Roman Early-Definition Astrophysics Survey Opportunity

(1) Submission Title or Survey Name: Establishing a Roman Ultradeep Legacy Field

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On behalf of the *Roman* EXPO Science Investigation Team

(4) Do you support the selection of a Roman Early-Definition Astrophysics Survey (as described in the "Request for Information"; yes/no, with supporting motivation, 10 lines max):

Yes, we support the selection of a *Roman* Ultradeep Legacy Field (RULF) that represents the next evolutionary stage in pushing the forefront of our knowledge about the first billion years of cosmic history. *Roman* can establish for the first time an ultradeep (~30 AB mag) infrared survey that probes the scales of cosmic structures by surveying ~one square degree with both imaging and slitless spectroscopy. The RULF science return is unprecedented for the study of galaxy formation and the reionization epoch, as it will teach us new information about the connection between the galaxies that reionize intergalactic hydrogen and the cosmic environments hosting their formation. Given the important advantage of coordinating precursor observations by *JWST* and *Rubin/LSST*, especially given the limited *JWST* lifetime, we must act now to preserve the opportunity to conduct this transformative survey after *Roman* launches in 2027.

(5) Describe the science investigations enabled by the survey (as relevant, briefly describe: key science drivers and breadth of science areas engaged; datasets expected upon survey completion; comparison of science enabled, parameter space opened up, or complementarities with respect to ground/space-based state-of-the-art at time of *Roman* launch; key differences from, and/or complementarities with, *Roman* core community surveys; one page max):

Cosmic reionization transformed the intergalactic medium from a neutral to an ionized state and provides a unique opportunity to study an event where small-scale structures completely rewrite the large-scale properties of the universe. Understanding reionization involves a census of the UV light from galaxies, multiband imaging to constrain the nature of early stellar populations, spectroscopic probes of Ly-alpha emission, and sufficient area to resolve cosmic variance uncertainties and quantify environment. Studying the connection between galaxies and reionization requires 1) extremely sensitive, multiband imaging to discover the abundant faint galaxies at the right era, 2) a very wide area (~square degree) to constrain the contribution of rare, bright galaxies and to probe a range of environments, and 3) unbiased spectroscopy of high-z Lyman-alpha emission without preselection. *Roman* Z-band provides constraints at the critical redshift $z{\sim}7$ when the IGM ionization state changed most rapidly (e.g., Robertson et al. 2015), which is a redshift window no other facility can study over sufficient areas to reveal the precise role of galaxies in reionization. The RULF requirements and science have been studied in exquisite detail, and the RULF provides a low-risk, extremely high-reward option for a *Roman* Early-Definition Astrophysics Survey. The *Roman* EXPO Science Investigation Team used high-resolution cosmological simulations with a data-driven model for the redshift-dependent galaxy population to model the scientific benefits provided by a RULF (Drakos et al. 2021; D21). Figure 1 shows a simulated RULF multiband image (D21), showing the enormous dynamic range and survey power that *Roman* provides. Figure 2 shows the resulting unmatched, sub-percent level constraints on the high-z UV luminosity function. The execution cost and implementation of a RULF is already well-studied, as EXPO created a survey simulation tool to determine the program costs (Figure 3) while carefully balancing image quality and filter depth. Data products will include unprecedented galaxy catalogs including photometric redshifts, SED model-based stellar mass determinations, spectroscopic redshifts, clustering, inferred stellar mass-halo mass ratios, and emitted line strengths. RULF data will enable ancillary studies of galaxy evolution over a wide range of redshifts, including the connection between galaxy morphology, spatially resolved stellar populations, and environment, spectroscopic H-alpha SFR determinations as a function of stellar mass and environment, faint AGN identification, clustering and stellar mass-halo mass relation variations with environment. With ~30AB depth imaging, the dark matter density underlying the galaxy distribution can be constrained, allowing for a redshift-dependent inference of the ionization field from the galaxy population alone (Trapp+2021). These studies require deep, high-resolution imaging, wavelength coverage from ~0.6-2 microns to ~30AB, and unbiased, flux-limited spectroscopy that no other facility (*Rubin*, *JWST*, *Euclid,* etc.) can provide alone and that will not be achieved through the *Roman* wide-area community survey (less sensitivity, with limited filters) or the *Euclid* deep fields that only reach to ~26AB. In an ultradeep (~50 hour) G150 grism exposure, *Roman* will reach 5-sigma line flux limits of ~10^{-17} erg/s/cm^2, corresponding to Ly-alpha detections of z~8 galaxies with SFR~7-15 Msun/yr, and a *Roman* P127 prism campaign would reach even deeper. RULF will serve as the essential ultradeep tier on the "wedding cake" layers the wide-area and time-domain community surveys will provide, completing a triumvirate of legacy surveys for extragalactic astrophysics.

(6) Provide a possible observational outline of the survey: The RULF could consist of R, Z, Y, J, H, F184, and Ks *Roman* images at depths ~30AB (R-H) or ~28AB (F184-Ks) with grism/prism spectroscopy to ~10^{-17} erg/s/cm^2, and the survey would run between 0.3-1 square degrees depending on the on-sky performance of *Roman*. With overheads, a single pointing of the imaging component would require ~350 hours (e.g., Koekemoer+2019). The spectroscopic campaign will require another ~50 hours. The total required time is then ~400 hours per pointing. For field placement, there are two clear strategies. First, a RULF could be situated in the *Roman* time-domain fields, saving on observational time, benefiting from improved cadence, and easily enabling multiple spectroscopic roll angles. A second option would be to maximize ancillary data by using an equatorial field. Primary candidates are COSMOS and XMM-LSS, which benefit from being *Rubin* Deep Drilling Fields (ground-based *ugriz* ~ 28.5AB). COSMOS has large *JWST* GO programs and XMM-LSS has valuable x-ray data. *Roman* uniquely provides high-resolution, wide-area IR imaging and slitless spectroscopy, and the RULF cannot be conducted with any other facility. The R-H imaging can be conducted early in the GO with any cadence allowed by other scheduling constraints. The F184 and Ks imaging could be conducted with ~quarterly cadence over the 5-year mission to find high-redshift exotic SNe, avoid windows with high background, and provide multiple grism/prism roll angles. Multiple *Roman* WFI pointings would maximize overlap of spectroscopic and imaging. Depending on complementarity with other *Roman* programs, and the availability of ancillary data, multiple RULFs could be considered (e.g., one in the *Roman* CVZ and one in an equatorial field).

(7) Describe specific preparatory activities enabled by early definition: The primary benefit of selecting a RULF as a Roman Early Definition Astrophysics Survey is to convince other complementary, precursor facilities to invest observational time ahead of Roman launch. Establishing a panchromatic extragalactic survey requires years of advanced preparation and investment. Since Roman will follow, e.g., *JWST*, *Rubin*, and *MeerKAT* by several years, to establish ancillary data simply requires a RULF selection as a Roman Early Definition Astrophysics Survey and commit to an ultradeep program. Important potential synergies requiring pre-planning include deep/wide narrow band imaging with Subaru/HSC or unique deep/wide medium band imaging with Tokyo Atacama Observatory. For reionization, establishing redshifted 21cm coverage would be powerful (e.g., Zackrisson et al. 2020). Early selection would enable preparatory science investigations of the optimal dithering strategy to provide oversampled, high-resolution mosaics, and investigations of the number of roll angles to provide de-confused slitless spectra. Early definition would enable continued development of machine learning models to perform deblending, pixel-level morphological classifications, low surface brightness science, merger histories, and stellar halo analyses. Getting a "head start" on planning the RULF would allow for improved simulation efforts including more realistic treatments of morphology and environmental impacts. Advanced planning would greatly benefit the detailed survey strategy including the distribution of exposure times and trade-offs between possible prism/grism spectroscopic campaign strategies.

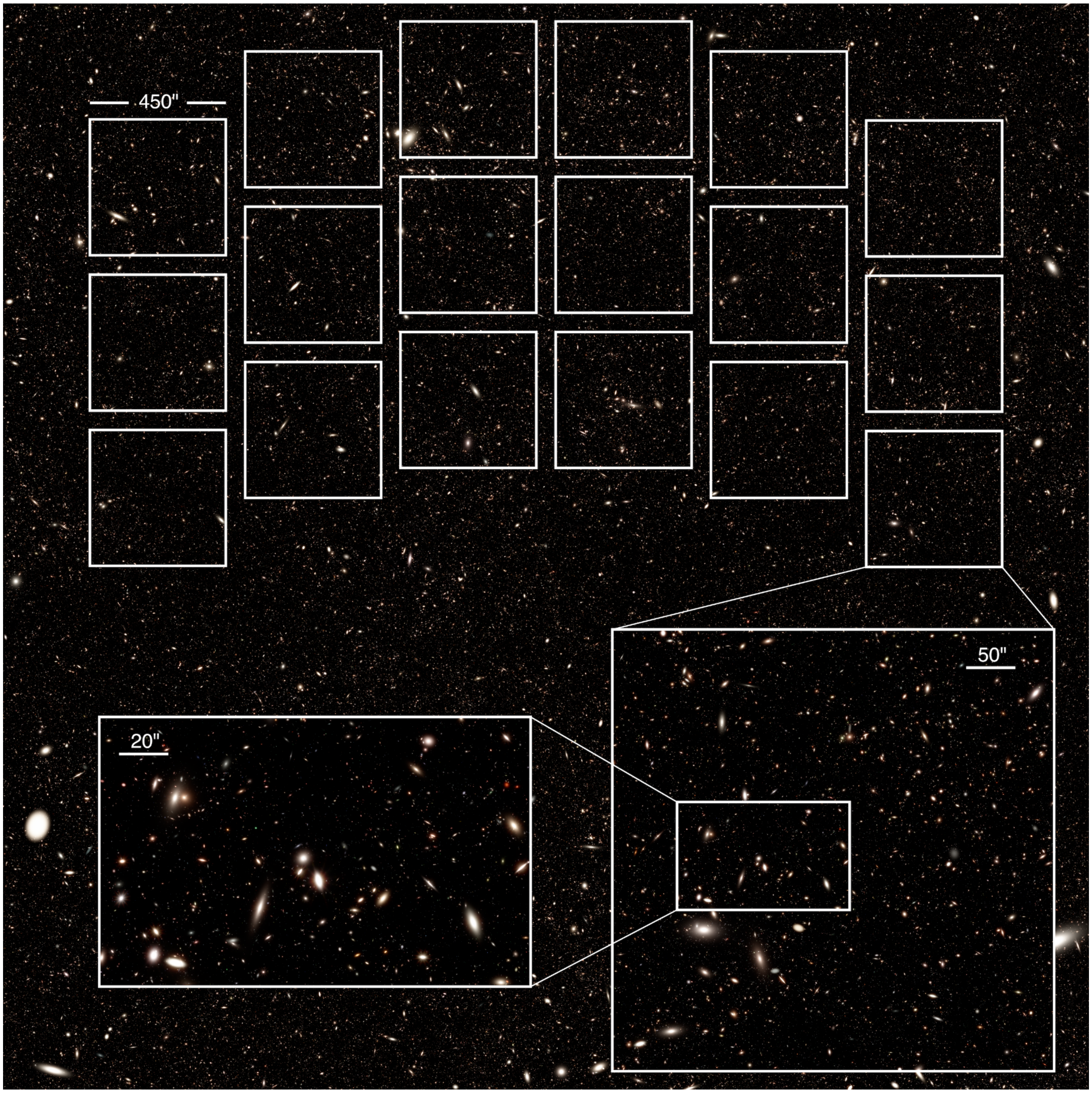

Figure 1: Composite simulated image (Drakos et al. 2021) of a *Roman* Ultradeep Legacy Field computed with the Deep Realstic Extragalactic Model (DREaM) using the Z087 (blue), Y106 (green), and H158 (red) filters convolved with the *Roman* PSF. Noise is calculated assuming a depth of $\sim$ 30AB in each filter. The image was created by combining the DREaM results with the *Roman* module in GalSim. The *Roman* footprint is shown with an overlay, as well as with insets showing a zoomed in region of the image. A native resolution version of this 1 deg^2 visualization is available online at https: //www.nicoledrakos.com/dream.

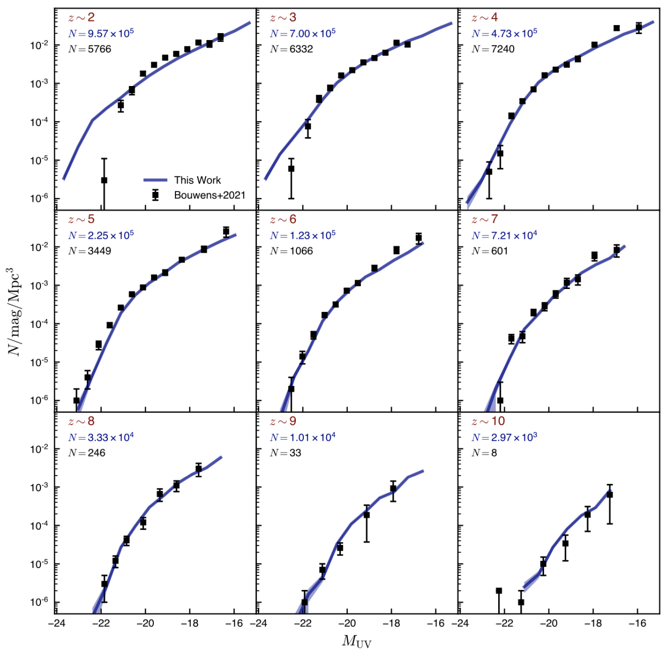

Figure 2: UV luminosity functions achieved by a *Roman* Ultradeep Legacy Field. Shown are galaxies from the Drakos et al. (2021) DREaM synthetic galaxy catalog (blue lines) and corresponding 1-σ constraints (shaded region) on the redshift-dependent luminosity function a RULF will provide. Also shown is the recent determination by Bouwens et al. (2021) for comparison (black points), which illustrates the enormous advance in constraining power the RULF provides, yielding remarkably tight constraints on the faint end of the UV LF at high redshifts.

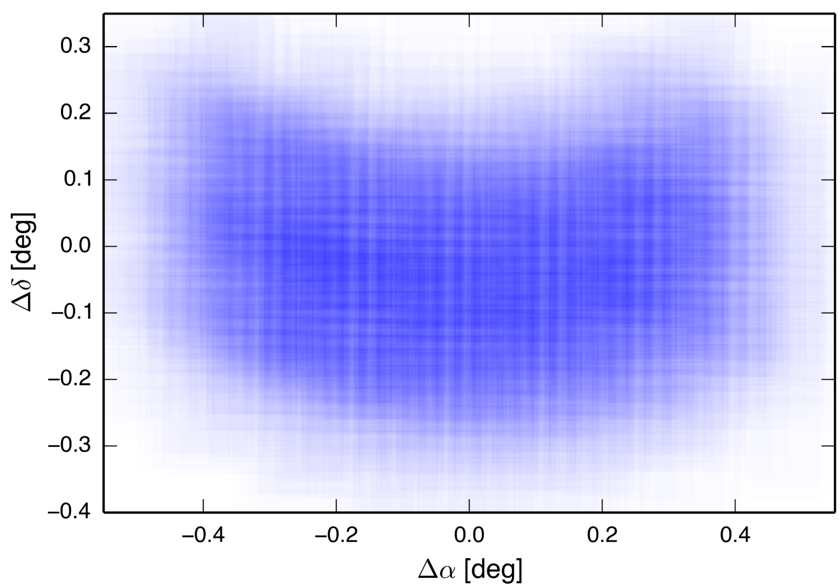

Figure 3: Example simulated exposure time map for a *Roman* Ultradeep Legacy Field with distributed dithers to improve image quality. The *Roman* EXPO Science Investigation Team created a detailed survey simulator for *Roman* UDF surveys, including overhead costs associated with slewing and settling, allowing for an accurate computation of the cost associated with acquiring a RULF.

References

Bouwens, R. J., et al., AJ, 162, 47 (2021); Drakos, N., et al., submitted to ApJ, arXiv:2110.10703 (2021); Koekemoer, A. et al., "Ultra Deep field Science with WFIRST", BAAS, 51, 550 (2019); Moriya, T., Quimby, R. M., & Robertson, B. E., submitted, arXiv:2108.01801 (2021); Robertson, B. E., Ellis, R. S., Furlanetto, S. R., & Dunlop, J. S., ApJL, 802, 19 (2015); Trapp, A. C., Furlanetto, S. R., & Yang, J., arXiv: 2110.05591 (2021); Zackrisson, E., et al., MNRAS, 493, 855 (2020)