(1) Submission Survey Name:
Roman Multi-Tiered Surveys (RomanMTS) for Extragalactic Science

(2) Contact author: Casey Papovich, Department of Physics and Astronomy, Texas A&M University, College Station, TX, 77843-4242; papovich@tamu.edu

(3) Co-authors: Steven Finkelstein (UT Austin), Russell Ryan (STScI), W. Niel Brandt (Penn State), Caitlin Casey (UT Austin), Mark Dickinson (NOIRLab), Harry Ferguson (STScI), Eric Gawiser (Rutgers), Jeyhan Kartaltepe (Rochester), Anton Koekemoer (STScI), Jennifer Lotz (NOIRLab), Nor Pirzkal (STScI), Rachel Somerville (Flatiron), L. Y. Aaron Yung (NASA/GSFC)

(4) Do you support the selection of a Roman Early-Definition Astrophysics Survey:

Yes, the authors of this submission support the selection of Roman Early-Definition Astrophysics Surveys, specifically to facilitate extragalactic studies. Defining the parameters and target fields of primary surveys early (i.e., pre-launch) is crucial for the overall success of the Roman project as it maximizes the scientific potential. Early selection can establish the target fields and depths, which allows the community to obtain ancillary imaging and spectroscopy (rather than wait for possibly years after Roman launches for these data), and to build data-pipelines (infrastructure) and to build simulations to forecast results (to prepare for science and to test the infrastructure). This early preparation is especially important for lifetime limited space-borne missions The Early-Definition Astrophysics Surveys can provide a legacy for Roman similar to the Legacy and Treasury programs for Spitzer and Hubble.

(5) Describe the science investigations enabled by the survey:

Studies of galaxy evolution in extragalactic astronomy require two things: characterizing distant galaxies (their masses, star-formation rates, resolved structure/morphology, stellar populations and ISM properties) and measuring an accurate census of key distributions (e.g. luminosity and stellar mass functions). To achieve these goals forces us to a tiered strategy, where bright/massive galaxies are relatively rare and require large areas of moderately-deep depth, while fainter galaxies are more common, but require the deepest data. **Here, we describe a strategy using "*Roman* Multi-Tiered Surveys (RomanMTS)", which provides a combination of moderately deep, wide area (2-3 sq. deg) and ultra-deeper, smaller area (0.5-1 sq. deg) coverage.** RomanMTS provides a natural extension of the ultra-wide High Latitude Survey (HLS) and the Time Domain Survey (TDS), going both deeper and increasing the WFI wavelength coverage with broadband filters. This opens new parameter space in galaxy evolution that will not be addressed by the existing community surveys (and this science is not feasible with JWST given its small field coverage, nor with Rubin+Euclid given their wavelength coverage and shallower depth). Some key science goals are the following, and they motivate observational requirements:

How do massive galaxies evolve? To address this question, we need to make an accurate census of massive galaxies out to redshifts of > 4 and characterize their properties. The formation of massive galaxies involves extreme physical conditions: these galaxies form quickly and quench early, and require rapid accretion of baryonic gas, the conversion of this to stars, and strong feedback mechanisms to quench that star formation (see, e.g., [1]). To work this problem requires a multiband survey (to identify the galaxies from photometric redshifts) including the *Roman* WFI K-band (F213), which can select mass-complete samples of galaxies out to redshifts > 4 (e.g., down to stellar masses, Log M*/Msun ~ 10.5 at z=4, see Figures 1 and 2). Multiband data (0.8-1.8 micron) enables us to constrain the galaxies' stellar populations (e.g., [2]). Spatially resolved data (like from *Roman*) enables us to study morphologies, internal colors, and the formation of bulges. Slitless spectroscopy (e.g., with the *Roman* prism) enables studies of the emission lines (ionization, metallicity, star-formation rates) and can be used to study the stellar populations, star-formation histories and formation mechanisms ([3-7]). Multiband, deep imaging and spatially resolved prism spectroscopy will enable us to identify massive, quenched galaxies at the earliest times and identify when those galaxies first form.

How does the rest-frame UV luminosity evolve into the Epoch of Reionization? This is fundamental to our understanding of galaxy formation, star-formation in extreme conditions (including low-metallicity, gas-rich, high density systems of "first galaxies") and the ability of these galaxies to reionize the Universe. One of the key questions is why does the number density evolution of galaxies in the early universe *not* follow the predicted number density from dark-matter halo formation? The answer must be related to baryonic physics, the generation of radiation from star-formation and accreting supermassive black holes (i.e., active galactic nuclei), and the ability of this radiation to "leak" into the Intergalactic medium. The effects of these aspects imprint themselves on the UV luminosity function (UVLF). To study this requires identifying galaxies at redshifts z > 7 and measuring their evolution to z~11 (e.g., [8]). To measure the UVLF accurately requires observations of the tails of the distribution (bright and faint, covering regimes where differing feedback effects dominate) combined with an accurate zeropoint around "L*", the characteristic luminosity. The bright end will be well covered by planned *Roman* community surveys (e.g., HLS). However, we need surveys that will measure galaxies at fainter magnitudes. . Figure 1 shows how the proposed RomanMTS observations here provide this needed coverage and depth to identify these populations. Figure 2 shows how this translates to the needed coverage of the UVLF.

The science questions above require a multi-tiered strategy, like that we envision with RomanMTS. In addition, these data will provide a treasure trove for extragalactic science, similar in depth to deep *Hubble* extragalactic fields (e.g., CANDELS, [9-10]) but covering galaxy samples larger by more than an order of magnitude. The range of science possibilities is therefore extremely broad, including studies of merger rates, environmental impact on galaxy evolution, and searches for rare objects. This will provide a lasting legacy for *Roman*.

(6) Provide a possible observational outline of the survey:

The capabilities of the *Roman* allow an opportunity to advance our understanding of the science listed above. This science also forces us to design multi-tiered surveys with *Roman*'s Wide Field Instrument (WFI). We envision both a medium-deep, wider area survey covering ~ 2-3 sq. deg on the sky (we assume 10 WFI pointings as a baseline, achieving AB~28.3 mag) to probe accurately the massive/luminous galaxies at high redshift, and an ultradeep, smaller area with a deeper pointing covering ~0.5-1 sq. deg (we assume 2 WFI pointings as a baseline, achieving AB ~ 29.8 mag). The proposed depths for the moderately deep and ultra-deep surveys are in Table 1.

The total time would include roughly ~500 hrs of imaging and ~100 hrs of prism spectroscopy (neglecting overheads). Both tiers of this "wedding cake" include broad multiwavelength imaging (0.8 - 2.3 micron) and prism spectroscopy (R~80-180 from 0.8-1.8 micron) sufficient to detect faint emission from red and distant galaxies in the early universe (z~2-4 and z >7, see Figures 1 and 2).

We envision the survey would cover 3 widely space fields, and include likely targets such as the LSST Deep Drilling Fields (DDFs)[1]. These fields each cover a circular area of 3.5 deg in diameter and will achieve excellent broad-band imaging in the LSST optical basspands, to support the *Roman* WFI observations. These fields also have substantial *Spitzer/*IRAC coverage (3-5 micron) and other ancillary data. While there would be no strict timing requirement for these *Roman* observations, targeting the LSST DDFs would cover a large range of right ascension (0.5-10 hrs) facilitating wide accessibility for follow-up observations throughout the year. *Roman* observations to the proposed depths here will build a lasting public survey. Compared to other community surveys, the TDS will not overlap with the LSST DDFs, and will lack the deep optical imaging. Moreover, the TDS is not expected to include the wide range of passbands critical to the science case here (we propose to cover 0.8-2.3 micron with 6 filters).

The need for a multi-tiered strategy is apparent from Figure 3, which shows the spatial distribution of massive galaxies at z ~ 4 and luminous galaxies at z ~ 7. In each case, the limiting "cosmic variance" for massive/luminous galaxies in a single WFI field is substantial. In a single WFI pointing the expected variance is at least 15% (for massive galaxies at z~4) and 10% for z~7 galaxies. These can both be reduced to a few percent (~2-3%) by targeting ~4 pointings in ~3 widely spaced fields. Furthermore, the uncertainty on the clustering goes as the inverse of the area (see below) so we will make an accurate measurement of the clustering itself.

(7) Describe specific preparatory activities enabled by early definition:

It is important to define *Roman* surveys early (ideally before the launch) to facilitate data collection, the building of infrastructure (software, data pipelines), and development of simulations (to test infrastructure and to forecast results). This reduces the overall risk for the scientific success of the *Roman* mission.

The specific preparatory activities for the survey include: (1) Design and run cosmological simulations to match the expected observational strategy. We envision a multi-tiered approach in depth and area, and it will be necessary to build cosmological simulations that extend well beyond (at least ~10 x) of the survey area. This is crucial to test methods and to predict uncertainties, including the cosmic variance: e.g., the cosmic variance uncertainty will go as $1 / \sqrt{2(N-1)}$ for N times the survey area (i.e., if a simulation covers 10x the area, the uncertainty on the cosmic variance is $\delta\sigma/\sigma = 24\%$); (2) Develop analysis pipelines and build software to generate multiwavelength catalogs, derive stellar population properties, redshifts, etc. (3) Facilitate the early collection of spectroscopic redshifts from dedicated campaigns from wide-field multi-object spectrographs. This will provide important data for calibrating photometry, photometric redshifts, and emission line studies. Given the importance of the success of *Roman*, it is crucial to invest effort in infrastructure as much as possible before launch.

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[1] https://www.lsst.org/scientists/survey-design/ddf

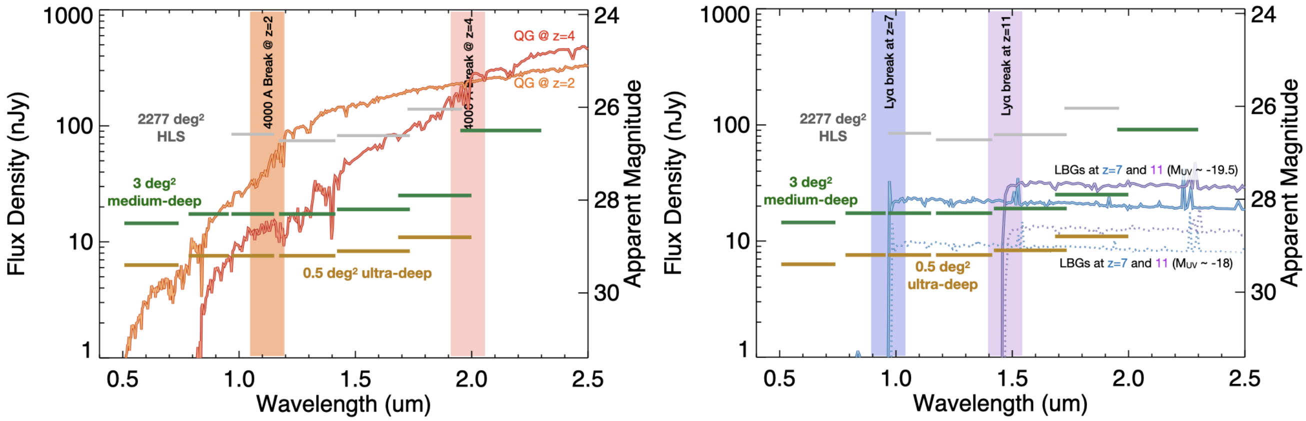

Figure 1: Spectral energy distributions of primary galaxies targeted here compared to the envisioned WFI magnitude limits for different surveys in different passbands. The LEFT panel shows "quiescent galaxies" whose light is dominated by more evolved stellar populations at z=2 and 4 with stellar masses, Log M* / Msun ~ 9.5 and 10.5, respectively. The RIGHT panel shows star-forming galaxies at z=7 and 11 (with two absolute magnitudes). In each panel thick, horizontal bars show the magnitude limits of our WFI survey in both a medium-deep portion (covering ~2.5 sq. deg [green]) and an ultra-deep portion (covering 0.5 sq. deg [gold]). The imaging here is deeper than that expected from the HLS [shown in gray], and covers a broader range in filter wavelength. Both of those aspects are important to detect and characterize the first quiescent and the highest-redshift star-forming galaxies.

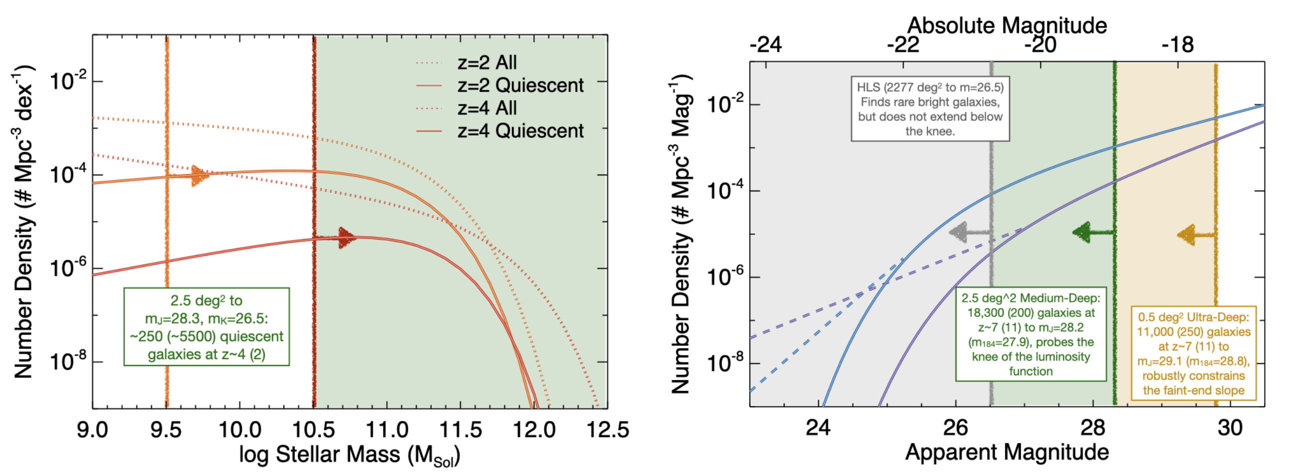

Figure 2: Stellar-mass and UV-luminosity functions of the primary types of galaxies targeted here. The LEFT panel shows the estimates of the galaxy stellar-mass function ([11]) for galaxies at z~2 and 4 (labeled). The vertical lines (and arrows) show mass limits for our envisioned survey. WFI observations to AB=28.3 mag will achieve mass-completeness limits of Log M* ~ 9.5 at z=2 and 10.5 at z=4. This is primarily important as it will provide the first accurate census of massive galaxies at z=4. The RIGHT panel shows estimates of the UV luminosity function at z=7 and 11 ([12]). The observations described here will constrain the number density of galaxies at the "knee" of the luminosity function (which requires wide-areal coverage of ~2-3 sq. deg to AB=28.3 mag) and at the faint-end slope (which requires deeper exposures, AB ~ 29.2 mag, but over less area). Combined with the shallower, wider observations that are expected from the HLS, the survey described here will enable a full characterization of the UV luminosity function into the epoch of reionization.

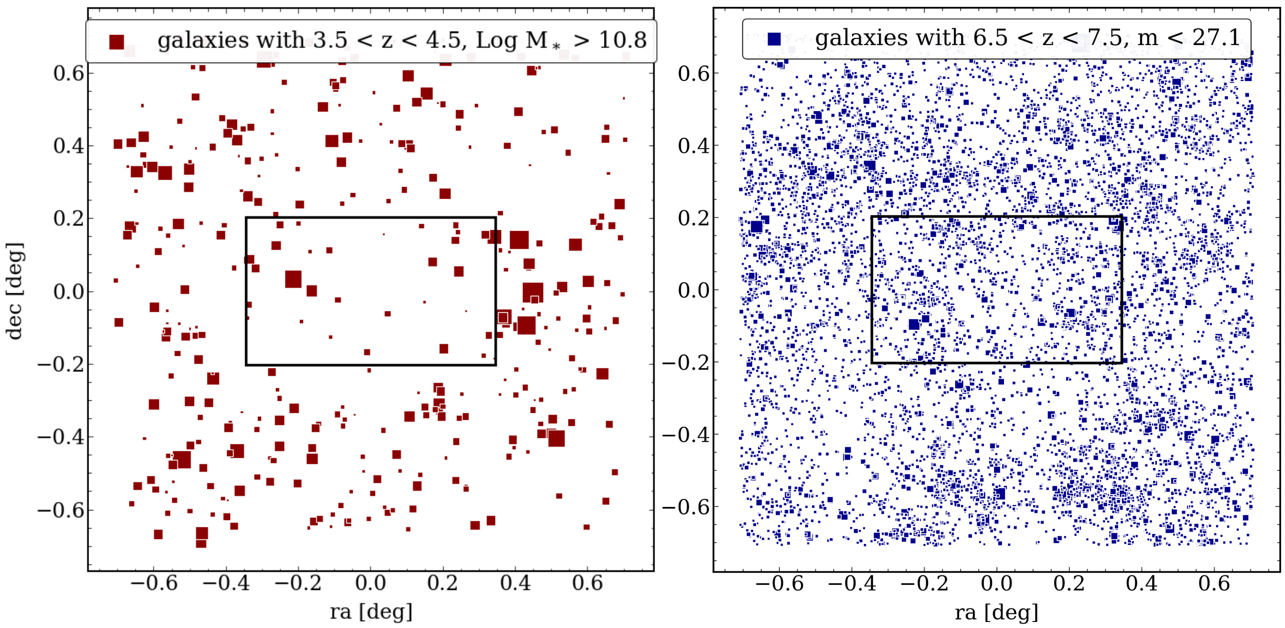

Figure 3: Expected spatial distribution of some of the types of galaxies targeted here. Each panel shows the distribution of galaxies of interest from a simulated light cone [13]. The large black rectangle shows the area covered by a single Roman WFI field of view. In each panel the symbol size increases with galaxy mass. The LEFT panel shows the spatial distribution of massive galaxies at $3.5 < z < 4.5$. These galaxies are highly clustered, and a single WFI pointing has an expected cosmic variance of at least 15%. The RIGHT panel shows the distribution of luminous galaxies at $6.5 < z < 7.5$. The cosmic variance here is 10% in a single WFI pointing. By targeting multiple pointings with WFI (e.g., 4 WFI pointings per field) in multiple fields (e.g., 3 widely space fields) we can reduce these uncertainties by a factor of order 6 so they are less than a few percent.

Table 1: Summary of program scope, area and exposure times. The depths are 5 sigma limits (in R=0.22" aperture) in the stated exposure times. The ultra-deep times will be in the moderate-deep fields, so those times are in addition to the moderate-depth coverage.

WFI band (wavelength)	F087 (0.87μ)	F106 (1.06 μ)	F129 (1.29 μ)	F158 (1.58 μ)	F184 (1.84 μ)	F213 (2.13 μ)	Prism (0.8-1.8μ)
moderate depth (~2.5 sq deg = ~10 WFI fields)	28.3 AB 5 hr/exp	28.3 AB 5 hr/exp	28.3 AB 5 hr/exp	28.2 AB 5 hr/exp	27.9 AB 5 hr/exp	26.5 AB 5 hr/exp	24.5 AB (cont.) 10 hr / exp
ultra-deep (~0.5 sq. deg = ~2 WFI fields)	29.2 AB +20 hr/exp	29.2 AB +20 hr/exp	29.2 AB +20 hr/exp	29.1 AB +20 hr/exp	28.8 AB +20 hr/exp	---	---
Totals:	~500 hours of imaging, ~100 hours of prism data = ~600 hours total.						

References: [1] Glazebrook et al. 2017; [2] Merlin et al. 2019, A&A 622, 169; [3] Estrada-Carpenter et al. 2019, ApJ, 870, 133; [4] Estrada-Carpenter et al. 2020, ApJ, 898, 171;

[5] D'Eugenio et al. 2021, 653, 32; [6] Morishita et al. 2019, ApJ, 877, 141; [7] Tacchella et al. arXiv:2101.12494; [8] Finkelstein et al. 2021, arXiv:2106.13813; [9] Grogin et al. 2011, ApJS, 197, 35; [10] Koekemoer et al. 2011, ApJS, 197, 36; [11] Muzzin et al. 2013, ApJ, 777, 18; [12] [12] Finkelstein 2016, PASA, 33, 37; [13] Yung et al. 2019, MNRAS, 483, 2983