield simulations and data reduction pipelines. Accordingly, our proposed effort is especially suited as a precursor effort ~3-4 years before launch.

Our work is especially relevant as a regular WFS effort in *this cycle* since our simulations will open the path towards designing strong lens surveys with *Roman* and optimizing other community surveys for ancillary strong lensing science. Therefore, it is a uniquely suited and timely precursor science effort to be optimally completed ~2 years before the launch of *Roman*.

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**John Woodward / National Institute of Standards & Technology, Co-PI**  
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**J Allyn Smith / Austin Peay State University, Institutional PI**  
*Establishing SI-traceable Standard Reference Fields and Low Redshift Type Ia  
Supernova Calibration for Roman Wide Field Science*  
**WIDE-FIELD SCIENCE – LARGE**

Establishing Infrared Flux Standards for *Roman* Wide Field Instrument Science

The Nancy Grace Roman Space Telescope (*Roman*) is NASA's next large flagship mission scheduled for launch by 2027. *Roman*'s Wide Field Instrument (WFI) will have a large field of view (0.28 sq deg), providing Hubble-like sensitivity and resolution in the infrared enabling transformational investigations in cosmology, exoplanet science and general astrophysics. The core community surveys include a High Latitude Wide Area survey, a High Latitude Time Domain survey, and a Galactic Bulge Time Domain survey.

In order to meet *Roman*'s dark energy goals, a requirement on the design of the imaging component of the High Latitude Wide Area Survey is to enable accurate measurements of the color to less than 0.5% as well as precision photometry over 11 mag in brightness of 0.3% of thousands of Type Ia Supernovae, and accurate photometric redshifts of millions of galaxies. These observations will be used to measure the accelerated expansion of the universe and to better constrain the nature of dark energy. Further, synergies with ground-based programs like the LSST with the *Rubin* Observatory and with space-based observatories like *Euclid*, will also require high fidelity for accurate cross-mission calibration.

At present the principal limitation to achieving these requirements is the paucity of standard stars that are both well characterized and have NIST-traceable spectral energy distribution in the critical brightness range between about  $V = 14-20$  mag. We propose to use a combination of ground-based and space-based assets to conduct a multi-year campaign to establish several hundred flux standards with an accuracy of a few millimags that will help *Roman* meet its demanding photometric requirements that enable transformational science.

**Rosanne Di Stefano / Harvard-Smithsonian Center for Astrophysics, PI**  
***Observatory Microlensing and Binary Self Lensing with Roman and with Rubin***  
**WIDE-FIELD SCIENCE – REGULAR**

One of the primary goals of the Nancy Grace Roman Space Telescope mission is to establish the population properties of planetary systems in the Galactic Bulge. Its Galactic Bulge Time Domain Survey will be keenly sensitive to microlensing events. With its 15-minute cadence, it is particularly well suited to discover short events that could be free-floating planets, and also the short-term subtle deviations in a stellar-lensing light curve that are caused by planets. Predictions have been made that *Roman* will discover ~1400 planets via microlensing.

The *Rubin* Observatory's Large Survey of Space and Time (LSST) is presently slated to cover the *Roman* field. It will start observations roughly a year earlier, observe the field in between *Roman*'s 72-day observation intervals, and continue for several years after *Roman* concludes. Our team, experts in microlensing and members of the *Rubin* microlensing group, proposes work that will use the *Roman/Rubin* Synergy to enable *Roman* to achieve its bold microlensing goals.

For long events, whether caused by black hole lenses or slow-moving stars, *Rubin* can play a crucial role in making sure we identify lensing events that do not start and complete within *Roman*'s observing window. We have been deeply engaged in developing event detection within LSST data, and will be working to identify the roughly 1200 *Rubin*-detectable events that are expected each year in the 2 square degree *Roman* field. Many *Rubin*-detected events that can be detected by *Roman*, even near baseline, will still be active when *Roman* starts observations. This applies not only to black-hole lenses. In fact, the events that can be detected by both observatories will be dominated by events with durations of weeks or months.

To increase the numbers of lensing events *Roman* will identify, and to increase the efficiency for the extraction of correct system parameters, we have devised a two-part plan.

First, we will conduct a sequence of light curve simulations in which we use, sequentially, a variety of *Roman* and *Rubin* sampling strategies in the *Roman* field. Our analyses of the simulated data will help us to identify optimal observing strategies, and should shape the approach both observatories take in the *Roman* Bulge field.

Second, we will create a *Roman* Input Microlensing Catalog for the Galactic Bulge. The entries in the catalog will be the event coordinates and the full LSST-multi-band light curves for each lensing event candidate. We will also create a complementary catalog of microlensing imposters—those events that could be easily confused with microlensing events, but which we have found to have other natures. With these catalogs in hand (or rather, downloaded from IPAC), *Roman* will start observations knowing the locations and prior histories of, potentially, hundreds of events. This will increase *Roman*'s early science return.

The science return will also be significantly increased by another aspect of the *Roman/Rubin* Synergy: the complementarity of their spectral coverage. *Rubin*'s multiband (up to 6) coverage will provide spectral information about the lensed source and other objects along the line of sight.

From a physical perspective, the importance of this work is not simply an increase in the number of events *Roman* discovers. Our work will play crucial roles in allowing *Roman* to correctly characterize the events and, eventually, the full population responsible for planetary microlensing in the Bulge. If our work conducted under the aegis of this program is successful, as we expect it to be, we will take advantage of future funding opportunities to transform the catalog into a dynamic resource that is continuously updated with the combination of *Roman* and *Rubin* microlensing data.

Our team is uniquely qualified to conduct this research, which should be started as soon as possible if *Roman* is to derive the full scientific advantage of the *Roman/Rubin* microlensing synergy.

**Olivier Doré / Jet Propulsion Laboratory, PI**  
**Katarina (Dida) Markovič / Jet Propulsion Laboratory, Deputy PI**  
**Brendan Crill / Jet Propulsion Laboratory, Pipeline Manager**  
**Rachel Bean / Cornell University, Institutional PI**  
**Tim Eifler / Steward Observatory – University of Arizona, Institutional PI**  
**Christopher M. Hirata / The Ohio State University, Institutional PI**  
**Shirley Ho / New York University, Institutional PI**  
**Bhuvnesh Jain / University of Pennsylvania, Institutional PI**  
**Rachel Mandelbaum / Carnegie Mellon University, Institutional PI**  
**Vivian Miranda / Stony Brook University, Institutional PI**  
**Michael A. Troxel / Duke University, Institutional PI**  
*Maximizing Cosmological Science with the Roman High Latitude Imaging Survey*  
**PROJECT INFRASTRUCTURE TEAM**

The most surprising cosmological discovery of the last decades has been the demonstration that the expansion of the universe is accelerating rather than decelerating. We have since measured the cosmic expansion history by multiple methods with much greater precision over a wide range of redshift, but understanding the origin of cosmic acceleration remains one of the most pressing unsolved problems in fundamental physics.

Alongside the expansion history, one can probe the physics of cosmic acceleration by measuring the growth of matter clustering from primordial fluctuations measured in the cosmic microwave background (CMB) to low redshift structure measured through weak gravitational lensing or redshift-space distortions of the galaxy distribution.

Measurements of structure growth are especially important for distinguishing theories that explain cosmic acceleration with an exotic energy component (a cosmological constant or more general “dark energy”) from theories that modify general relativity itself.

The Nancy Grace Roman Space Telescope (hereafter *Roman*) will be one of the most powerful facilities for weak lensing cosmology ever built; compared to the Vera C. *Rubin* Observatory’s Legacy Survey of Space and Time (hereafter LSST), *Roman* measures a similar number of galaxy shapes per unit observing time with the high angular resolution and stability afforded by space-based observations. Forecasts imply that cosmological weak lensing in a 2000 square degree high-latitude imaging survey (HLIS) with *Roman* could lead to an order of magnitude improvement in precision over current measurements. Cross-correlations with galaxies and the masses and abundance of galaxy clusters will provide valuable additional cosmological information. To realize *Roman*’s cosmological goals, it is critical to control sources of systematic uncertainty and extract information from small scales and non-Gaussian statistics that are enabled by the gains in redshift coverage, galaxy number density and the quality of space based imaging with *Roman*. These measurements have the potential to revolutionize our understanding of cosmology, gravity, and fundamental physics.

We propose a program of infrastructure development that will enable the *Roman* high-latitude imaging survey to achieve its extraordinary cosmological potential, while simultaneously providing unprecedented volumes of exquisite data for an enormous range of astrophysical investigations. We have structured this proposal tightly around a list of deliverables, grouped under the broad categories of survey strategy, weak lensing measurements, cosmological inference, and community engagement. Our team is composed of leading experts on these topics, many of whom have been heavily involved with the *Roman* mission for a decade or more. The infrastructure proposed here will build heavily on the work that we have done over the past six years as members of the Science Investigation Team for cosmology with the HLIS. We look forward to working with the mission team and with scientists from the Science Operations Center (SOC), the *Roman* community, and the astronomy and cosmology community at large. Our program will build the infrastructure required to meet the relevant *Roman* cosmological science goals and will lay the foundations for future powerful joint analysis between *Roman* and other cosmological surveys such as DESI, *Rubin*, *Euclid*, SO and CMB-S4, which will greatly enhance the scientific impact of the *Roman* HLIS.

**Bernard Gaudi / Ohio State University, PI**  
**David Bennett / University of Maryland – College Park, Science PI**  
**Keivan Stassun / Vanderbilt University, Human Infrastructure Teams Lead**  
**Christopher Brandon / The Ohio State University, Project Manager**  
*The Roman Galactic Exoplanet Survey Project Infrastructure Team*  
**PROJECT INFRASTRUCTURE TEAM**

The primary science driver for the Galactic Bulge Time Domain Survey (GBTBS) of the Nancy Grace Roman Space Telescope (*Roman*) is the requirement to obtain a statistical census of cold planets orbiting stars in the Galactic disk and bulge using the gravitational microlensing method. We refer to this as the *Roman* Galactic Exoplanet Survey (RGES). This science is at least as compelling as when *Roman* was selected by the 2010 Decadal Survey. The 2020 Decadal Survey states that *Roman* is “the only platform in the coming decades that can produce a statistical census of planetary occurrence as a function of orbital separation and mass, from terrestrials to gas giants, beyond 1 AU”.

We propose to develop the infrastructure required to plan, execute, and extract cold exoplanet demographics from the RGES survey. Specifically, we will (1) confirm and/or reconfirm the five level-1 RGES science requirements, (2) improve the microlensing event rate and yield calculations by improving the input Galactic models, incorporating new measurements of the near-infrared event rate obtained by the PRime-focus Infrared Microlensing Experiment (PRIME) survey, (3) develop and test the prototype photometry and astrometry pipeline, event detection pipeline, light curve modeling pipeline, and detection efficiency (or completeness) pipeline, which we will make publicly-available and user-friendly, (4) develop the occurrence rate formalism and methodology. In order to test and refine the photometry and astrometry pipeline, we will develop detailed image simulations that reproduce, as faithfully as possible, the actual images obtained by the *Roman* Wide Field Instrument.

The number of US scientists working in the exoplanet microlensing field is usually small, and the microlensing method is considered to be obscure by many scientists in the exoplanet field. In order to overcome this shortage of exoplanet microlensing experts, the *Roman* Project and the Science Support Center (SSC) have committed to produce an unusually large set of high level data products to enable newcomers to the field to work productively with the data. We will work very closely with the *Roman* Science Centers, the *Roman* Project team and the Community Science Collaborations relevant to the GBTDS to develop and test these data products. We will make our photometry, astrometry and event modeling software publicly available and user-friendly to enable broad participation in RGES science. The same is true for our exoplanet yield simulation tools, and this will enable those interested in doing science with the GBTDS to assess how the survey parameters affect their science yield, as well as that of the RGES.

Finally, we will develop a comprehensive plan that will not only seek to establish a culture of inclusiveness, diversity, and equity in the RGES Project Infrastructure Team and the larger microlensing community as a whole, but also include and train early career researchers from other disciplines to exploit the cutting-edge science enabled by the

RGES. While the small size of the US exoplanet microlensing community is a challenge for RGES science, it offers an unusual opportunity to help develop a more inclusive astronomical community. We propose to establish a new undergraduate, graduate, and postdoc inclusion program through Howard University to attract promising young scientists from underrepresented backgrounds without significant microlensing experience to study the exoplanet microlensing method with the RGES team. This would prepare them to take leading roles in the analysis of *Roman*'s exoplanet microlensing data once those data become available.



**Shirley Ho, New York University, PI**  
***Machine Learn the Roman Universe***  
**WIDE-FIELD SCIENCE – LARGE**

The Roman Space Telescope (*Roman*) with its large-scale structure (LSS) survey will provide us with data of unprecedented information content to elucidate fundamental questions about our Universe, such as its origins, content, and its future. Progress in any one of these directions could constitute a groundbreaking discovery in physical cosmology. However, nonlinear gravitational evolution makes extracting the pertinent information with traditional methods challenging, as none of the current methods deployed by LSS surveys are able to extract the full information content of the Universe.

To address this challenge, we propose to develop three Machine Learning (ML) based methods to learn the information in the data and determine the cosmological parameters and initial conditions of the Universe. The proposed methods have the potential to optimally (information theoretically) extract information from the Roman LSS data. The first method is based on a Bayesian statistical inference framework, where one first reconstructs the initial conditions and uses that information to learn the data likelihood. The second method is based on unsupervised learning, where we learn the data likelihood as a function of cosmological parameters via a Normalizing Flow. The third method is based on diffusion models, which generate posterior samples of the initial conditions and properties of the Universe from non-linear large-scale structure using score-based generative models.

We will pay special attention to robustness of all of the methods against systematic errors and astrophysical effects, leveraging astrophysical nuisance parameters that can be marginalized over, and utilizing scale separation information. An important contribution of this proposal is the generation of mock survey datasets via deep-learning accelerated simulations of the galaxy surveys. They will also serve as a testbed for our ML methods. As an example use case, we will apply these tools to the problem of extracting information about the initial conditions of the universe via primordial non-Gaussianity from space-based galaxy survey data.

A second major goal of the proposal is to develop a community framework within which different ML methods can be tested and compared. We will create deep-learning accelerated simulated datasets with survey realism that can be used for bench-marking and for blind analyses of different methods using realistic computational simulations. We will promote open access ML tools by releasing both the software and simulated datasets into the public domain, and by providing community support for these products. We will encourage community engagement through data challenges.

Results of this study will provide new ML methods that promise to considerably improve the information content of existing methods of LSS analysis, which could unlock an expanded potential not only for *Roman*, but also space-based LSS missions to illuminate the fundamental physics of the Universe.

**Mansi Kasliwal / California Institute of Technology, PI**  
**Schuyler Van Dyk / Caltech , Science Definition Lead**  
**Benjamin Rusholme / Caltech, Pipeline Development Lead**  
**Lin Yan / Caltech, Testing & Validation Lead**  
***RAPID: Roman Alerts Promptly from Image Differencing***  
**PROJECT INFRASTRUCTURE TEAM**

The 2020 Decadal Survey identified time-domain and multi-messenger science as a high priority this decade. We propose a Project Infrastructure Team to enable a wide suite of dynamic sky science for the Nancy Grace Roman Space Telescope. Our goal is to provide four services:

1. Rapid image-differencing of every new *Roman* image from a reference image
2. Prompt public alert stream of all transient and variable candidates in the *Roman* difference images
3. Source match-files recording candidate photometry for every *Roman* source observed more than once in the same filter
4. Forced-photometry service to investigate precise photometric history at any location by drilling into all available *Roman* data.

The proposing team has extensive prior experience in building similar services for dedicated time-domain surveys. By promptly delivering a reliable alert stream, the transient and variable communities will be able to undertake timely panchromatic follow-up of the most interesting *Roman* discoveries. It is essential to provide full history and context to alerts in order to correctly identify high-value transients, and properly allocate follow-up resources, especially spectrographs.

Much of the proposed infrastructure will leverage previous work on other projects. We plan to broadcast the public alert stream in the same format as pioneered by the Zwicky Transient Facility. This format has recently been adopted by NASA's GCN circulars and will also be used by the *Rubin* Observatory. This format is understood by the many international transient event brokers such as Alerce, Antares, Fink and Lasair.

Development work will be required to adapt and tune our methods to *Roman*. We will use simulated *Roman* images to develop and test our pipeline before launch. We will solve image differencing to tackle the undersampled PSF and lack of a fixed reference grid in the *Roman* data. We will also develop machine learning for robust candidate identification. We have discussed this plan with colleagues at STSCI to understand how the initial input to this pipeline will come from MAST and how the final output of this pipeline will be returned to MAST for alert archiving.

**Elisabeth Krause / University of Arizona, PI**  
**Eric Huff / Jet Propulsion Laboratory, Institutional PI**  
*Kinematic Lensing with the Roman Space Telescope*  
**WIDE-FIELD SCIENCE – LARGE**

Weak gravitational lensing (WL) is one of the core probes of the Nancy Grace Roman Space Telescope to study multiple high-profile NASA science goals such as the origin and composition of the Universe and the processes of structure formation and galaxy evolution.

WL however is a very challenging measurement. Most importantly, the fact that the intrinsic shape of the lensed galaxy is unknown results in large statistical uncertainties of WL shear measurements. This so-called shape noise dilutes the desired measurement of the shear effect and as a consequence, traditional WL requires a large ensemble of galaxies to boost signal-to-noise of the shear signal. Unsurprisingly, this implies the inclusion of a substantial sample of faint galaxies that are affected by systematic uncertainties in shape and redshift measurement algorithms; perfectly controlling these systematics is impossible and can limit the constraining power of *Roman* cosmology.

Kinematic Lensing (KL) combines imaging and spectroscopic data into a new type of lensing inference. This reduces the shape noise uncertainty haunting WL by more than an order of magnitude. Further, the KL estimator automatically bypasses one of the most severe astrophysical systematics of weak lensing, so-called intrinsic galaxy alignments. The need for spectroscopic information, however, implies that the size of our KL galaxy sample will be smaller compared to that of standard WL. Nevertheless, the smaller KL galaxy sample will be significantly more robust to the two main observational systematics that are haunting standard WL galaxies. Firstly, the spectroscopic information renders redshift uncertainties obsolete; secondly, we can select large, bright galaxies, for which shape measurement uncertainties are well-controlled. Our team has run initial forecasts using the *Roman* spectroscopic sample as a KL galaxy sample, and we find that the KL constraining power on dark energy equation of state parameters is increased significantly over that of standard WL.

In this proposal we plan to develop a full KL inference pipeline that can ingest imaging and spectroscopic data from *Roman* and produce a corresponding KL shape catalog. We will also build the software infrastructure for the cosmological interpretation of the extracted KL signal, and we will use this infrastructure to create precision forecasts of KL science performance as a function of *Roman* survey strategy and systematics control.

**Xin Liu / University of Illinois – Urbana-Champaign, PI**

***DeepDISC-Roman: Detection, Instance Segmentation, and Classification for Roman with Deep Learning***

**WIDE-FIELD SCIENCE – REGULAR**

The Nancy Grace Roman Space Telescope will deliver deep high-quality images in the near infrared for precision cosmology and beyond. As both the sensitivity and depth increase, larger numbers of blended (overlapping) sources will occur. If left unaccounted for, blending would result in biased measurements of sources that are assumed isolated, contaminating key inferences such as photometry, photometric redshift, galaxy morphology, and weak gravitational lensing. In the *Roman* era, efficient deblending techniques are a necessity and thus have been recognized a high priority. However, an efficient and robust deblending method to meet the demand of next-generation deep-wide surveys is still lacking.

Leveraging the rapidly-developing field of computer vision, the open-source DeepDISC-*Roman* will provide a new versatile deep learning framework for the *Roman* research community. It makes it easy to efficiently process *Roman* images and accurately identify blended galaxies with the lowest latency to maximize science returns. The approach is interdisciplinary and fundamentally different from traditional methods, combining state-of-the-art survey data with the latest deep learning tools. A unique feature of DeepDISC-*Roman* is the robust quantification of the uncertainty of the prediction, which can be then propagated into the final error budget for precision cosmology. Because of limitations with the previous deep learning applications, a new framework is under development, leveraging Detectron2 – Facebook AI Research’s next-generation open-source platform for object detection and segmentation. This program will support transforming DeepDISC-*Roman* from a proof-of-concept pilot study to a fully featured, developed and science-ready platform for astronomical object detection, instance segmentation, classification, and beyond. Leveraging existing software infrastructure and production-ready packages, DeepDISC-*Roman* will be trained and validated using a hybrid of real data and more realistic simulations by combining traditional image simulations with deep generative models. DeepDISC-*Roman* can be applied to many other higher-level downstream science applications such as photometric redshift estimation and galaxy morphology inferences. It will combine *Roman* with *Rubin* and *Euclid* to leverage the wider optical-to-near-infrared coverage to improve the reliability of photometric redshifts and to facilitate the deblending of *Rubin* ground-based images. The program has strong implications for a wide range of subjects, from efficiently detecting transients and solar system objects to the nature of dark matter and dark energy.

DeepDISC-*Roman* will deliver several key scientific, software, and data products to maximize *Roman* science. It will produce a versatile deep-learning framework which can be integrated into the analysis software provided by the *Roman* Science Centers. It addresses the *Roman* research and support participation program through “Development of *Roman* analysis software beyond that provided by the Science Centers” and “Development of algorithms for joint processing with data from other space- or ground-based observatories such as deblending algorithms, photometric redshift training and

calibration, or forced photometry”. DeepDISC-*Roman* will complement and augment activities of the *Roman* Science Centers but does not overlap/duplicate them. The proposed work should be performed now, rather than closer to launch or post-launch, because deblending is fundamental to the *Roman* data analysis infrastructure and critical for enabling many downstream applications. As part of the proposed work, the program will train undergraduate students through the Students Pushing Innovation at the National Center for Supercomputing Applications. Finally, the program will develop a diverse and inclusive scientific workforce and clearly defines roles and responsibilities for all team members toward pursuing those goals.

**Pamela Marcum / NASA – Ames Research Center, PI**  
**Alejandro Borlaff / NASA – Ames Research Center, Science PI**  
***ROSALIA: Roman Sky Analyst for Low surface brightness Imaging & Astronomy***  
**WIDE-FIELD SCIENCE – LARGE**

Deep imaging is the next frontier for many studies in galaxy evolution and cosmology, providing unprecedented views of ultra-low surface brightness realms of the universe that are thousands of times dimmer than the sky background, including stellar galactic halo structure, intracluster light, and the traces of galaxy assembly (tidal tails, stellar streams, shells, faint satellites). Detector sensitivity is a double-edged sword: while enhancements facilitate detection, they also result in a dramatic rise of systematic biases such as flat-fielding residuals, scattered light of bright objects in the field of view, and loss of extended sources due to sky over-subtraction. The objective of this proposal is to develop, test, and implement a complete suite of low surface brightness processing tools for the analysis of space imaging observations that will minimize the undesirable gradients in images caused by these sources. The proposed application of these tools is the Wide Field Instrument (WFI) of the Nancy Grace Roman Space Telescope. These methods will improve the photometric calibration and maximize the quality of the data product, enabling a new range of science objectives beyond the original mission. The proposed pipeline will be developed and tested with a set of end-to-end simulations of *Roman*/WFI mosaics based on cosmological simulations that include the complexity of high- $z$  objects and local universe objects. We will implement these tools as additional modules to support observations of the astronomical community with the Nancy Grace Roman Space Telescope.

**Max Millar-Blanchaer / University of California – Santa Barbara, PI**  
***Calibrating Roman’s Coronagraphic Imaging and Polarimetry Modes***  
**CORONAGRAPH COMMUNITY PARTICIPATION PROGRAM**

The *Roman* Space Telescope Coronagraphic imaging modes promise to demonstrate exciting new technologies that will set the stage for NASA’s next great observatory, the Habitable Worlds Observatory. Achieving both the baseline requirements and meeting the “best-effort” goals will require careful target selection and a sophisticated calibration program. Here we propose a *Roman* Coronagraph Community Participation Program contribution that will cover four main aspects of the call for proposals: B, E, F, H and I. Our team will focus on the development of detailed calibration simulations, calibration analysis toolkits, and the development of software for applying calibrations to in-flight calibration data. These tasks will be critical for the successful achievement of the primary TTRL5 mission success requirement. A second major component of our proposed program will be to focus on *Roman*’s polarimetry mode. The *Roman* polarimetry mode will provide a unique opportunity to demonstrate high contrast polarimetry at contrasts that are not achievable from the ground, opening the doors to future polarimetric studies of not only disks, but planets as well. We will develop a polarimetric commissioning and calibration plan, complete with image processing analysis software. Calibration target vetting and precursor observations for the polarimetry mode will be included where necessary. Our team brings a breadth of experience in the commissioning, characterization, calibration and use of both ground-based and space-based high contrast imaging instruments. Furthermore, the PI is an expert in the calibration and use of high-contrast polarimetric instrumentation. Given the breadth of expertise and experience of our team, should the project need our efforts to focus on other topical areas or should resources prevent a focus on the polarimetry mode, there are many other topical areas the team is interested in.

**Jeffrey Newman / University of Pittsburgh, PI**  
*A Statistical Framework for Optimizing Roman Spectroscopic Training Sets*  
**WIDE-FIELD SCIENCE – REGULAR**

The vast majority of galaxies in *Roman* imaging will lack spectroscopic redshifts, so photometric redshifts (photo-*z*s) will be crucial for both cosmology and galaxy evolution studies. We propose to build on machine learning methods that can interpolate between the limited sampling of the color-redshift relation from deep but small-area spectroscopic surveys and clean incorrect redshifts out of spectroscopic training sets for *Roman* photo-*z*s, enabling the construction of nearly-ideal spectroscopic training data from sparse and imperfect samples. The methods we will explore should enable improvements in both the performance of photo-*z* algorithms at predicting redshifts for individual objects as well as in the calibration of the outputs of those algorithms, which otherwise may be a dominant systematic uncertainty in *Roman* cosmology studies.

First, we will apply a powerful non-linear dimension reduction technique, UMAP (Uniform Manifold Approximation and Projection), to compress galaxy SEDs into a low-dimensional continuous space, using existing data from fields with existing multiwavelength and spectroscopic data. In contrast to the Self-Organizing Maps (SOMs) often used to map observed galaxy SEDs onto a 2-D rectangular and discrete grid for photo-*z* applications, UMAP provides a continuous, topologically flexible, and robust low-D representation of optical-IR color space, which can be trained using large photometric galaxy samples. We expect that observed SEDs should intrinsically occupy a roughly 3-D manifold, since apparent colors are determined primarily by redshift, specific star formation rate, and a degenerate combination of dust/metallicity. Supervised variants of this algorithm trained using high-quality redshifts may help to make the structure of the low-dimensional color-redshift manifold more informative.

We will then train a robust Gaussian process regression algorithm, which can interpolate optimally and identifies and ignores outliers, to map from location in the low-dimensional UMAP space to redshift. Current spectroscopic and many-band photo-*z* samples have incorrect-redshift rates that are large enough to compromise the calibration of redshift distributions for cosmology; however, such incorrect redshifts should be easily identifiable in the lower-dimensional UMAP space, as they will be out of line with other redshifts in the same region of the color manifold. If the robustness to outliers is great enough, the numerous but less-certain low-resolution spectroscopic redshifts and many-band photo-*z*s could be incorporated into *Roman* photo-*z* training and characterization. Our procedures will also address the problem that objects with spectroscopic redshifts provide only a sparse and inconsistent sampling of the relationship between the colors of galaxies and their redshifts due to shot noise/limited sample size, selection effects in spectroscopic data sets, and sample/cosmic variance. For instance, galaxy populations that only inhabit the densest regions of the Universe may be missing entirely from training sets built from small fields at some redshifts but will be present at others; no amount of re-weighting can make up for their absence. With a mapping from UMAP coordinates to redshift in hand, however, we can construct augmented spectroscopic samples of arbitrary size that perfectly match the distribution of photometric samples in UMAP space (and hence color space) and that include objects that fill in gaps in the



existing sparse spectroscopic samples, with minimal impact from sample/cosmic variance. Such training sets would be the ideal inputs for machine-learning-based photo- $z$  algorithms and would be invaluable for determining accurate redshift distributions for any photometrically-defined samples. Our results could have considerable impact on the strategies and requirements for *Roman* spectroscopic training sets, so completing it in the next two years is critical.

**Marc Pinsonneault / The Ohio State University, PI**  
***Asteroseismology Using The Galactic Bulge Time Domain Survey***  
**WIDE-FIELD SCIENCE – REGULAR**

Overview: Evolved red giant stars are detected as high-amplitude non-radial oscillators in time-domain space missions. Precise, regularly sampled, long-duration photometric observations can be used to characterize their oscillation frequency pattern. Masses, radii, and ages have been measured for tens of thousands of stars observed by *Kepler*, K2 and TESS by combining this asteroseismic data with stellar metallicity and  $T_{eff}$ . We propose to quantify the unique asteroseismic capability of the Nancy Grace Roman Space Telescope by: 1) generating a detailed model of asteroseismic detectability with *Roman* light curves; 2) simulating the expected population of bulge red giants that would be detectable; 3) curating a target list with existing ancillary spectrophotometric data; and 4) exploring the potential of *Roman* astrometry and photometry to greatly expand the sample size, precision, and accuracy. *Roman* asteroseismology will constrain the properties of an important Galactic population and will be important for interpreting the results of the *Roman* Galactic Bulge Time Domain Survey (GBTDS).

Background: *Roman* is especially well-suited for asteroseismology of core He-burning, or red clump (RC), stars in the Galactic bulge because of its high spatial resolution, IR passband, aperture, and observing cadence. Asteroseismology requires the ability to detect oscillations and key stellar properties ( $T_{eff}$  and metallicity) to infer mass and age. If  $L$  and  $T_{eff}$  are known,  $R$  can be inferred, reducing the information needed for masses. Our project therefore begins with detectability and proceeds to catalog stars with  $T_{eff}$  and metallicity (of order 110,000). We then explore the prospect of using *Roman* astrometry and photometry to provide  $R$  and  $T_{eff}$  for numerous fainter stars (of order 420,000). Methods: Prior work has established the feasibility of asteroseismology in *Roman*. Saturation will be important for RC stars in the Galactic bulge. We will develop an improved asteroseismic detection model, including the effect of saturation on variability and detection probabilities as a function of magnitude and intrinsic luminosity. We will then generate a mock RC catalogue to predict detections once *Roman* is launched. It will also serve as a reference for testing how different color and magnitude cuts, and different survey footprints, affect the predicted yields.

Based on the mock catalog, we will then assemble an asteroseismic target list (ATL) based on real data in the GBTDS footprint. The target list will consist of RC stars with *Gaia* and 2MASS photometry whose solar-like oscillations we determine to be detectable, and we will use it to motivate spectroscopic survey follow-up. We will also provide target lists with metallicities and temperatures from low-resolution optical *Gaia* BP/RP spectra and high-resolution infrared APOGEE spectra. We will use this data to iteratively calibrate the mock catalog parameters and infer the selection function for the ATL.

*Roman* astrometry is precise but needs to be tied to the *Gaia* system to place it on an absolute scale. We will combine an improved astrometric and photometric model with data from our mock catalog to infer the density of *Gaia* calibrators and make predictions

for uncertainties in *Roman* RC parallaxes and radii, crucial for extending asteroseismology to fainter targets.

Future impact: The catalogs and codes will be resources for the *Roman* centers and the microlensing PIT. The detectability and astrometry models that we develop are applicable to other science cases, especially those involving saturated stars. Our projections for what *Roman* will achieve for asteroseismology will motivate broader science cases for *Roman*, such as insights into the ages and chemical properties of the bulge stellar population from which stellar exoplanet hosts are sampled. Population-level discoveries will likewise revolutionize our understanding of the primordial bulge from a Galactic archaeology standpoint.

**Laurent Pueyo / Space Telescope Science Institute, PI**  
*Data driven investigations of the Coronagraph Instrument as a starlight suppression yardstick.*

**CORONAGRAPH COMMUNITY PARTICIPATION PROGRAM**

Objectives:

We will work with the *Roman* Coronagraph Instrument project to maximize the return of the Coronagraph Instrument technology demonstration mission, and transfer knowledge to the Astro2020 recommended Habitable World Observatory (HWO). We will do so by carefully analyzing ground test data during the initial period of performance.

Background:

the Coronagraph Instrument is the only flight demonstrator of a suite of technologies that are critical to exo-earth detection and characterization with HWO. For instance, lessons learned from the Coronagraph Instrument ground testing will inform the experimental design of system level technology demonstrations that will occur under the purview of the Great Observatories Maturation Program (GOMAP). Successful Coronagraph Instrument operations during the technology demonstration phase will define the baseline exoplanet imaging observing sequence for HWO during formulation (Phase A). Because the Coronagraph Instrument is a class D instrument, with reduced assurance standards permitted, the Coronagraph Instrument I&T data might not be as thoroughly scrutinized as was done for previous NASA flagships such as JWST. Our proposed CPP program will augment existing Coronagraph Instrument project resources to characterize performance and optimize the observations during the technology demonstration phase. We will also extrapolate the Coronagraph Instrument results to HWO.

Methods:

We propose to conduct a suite of data driven investigations based on the Coronagraph Instrument ground test measurements to inform HWO technology maturation and mission formulation plans, and maximize the return of the Coronagraph Instrument the technology demonstration. This will include:

- Evaluating raw contrast model uncertainties using ground tests data, and establishing best practices to set Model Uncertainty Factors (MUFs) for HWO error budgets.
- Quantifying the relationship between model uncertainties and WFS&C convergence time and identifying the tall poles in the instrument's configuration. These will be precious lessons learned to design GOMAP demonstrators and preliminary HWO architectures during mission formulation.
- Measuring the wavefront noise rejection function of the Coronagraph Instrument's WFS&C subsystems –either using the LOWFS or the science camera. We will then use these measurements as yardsticks to quantify how much ground GOMAP needs to cover in order to demonstrate HWO compatible wavefront stability.
- Developing a target list composed of a wide range of companions, from stellar binaries to self-luminous planets. We will build an empirical flight contrast ladder that will be essential to demonstrate the Coronagraph Instrument's science capabilities during its commissioning and technology demonstration phases.

- Designing observing sequences for the Coronagraph Instrument's technology demonstration phase that are as informative as possible for HWO.

**Significance:**

This work will help optimize the Coronagraph Instrument observations during the technology demonstration phase, which will in turn pave the way towards compelling Coronagraph Instrument observations later in the mission. Such successful observations will provide a unique opportunity to anchor HWO yield predictions with the Coronagraph Instrument data.

**Elisa Quintana / NASA – Goddard Space Flight Center, PI**  
**Robert Wilson / NASA – Goddard Space Flight Center, Science PI**  
**David Ciardi / Caltech – NASA Exoplanet Science Institute, Deputy PI**  
*Laying the Foundation for a Comprehensive View of Transiting Exoplanets with the Galactic Bulge Survey*  
**WIDE-FIELD SCIENCE – LARGE**

The primary science driver of the *Roman* Galactic Bulge Time-Domain Survey (GBTDS) is the detection and demographics of cold exoplanets via microlensing (Astro2010, Penny et al. 2019). However, additional science can be extracted from this survey (Gaudi et al., 2019), including the potential to detect an unprecedented ~100,000 transiting exoplanets (Bennett & Rhie, 2002; Montet et al., 2017) and the transformative science this would enable.

We propose to investigate and build the infrastructure necessary to develop a transiting exoplanet science case with *Roman* that will benefit the astronomical community. Specifically, we will develop a GBTDS transiting exoplanet science case by:

1. Developing accurate and precise pixel-level simulations of the GBTDS,
2. Building a robust transit search and vetting infrastructure based on proven techniques developed for *Kepler*, K2, and TESS,
3. Identifying and providing recommendations for GBTDS design trades that maximize the transiting planet science return, and
4. Performing simulations of transiting exoplanet atmospheres to develop *Roman*'s potential for transformative atmosphere population studies.

This work will produce publicly-available pipelines to simulate GBTDS pixel-level data, generate light curves, detect transiting exoplanets and identify false positives, as well as simulation software for producing synthetic transit populations. We will work with the *Roman* project and other selected teams to leverage and augment their simulation tools. The proposed work must begin now in order to provide timely recommendations to the *Roman* project on survey design trades and prepare the community to maximize the science return of *Roman*'s first few years.

**James Rhoads / NASA – Goddard Space Flight Center, PI**  
**Andrew Fruchter / Space Telescope Science Institute, Institutional PI**  
**Isak Wold / Catholic University Of America, Institutional PI**  
***SPQR: Spectroscopic Probes of Quantitative Reionization***  
**WIDE-FIELD SCIENCE – LARGE**

Reionization of intergalactic hydrogen was the first time that stars and galaxies had a global impact on the universe around them, and the last phase transition for ordinary matter in the universe. The Nancy Grace Roman Space Telescope will enable critically needed wide field surveys for galaxies in the epoch of reionization (EoR). In particular, *Roman*'s wide field spectroscopic capabilities will allow direct observation of the Lyman alpha line from EoR sources, providing direct, local tests for neutral intergalactic gas, over scales that are large enough to study this inherently inhomogeneous process and that are unachievable with other facilities.

This proposal builds upon the work of the previous Cosmic Dawn Science Investigation Team to prepare for WFI investigations of Cosmic Dawn through deep imaging and spectroscopy. For this we will:

- (1) Simulate cosmic dawn galaxies, by combining large semi-analytic simulations with high-resolution hydrodynamic simulations and radiative transfer of Lyman-alpha at  $z > 7$ . These simulations will be informed and constrained by deep observations from JWST.
- (2) Develop high fidelity scene simulations, custom built for *Roman* Grism and Prism, starting with observed deep and wide field imaging from JWST.
- (3) Optimize selection methods for high redshift line emitters, quasars, and Lyman Break Galaxies, incorporating spectroscopic information that will increase the robustness and efficiency compared to photometric searches.
- (4) Explore quantitative metrics to measure reionization using robust measures such as clustering of Lyman alpha sources, topology of Lyman alpha emitter distribution, and cross-correlation with 21cm measures.

Applying wide field slitless spectroscopy to studies of cosmic dawn requires optimized extraction of spectral lines 10 times fainter than those sought in the High Latitude Wide Area Survey. Such observations will have more significant crowding than shallower surveys. This requires new strategies for both observations and source detection algorithms, and data simulations with unprecedented detail that go beyond the tools and methods currently planned.

We will develop the required tools to simulate *Roman* slitless data. We will produce high fidelity simulations that include (a) the defocused higher diffractive orders in grism data, whose wavelength-dependent pattern cannot be simulated by existing packages; (b) the highly nonlinear prism dispersion; (c) position-dependent trace, dispersion solution, and passband edges, and (d) wavelength and position dependent point spread functions. Using these tools, we will examine how depth, area, number of distinct roll angles, and other observational parameters affect the ability to recover input structures. We will also develop figures of merit that will help quantitatively evaluate future tradeoffs such as

depth vs area. We will define strategies to study the ionizing photon budget as a function of redshift, and to study the dependence of epoch-of-reionization galaxy properties on their local environments.

The results will ultimately benefit all applications of *Roman* slitless spectroscopy, reaching a wide user community. We will provide tools to inject simulated sources with user-provided spectra and spatial profiles into realistic background scenes, in order to test detection efficiency and measurement fidelity. This may be applicable to diverse general astrophysics survey programs, and also to galaxy redshift survey cosmology results from the high latitude wide area survey. We expect to work with the science centers to share results and algorithms, and also to offer data challenges and training for the general community. By developing these tools now, we will help the community to be ready for scientific applications of *Roman* spectroscopy, from galaxies to kilonovae, on day one of science operations.



**Tyler Robinson / University of Arizona, PI**  
***Roman's Giants: Jovian Exoplanet Modeling and RCI Detectability***  
**CORONAGRAPH COMMUNITY PARTICIPATION PROGRAM**

The *Roman* Coronagraph Instrument (RCI) aboard NASA's Nancy Grace Roman Space Telescope is a critical technology demonstration to guide many future NASA endeavors in high-contrast imaging. The stated RCI Threshold Technical Requirement (TTR) represents a challenge that can only be met through collaborative efforts spanning engineers, instrument scientists, and exoplanet modeling experts. To enable target selection and prioritization, and to empower future interpretation of RCI results, we propose to execute a novel grid of giant exoplanet atmospheric models, spectral simulations, and inverse studies. The atmospheric models and associated spectral simulations will be guided by likely RCI targets and anticipated planetary properties. Our inverse studies will use the planned spectral models to demonstrate the range of exoplanet atmospheric science that can be completed with varying levels of RCI observing time commitment.

We anticipate active engagement with a broader CPP Team to enable improved star/exoplanet/disk/instrument scene models and to best understand the connections between planned instrument performance, the likelihood of TTR success, and the potential for first-of-its-kind exoplanet atmospheric science that would prove foundational for the forthcoming Habitable Worlds Observatory. Our proposed efforts are relevant to the CPP topical area of “[m]odeling astrophysical targets” and, as stated in the call, the efforts are, then, relevant to NASA's Science Plan. More specifically, our RCI-focused modeling studies enable understanding of the universe and a search for life elsewhere (2022 Strategic Plan, Objective 1.2) and are specifically designed to enable new space technologies (2022 Strategic Plan, Objective 3.1) within NASA's Decadal Survey-guided “balanced science program” (2020-2024 NASA Science Plan, Strategy 1.1).

**Robyn Sanderson / University of Pennsylvania, PI**  
**Carl Rodriguez / University Of North Carolina – Chapel Hill, Team Lead**  
**Tjitske Starkenburg / Northwestern University – Evanston, Team Lead**  
**Kari Frank / Northwestern University – Evanston, Institutional PI**  
*A new theoretical framework for globular cluster science with the Roman Wide-Field Imager*  
**WIDE-FIELD SCIENCE – REGULAR**

The *Roman* Space Telescope will be an excellent tool for finding thin stellar streams, i.e. those formed from globular clusters, in external galaxies for the first time. To date, we only know of globular cluster tidal streams within our own Milky Way. In combination with the population of still intact globular clusters, these tidal streams have provided unique insights into the early formation and accretion history of our Galaxy, as well as the shape of its dark matter potential and constraints on the clumpiness of dark matter. Despite their demonstrated power in our own Galaxy, however, there are currently no theoretical predictions of the expected number of GC streams in nearby galaxies, or how many *Roman* will be able to find, severely limiting our ability to interpret *Roman* observations. Studying the formation of GC streams in cosmologically-evolving galaxies is computationally challenging, and previous work has been forced to oversimplify models either for the formation and evolution of GCs or for the galactic tidal field.

In this proposal we will, for the first time, include all components of globular cluster formation and evolution in a cosmologically evolving galaxy. Our project will build upon an existing model for the formation of globular clusters based on zoomed cosmological-hydrodynamical simulations, and explore variations on these initial conditions. We will then build a stream formation model that will inject test particles of the growing streams into the same cosmological simulations used to determine the cluster population, optimized to reproduce the changing potential of the full halo and galaxy environment at all cosmic times. The result will be the first predictions for the population of thin streams and globular clusters around galaxies in a self-consistent and fully cosmological context.

These results will let us answer crucial questions related to globular cluster and galaxy formation science for the first time. We will predict the mass and metallicity distributions of surviving and destroyed globular clusters and the morphology of thin stellar streams, and explore their dependence on the violence of the host galaxy's formation, the cluster formation model, and the presence or absence of dark matter substructure and satellite galaxies. Most importantly, however, we will use tools already developed by our team to produce full *Roman* synthetic observations of thin stellar streams, their morphology, and their stellar populations, in their cosmologically-motivated host halos, connecting the detectable set of clusters and streams to the origin and evolution of the full underlying population of globular clusters.

**Dmitry Savransky / Cornell University, PI**  
***Target Selection and Observation Modeling Tools for the Roman Coronagraph***  
***Technology Demonstration and Beyond***  
**CORONAGRAPH COMMUNITY PARTICIPATION PROGRAM**

The Space Imaging and Optical System Laboratory (SIOslab) at Cornell University has been actively supporting the Nancy Grace Roman Space Telescope Coronagraph Instrument since pre-Phase A activities. We currently maintain two open-source, community resources: a one-to-one port of the internal JPL Exposure Time Calculator (ETC) for the *Roman* coronagraph (available as a module of the publicly distributed EXOSIMS software framework) and a publicly accessible database of known planetary companions that could potentially be imaged by the *Roman* coronagraph (the Imaging Mission Database). We propose a suite of activities under the Coronagraph Community Participation Program aimed to further develop and expand both of these resources, and specifically targeting topic areas A (modeling of astrophysical targets), B (selecting suitable observing targets), D (planning observations) and M (enabling activities for possible further use of the coronagraph).

Specifically, we will continue development and maintenance of the EXOSIMS *Roman* coronagraph ETC to account for improvements in the instrument model and new characterizations of the flight instrument. For each ETC update, we will recompute detection probabilities for all targets in the Imaging Mission Database. The database will also continuously be updated with new targets as they are discovered, and with new orbital fits for current targets as they appear in the literature. We will augment the existing photometric model grids used in the database to provide better predictions of known planet detection probabilities with the coronagraph, and will add optimal observation times for all targets observable by the coronagraph. Optimal observing times will be computed by applying new methodologies, recently published by our group, for the use of radial velocity data to optimize imaging observations. We will also expand these methodologies to work with all relevant targets in the database. Finally, we will continue development of the EXOSIMS blind search simulation capabilities for the *Roman* coronagraph to prepare for any potential science program following a successful technology demonstration, and similarly update the blind search (and unknown companion) search targets in the database.

In addition to these specific activities, the PI and members of the proposing team have broad expertise and experience in coronagraphic exoplanet imaging and instrumentation, and could support multiple other activities, as required by the final makeup of the CPP team.

**Dan Scolnic / Duke University, Co-PI**  
**Rebekah Hounsell / University of Maryland – Baltimore County, Co-PI**  
**Benjamin Rose / Duke University, Co-PI**  
**David Rubin / University of Hawaii – Honolulu, Co-PI**  
**Charles Baltay / Yale University, Institutional PI**  
**Susana Deustua / National Institute Of Standards & Technology, Institutional PI**  
**David Jones / AURA, Institutional PI**  
**Patrick Kelly / University of Minnesota, Institutional PI**  
**Richard Kessler / University Of Chicago, Institutional PI**  
**Diane Markoff / North Carolina Central University, Institutional PI**  
**Vivian Miranda / State University Of New York – Stony Brook, Institutional PI**  
**Saul Perlmutter / University of California – Berkeley, Institutional PI**  
**Russel Ryan / Space Telescope Science Institute, Institutional PI**  
**Masao Sako / University Of Pennsylvania, Institutional PI**  
**Michael Wood-Vasey / University Of Pittsburgh, Institutional PI**

*A Roman Project Infrastructure Team to Support Cosmological Measurements with Type Ia Supernovae*

#### **PROJECT INFRASTRUCTURE TEAM**

The Nancy Grace Roman Space Telescope (*Roman*) is NASA's next large flagship mission due for launch no later than May 2027. This mission will conduct a generation-defining experiment in time-domain astronomy, with a focus on Type Ia supernovae (SNe Ia). The core community survey planned for *Roman* which focuses on collecting data for SNe Ia is the High Latitude Time Domain survey. A key goal of this survey is to use the SN Ia data collected to measure the accelerated expansion of the universe and so better constrain the nature of dark energy. As such Type Ia SNe are highlighted in the NASA *Roman* ROSES call as one of the main cosmological probes.

In this Project Infrastructure Team (PIT) proposal, we present a pixels-to-cosmology plan that will satisfy the requirements for cosmological experiments with SNe Ia. As part of this work, a transient discovery and photometry/spectroscopy pipeline will be created, enabling a wide range of science that can be utilized by any Wide Field Science (WFS) group in addition to the broader *Roman* community.

In this proposal, we provide a list of deliverables that will ensure the completion of the *Roman* science requirements and goals regarding Type Ia SNe, as outlined in Section 3.4 of the ROSES call. These deliverables include fully developed pipelines for photometry and calibration products at the pixel level, the extraction of light curves and prism spectra, the creation of data products including transient alert streams and precision scene-modeling photometry catalogs, the creation of software to model SNe Ia information for standardization, and a survey optimization code that can be enmeshed with other teams as part of a broader community product. We will focus on robust software pipelines including emphasis on open development, validation, documentation and ease for the broader *Roman* community. Furthermore, we include the top industry-standard project-management tools for both internal organization and external liaising with the *Roman* Project, and emphasize for all our deliverables a series of validation

techniques and code/data releases, in addition to documentation for the broader community.

As our focus for this PIT is on infrastructure pipelines to support SN Ia cosmology, we outline what will be done by our team and how that ties to the work of the Science Centers, WFS teams, and the broader community. Our focus will be on a modular software infrastructure that other groups can utilize, be that on the latest ground-based discoveries or theoretical expectations. This work is oriented towards the stringent requirements of SNe Ia cosmology, but our work here can be leveraged to study a wide range of other classes of transients like strongly lensed supernovae, kilonovae, and other fast transients.

As part of the proposal, we present a plan for engagement with the two Science Centers and with the broader community in a series of workshops, data challenges, and regular updates. We also present a Diversity-Equity-and-Inclusion plan that establishes relationships with nearby universities with large populations of underrepresented minorities. We will use this plan to establish a pathway in astronomy for these individuals, running from the undergraduate level to PhD, all while leveraging the long-term baseline of the *Roman* mission.

**Louis-Gregory Strolger / Space Telescope Science Institute, PI**  
**Justin Pierel / Space Telescope Science Institute, Science PI**  
*Enhancing the Roman Cosmology Program with Strongly Lensed Supernovae*  
**WIDE-FIELD SCIENCE – LARGE**

One of the primary mission objectives for the Nancy Grace Roman Space Telescope is to investigate the nature of dark energy with a variety of methods. Observations of Type Ia supernovae (SNe Ia) will be one of the principal anchors of the *Roman* cosmology program, through traditional luminosity distance measurements from the High Latitude Time Domain Survey (HLTDS). The Wide Field Instrument (WFI) can provide another valuable cosmological probe, without altering the mission strategy: time delay cosmography with gravitationally lensed SNe. These rare events manifest when the light from a stellar explosion propagating along different paths is focused by a lensing potential (a galaxy or galaxy cluster), forming multiple images of the SN on the sky. Depending on the relative geometrical and gravitational potential differences of each path, the SN images appear delayed by hours to months (for galaxy-scale lenses) or years (for cluster-scale lenses). These time delays can be used to measure a combination of angular diameter distances that constrain the Hubble constant ( $H_0$ ) and other cosmological parameters, including the dark energy equation of state (e.g.,  $w$ ), in a single step. Constraints on cosmological parameters from lensed SNe are highly complementary and fully independent to those of non-lensed SNe Ia, providing a valuable check on systematics. This proposal will lay the groundwork for including this new probe in the *Roman* cosmology toolkit, which can provide a  $<1\%$   $H_0$  measurement, by producing simulations and tools needed for efficient detection and modeling of each new lensing system.

Previous work predicts the planned *Roman* HLTDS will discover over 40 strongly lensed SNe, but that assumes a robust detection pipeline with high efficiency. We have two avenues for identifying strongly lensed SNe in public *Roman* data. First, we can simply search all publicly available images for lensed SNe using convolutional neural networks (CNNs) designed to identify the combination of lensed arcs and multiple transient sources. Second, we can maintain a catalog of all known galaxy and cluster-scale lenses (currently  $>10,000$ ), and continuously search for transients in those locations. This method requires that we continuously update the catalog of known lenses that have been discovered throughout the *Roman* mission. CNN lens-finding algorithms will therefore be repeatedly run on all publicly available data, and newly identified lenses will be added to the catalog for future observations at the same location. Both CNN architectures will require a large ( $\sim 50,000$  lenses) training set to be reliable at the start of the mission.

The early success of *Roman* Lensed SN cosmology therefore depends upon a suite of accurate and detailed pixel- and catalog-level simulations of *Roman* lensed SN observations. The simulations are critical for developing and testing detection/analysis pipelines, developing plans and proposals for external follow-up resources, and optimizing existing tools for the unique capabilities of *Roman*. This proposal will produce the necessary simulations, which are an extension of (but not included in) those planned for the HLTDS. Using the simulations, we will create a data challenge to

identify the optimal static lens finding, lensed SN detection, and time delay measurement algorithms to be used with *Roman* data products. Adapting existing tools and incorporating the best performing methods from the data challenge, we will produce robust, well-documented, and public detection and analysis pipelines. Strongly lensed SNe have the potential to drastically improve the *Roman* cosmology program with a probe fully independent of SNe Ia. *Roman* and the HLTDS is truly the first opportunity to create a gold standard sample of lensed SNe, and this program produces all the components needed to ensure we can effectively leverage the enormous potential for cosmology.

**Jamie Tayar / University of Florida – Gainesville, PI**  
**Zachary Claytor / University of Florida – Gainesville, Science PI**  
*Spots, Faculae, and Ages: The Promise of Rotation with Roman and Deep Learning*  
**WIDE-FIELD SCIENCE – REGULAR**

We propose to improve our existing open-source tools to determine the efficacy of *Roman*'s proposed time domain survey's strategies in measuring stellar rotation periods, inferring gyrochronological ages, and distinguishing between magnetic structures on stellar surfaces.

The *Roman* mission is set to perform infrared time domain surveys, particularly in the Galactic bulge, but also at high latitudes. The *Kepler* mission showed us that large time domain datasets allow the measurement of rotation periods of stars across the HR diagram through the modulation of stellar brightness by magnetic spots. Those rotation periods can be used to infer precise (<10% error) ages using gyrochronology, even into the M-dwarf regime where most of *Roman*'s exoplanet hosts will be. However, work with the TESS mission has suggested that systematics and complex observing strategies like those proposed for *Roman* can make the extraction of periods with conventional techniques extremely challenging.

We have developed a deep learning technique that can estimate rotation periods in these challenging conditions, as well as a suite of simulations to determine how much additional information about star spot configurations (e.g., relative spot temperatures, sizes, evolution) can be extracted from the data. This technique has been used successfully to obtain periods from TESS and is flexible and adaptable to other missions. We will therefore 1) construct a suite of simulated spot-modulated light curves following *Roman*'s observing strategy in multiple photometric bands, 2) adapt our deep learning framework to predict what ranges of rotation periods, gyrochronological ages, spot amplitudes, and spot characteristics *Roman* will detect, and 3) evaluate the tradeoffs of the *Roman* survey strategy for measuring stellar rotation.

We will predict yields for stellar rotation and spot properties observable with *Roman* and suggest a survey optimization to extract the most stellar astrophysics science from *Roman*. Our modeling, simulation, and machine learning tools will provide public *Roman* analysis software beyond what the Science Centers will provide. Finally, the proposed work will support NASA objectives in studying the evolution of stars and enhance *Roman*'s exoplanetary science impact by placing its discovered planets into the context of galactic evolution.



**Yun Wang / California Institute of Technology, PI**  
**Nikhil Padmanabhan / Yale University, Deputy PI**  
***Project Infrastructure for the Roman Galaxy Redshift Survey***  
**PROJECT INFRASTRUCTURE TEAM**

The observed cosmic acceleration remains a mystery twenty-five years after its discovery. Illuminating its unknown cause, “Dark Energy”, is of fundamental importance in cosmology, and one of the science objectives of the Nancy Grace Roman Space Telescope. The Galaxy Redshift Survey (GRS), a powerful cosmological probe, is one of the three observational probes of dark energy on *Roman*. We propose to be the Project Infrastructure Team (PIT) for the *Roman* GRS (a survey to be defined in an open community process). We will develop and maintain the infrastructure tools and capabilities needed to address the mission objectives for the *Roman* GRS and to support Community Science Collaborations. We plan to work closely with the *Roman* Project, and partner with the Science Centers, providing all necessary support to ensure mission success.

Our program will have 15 deliverables, which require the execution of 13 tasks. These are designed to simulate the data, model and optimize the observing program, model systematic errors and develop methods to mitigate them, and measure compressed statistics including the 2-point correlation function and power spectrum, as well as higher-order statistics uniquely enabled by *Roman* GRS’s high galaxy number density. Our deliverables include simulated and value-added galaxy catalogs, covariance matrices, and a set of ready-to-apply models calculated using different cutting-edge approaches. Our infrastructure work will enable robust measurements of Baryon Acoustic Oscillations (BAO) and Redshift Space Distortions (RSD), meeting the *Roman* science objectives for the GRS. Our modular approach allows the community to complement and extend this work in further science directions. This work needs to start as soon as possible to be ready for the *Roman* data. Our PIT will coordinate work with the Weak Lensing and Cluster Growth & Type Ia Supernovae PITs to maximize *Roman* science.

Our team has all of the requisite expertise and commitment. The PI was the BAO/RSD lead on the *Roman*/WFIRST High Latitude Cosmology Science Investigation Team. She is the Deputy Coordinator of the *Euclid* Galaxy Clustering Science Working Group, and the author of a graduate textbook on dark energy. The team includes leaders from all of the current and planned ground-based GRS (BOSS/eBOSS/HETDEX/PFS/DESI: Padmanabhan, Percival, Ross, Saito, Samushia, Seo, Slepian, Wechsler), the *Euclid* mission (Percival, Wang), and the *Rubin* Observatory’s LSST Dark Energy Science Collaboration (Heitmann, Wechsler). On our team are world-leading experts on the design and data analysis of GRS (Padmanabhan, Percival, Ross, Samushia, Seo, Wang), space-based slitless spectroscopy analogous to that planned for *Roman* (Brammer, Colbert, Scarlata, Teplitz, Walth), and calibration (Appleton, Brammer, Padmanabhan). Our team brings extraordinary expertise both in breadth and depth, spanning all aspects of *Roman* GRS infrastructure work, as well as community connections that enable effective interactions in both cosmology and general astrophysics. Our team consists of 28 scientists (including 13 Collaborators) from a diverse range of institutions; 18 scientists are first-time participants in *Roman* work. Most team members are junior/mid-career scientists. The team includes 9 women and 6 persons of color, meeting NASA objectives for diversity and inclusion.

**Jason Wang/Northwestern University – Evanston, PI**  
***Imaging and Characterizing Exoplanets with the Roman Coronagraph and Open-Source Tools***

**CORONAGRAPH COMMUNITY PARTICIPATION PROGRAM**

I propose to join the *Roman* Coronagraph team to assist in the target selection, data simulation, data reduction, instrument performance characterization, and science demonstration, with a focus on adapting current open-source tools to support the *Roman* Coronagraph. I am a lead developer of two open-source tools popular in the community: “pyKLIP” for stellar point spread function subtraction and exoplanet characterization and “orbitize!” for Bayesian orbit fitting of imaged exoplanets. I propose to add functionality to these packages so that they can be used to assist in the technology demonstration activities. This will ensure open and reproducible science and will mature the tools to analyze visible-light coronagraphic data from space.

In the area of target selection, “orbitize!” can be used and upgraded to predict the locations of known imaged planets and planets detected through indirect methods such as *Gaia* astrometry. This will allow us to know which objects will be in the Coronagraph field of view and which need ground-based follow-up to refine their orbits. In the area of data simulation and reduction, I will work on optimizing “pyKLIP” for *Roman* Coronagraph data. pyKLIP is widely used for coronagraphic data from ground-based telescopes and JWST and was the top performing algorithm in the *Roman* Exoplanet Imaging Data Challenge, detecting faint planets that other algorithms did not. Using simulated data, I will further improve pyKLIP such as by using orbital constraints as priors in the detection framework and by adapting it for the spectroscopic mode of the Coronagraph. In the area of instrument performance characterization, I have a decade of experience calibrating and characterizing high-contrast instruments such as the Gemini Planet Imager and the Keck Planet Imager and Characterizer, and will bring my expertise to the *Roman* Coronagraph. I will create tutorials and pipelines based on pyKLIP to easily assess the final planet sensitivity of the *Roman* Coronagraph in simulation, in the lab, and in space. I can also help develop astrometric and spectrophotometric calibration strategies for the instrument. In the area of science demonstration, I will create recipes and pipelines to measure the photometry, astrometry, orbits, and spectral properties of exoplanets with simulated and real data from the Coronagraph. For reflected light planets, orbital and photometric information are covariant, and I will add functionality to “orbitize!” to include constraining the phase function of reflected light planets in orbital fits. In all these cases, in addition to contributing to the Coronagraph Instrument’s technology demonstration, the software modifications would be accessible to the entire astronomical community in well-established software packages, and the same functionality can be used in future space missions such as the Habitable Worlds Observatory.

**Benjamin Williams / University of Washington – Seattle, PI**  
**Robyn Sanderson / University Of Pennsylvania, Deputy Science PI**  
**Kari Frank / Northwestern University – Evanston, Institutional PI**  
**Roman Infrared Nearby Galaxies Survey**  
**WIDE-FIELD SCIENCE – LARGE**

We propose a large Wide Field Science program to develop software for the community to simulate and analyze *Roman* surveys of nearby galaxies. *Roman*'s wide field, superb sensitivity to faint stars and compact sources, and near-infrared bandpasses will permit panoramic mapping of hundreds of nearby galaxies out to their virial radii, simultaneously giving insight into the star formation histories of the central galaxy, its satellites, and its streams; charting its assembly from the cosmic web; and mapping its dark matter halo. With the help of powerful planning tools to optimize its potential, *Roman* will improve our current sample sizes of these resolved star maps a hundredfold, down to surface brightness limits comparable to those currently reached only in the Local Group and  $>4$  magnitudes fainter than achievable from the ground. The tools we develop will build mock *Roman* imaging data from numerical simulations to test model predictions related to all these long-standing science topics, making it simple and reliable to optimize observing strategies to answer key science questions. Many of the tools necessary for planning *Roman* observations in this level of detail are the same as those necessary to reduce and analyze those observations once they are made. Our suite will thus enable the community to efficiently plan and analyze *Roman* observations of resolved stellar populations, in both crowded and low surface brightness regions, from the very start of the mission.

*Roman* can resolve individual stars to map galaxy structure down to an equivalent surface brightness of 35 mag/sqarcsec, for any galaxy within 10 Mpc of the Sun. Such maps will reveal tidal streams in stellar halos and constrain the mass function of dwarf satellites around hundreds of hosts, providing stringent tests of galaxy formation and dark matter models on galactic and even sub-galactic scales, where the Lambda-CDM model has the most tension with observations. *Roman* imaging will also transform studies of star formation in galaxy disks, by tracking stellar mass growth as a function of time and position within a galaxy. *Roman*'s precision photometry will constrain critical stellar evolution models of the near-infrared bright, rapidly evolving stars that contribute significantly to the integrated light of galaxies in the near-infrared. Thus, with *Roman* we can derive the detailed evolution of individual galaxies, reconstruct the complete history of star formation in the nearby universe, and put crucial constraints on the theoretical models used to interpret near-infrared extragalactic observations.

To revolutionize the study of nearby galaxies, the community must have the necessary tools in place to take full advantage of *Roman*'s capabilities. The tools we propose to develop will make it straightforward and efficient to produce and analyze simulated (and real) *Roman* imaging of nearby galaxies and their halos to maximize the scientific yield in the limited observing time available, ensuring the most effective use of the mission and maximizing the value of the final data archive. Consequently, these tools will allow both

optimization of observing strategies (e.g., filters, coverage, depth) based on numerical simulation predictions and efficient analysis of real *Roman* observations.

These tools will be built, tested, and released by a Wide Field Science team that has decades of experience using nearby galaxies to inform fundamental topics in astrophysics and working with numerical simulations to test observables related to near-field cosmology, dark matter, and galaxy formation and evolution. Our team members have led the charge in observational and theoretical studies of resolved stellar populations and stellar halos. With our combined background, we are poised to help the community to take full advantage of the opportunities for discovery that *Roman* will offer to scientists studying the galaxies in our backyard.

**Schuyler Wolff / University of Arizona, PI**

***Circumstellar dust: A nexus of performance, calibration, and science potential in the Roman coronagraph technology demonstration***

**CORONAGRAPH COMMUNITY PARTICIPATION PROGRAM**

Planetary system architectures include rocky planets, gas giant planets, and dusty debris. All three components will appear in high contrast images from NASA's future Habitable Worlds Observatory (HWO). Along with its key flight demonstration of coronagraphy with precision wavefront control, the *Roman* Coronagraph (RC) will advance our understanding of how well HWO will be able to study these three elements of exoplanetary systems. The instrument should not only produce the first direct detection of a giant planet in reflected starlight, but can also provide unprecedented views of the spatial structure and scattering properties of circumstellar dust. The strong potential of RC polarimetry allows disk modeling degeneracies to be broken, allowing for the extraction of information on the size, composition and porosity of the scattering particles. We suggest that the *Roman* Coronagraph Team work to fully define the instrument's science potential for exozodi and debris disk studies.

Our proposed involvement in the RC Team focuses on two areas. The first focus area is to use the needs of exozodi and debris disk imaging to motivate investigations of instrument performance and calibration for extended sources. 1.) By fully exercising the built-in polarimetry mode of RC in Band 1 and Band 4, we will learn how well its instrumental polarization can be modeled, the limits to polarization sensitivity including the efficacy of polarimetric differential imaging at very high contrast levels, and the accuracy of its polarimetric calibration. From such work the RC team can gain confidence that polarized light can be a science tool for RC and eventually HWO, and not an optical design issue that curtails high contrast performance. 2.) By investigating the limits to LOWFS operation, our intended studies will map out the parameter space of dark hole contrast versus target star brightness - defining the full extent of what RC and eventually HWO can achieve in the way of disk and exozodi detections in the solar neighborhood. 3.) Building from the PI's ongoing involvement in JWST coronagraphy, we will provide a customized pipeline module for analyzing tech demo data of extended disk sources.

Informed by the results of the above, our second focus area is to develop options for two potential community projects that would figure into a decision on RC utilization beyond the tech demo phase. 4.) By leading the RC team and broader community in the definition and preparation of a ready-to-execute exozodi survey program, we will enable a timely NASA HQ decision on whether the benefits of an exozodi survey would justify the required resources, reducing the risk to the primary *Roman* Science mission and (should the survey go ahead) to HWO mission lifetime requirements. 5.) By building a database of disk models for the known debris disks accessible to RC, we can gain confidence that tech demo observations of extended sources will achieve their goals while simultaneously laying the groundwork for a possible future survey of inner warm debris disks with RC.

The success of future facilities like the *Roman* Coronagraph will require scientists with both a working knowledge of the technical challenges of high contrast imaging and an understanding of the fundamental research questions. We believe that our expertise in instrument commissioning and calibration, in disk science and disk modeling, and in data pipeline development will serve the community and the *Roman* Coronagraph Team.