Roman Early-Definition Astrophysics Survey Opportunity:
Submission Template

(1) Submission Title or Survey Name: ***Ultra Deep Field - Slitless Spectroscopy with Roman***

(2) Contact author (with institutional affiliation and full contact details, including email):
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(3) Co-authors (names and institutions only):
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(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 outline an ultradeep spectroscopy survey reaching 20 times fainter in line sensitivity than core community survey. This survey will provide spectra for ~ 10^7 galaxies in a 0.6 sq. degree in an unbiased way and will map Large Scale structure and clustering in three dimensions. Deep Grism observations will provide spectroscopic redshifts for (1) all galaxies with star-formation rates (SFR $\gtrsim$ 0.1 M_{sun}/yr) up to z=2 (cosmic noon) using emission lines (2) Prism spectra will yield redshifts for quiescent galaxies using continuum breaks. Overall, we should get redshifts for > 60% of the galaxies. For others, spectra will combine with photo-z's to improve photometric redshifts. Deep spectroscopy of 0.6 square degree will provide 5000 LyA emitters between redshifts $5<z<10$, enabling us to quantify the progress of reionization to distinguish between competing models. So far the number of z > 7 LyA emitters identified in grism spectra is less than 6. RUDF should get 1000.

[Answer the questions that follow only if proposing a specific survey concept; be aware that the content below may be made public should this concept, or one closely related to it, be documented in the Assessment Committee report.]

(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):

We propose a deep field consisting of 2x1 WFI pointings, and using nearly *all* WFI spectral elements, at a wide range of roll angles. 60% of the time will be spent on the two spectroscopic elements, to achieve the maximum astrophysical information that *Roman* is capable of providing. This will offer advantages that are unique to spectroscopy:

A. Probing cosmic dawn with Lyman-alpha emitting galaxies and quasars.
B. Probing cosmic star formation history and galaxy astrophysics with a range of emission line diagnostics at cosmic noon.
C. Identifying unique and extreme objects that may not be detected and/or identified in imaging surveys alone.
D. For all of these aims, Roman's large FOV will give sampling of many environments.

A: Lyman alpha emission offers a unique probe of the intergalactic medium, because it is resonantly scattered by neutral gas. Deep slitless spectroscopy with *Roman* can identify Lyman alpha emitting galaxies over a continuous redshift range, applying techniques developed for *HST* surveys (GRAPES, PEARS, FIGS, 3dHST, WISPS, and others) to combinations of depth and area not previously possible (Fig 1). Such data will enable new tests of reionization history based not only on luminosity function evolution but also clustering tests (Fig 5). The depth of the field is driven by the need to probe reionization. It is planned to be nearly 100 times deeper than Euclid and 20 times deeper than Roman core community spectroscopic survey. Multiple position angles will help alleviate confusion and superposition of spectra. Simulations show high recovery rates for line emitters using more than 24 Position Angles (Wold et al. 2021). High redshift faint quasars from low mass black holes, as well as obscured quasars will also be found with such a blind survey, leading to invaluable insights into black hole growth and formation.

B.Slitless spectra with both prism+grism, with combined wavelength coverage 0.75 - 1.93 microns, will enable a complete history of cosmic star formation for $0 < z < 4$ (using Hα for $0.15 < z < 1.9$; Paschen lines at lower z; and [OII] up to z=4.1). The spectroscopic detection limits correspond to star formation rates as small as <0.1 Msun/year over the range z=1-2, which is far below L^*. Spectra will provide Hα star formation rates, Balmer decrement dust corrections (0.55<z<1.9); metallicity estimates from R23 and AGN identification from the mass-excitation diagram. This UDF will sample a volume of 16 million Mpc^3 to z~3 and a large range of dense to sparse environments, informing us of galaxy evolution with the environment as a function of redshift.

C. Finally, direct spectroscopic surveys can find extreme and/or unusual objects that are difficult to identify in purely photometric searches. For example, ~ 30% of Lyman α galaxies from the MUSE deep survey are undetected in Hubble Ultra Deep Field imaging (Maseda et al 2018+-).

Combining spectroscopy with deep (~ 29.7 mag) imaging in nearly all WFI filters will enable joint imaging+photometry+spectroscopy projects. These could include one-stop photo-z calibration useful for weak lensing; AGN searches executed by seeking variable point sources with broad lines; 60% host galaxy redshifts for transients, and completion and systematics help for BAO cosmology.

(6) Provide a possible observational outline of the survey (as relevant/known, touch upon: survey area covered, possible location, and/or (types of) targets observed; optical element (filters/grism/prism) choices; cadence or other timing constraint (if relevant); depth to be achieved; total time needed including estimated overheads; how the survey leverages the unique observational capabilities of Roman; half-a-page max):

We tabulate below suggested total time per pixel on sky, per spectral element, for each field. The total time spent would be 2x longer to make a 2x1 mosaic of *Roman* WFI fields. This should be placed at high galactic and ecliptic latitude and within the continuous field of regard.

Element	Grism	Prism	R062	Z087	Y106	J129	H158	F184	K213	Total
Hours/field/filter	140	70	20	20	20	20	20	20	20	350
5σ AB, point	2.5e-18	2.9e-18	30.0	29.8	29.7	29.6	29.6	29.1	27.8	
5σ, r_{50}=0.3”	5.8e-18	6.7e-18	28.6	28.4	28.4	28.4	28.4	28.0	26.8	

For the grism and prism, the limiting sensitivity is quoted for emission lines in erg/cm^2/s, and for 1.4 micron wavelength. For imaging filters, the limiting sensitivity is given in AB magnitudes.

The 2x1 mosaic format maximizes overlap between observations taken at arbitrary roll angles. We propose dividing the observing program into at least 24 distinct rolls, which will enable data cube construction from slitless spectroscopy (e.g. Wold et al 2021). Given the instantaneous roll range of the spacecraft, this requires at least 8 epochs spaced over most of one year. Such a strategy would open up a wide range of time domain science.

(7) Describe specific preparatory activities enabled by early definition (e.g., supporting facility observations, software development work, theoretical/simulation efforts etc.; describe the benefits of conducting these activities early; half-a-page max):

Complementary data sets from existing facilities will be enabled by early selection of a deep field location. Subaru + HSC optical imaging is one prominent example, given the Japanese commitment to spend 100 nights of Subaru time in support of *Roman*, and given urgency to decide whether a portion of that time will be taken shortly using HSC. Because *Roman* does not go bluer than R band, these data are particularly crucial to completing SEDs. *HST* UV imaging for a subset of the selected field would be similarly valuable, but the aging of *HST* and its ultraviolet instrumentation means that earlier execution is better. In addition, once a deep Roman field is decided, many other observatories, present and future, will concentrate efforts on it.

NIR Slit spectroscopy at higher resolution from the ground would provide cross-calibration.. Obtaining spectra for ~ 10^3 objects in the chosen field, obtained prior to *Roman* launch, would enable the spectroscopic observations outlined here to be immediately useful in calibrating *Roman* spectroscopy; but such spectroscopic campaigns require lead time and planning. Optical slit spectroscopy from instruments like MOONS will extend the wavelength range of spectra Finally, development of analysis codes to optimally combine spectroscopic and photometric data for maximum astrophysical inference could be greatly accelerated given a specific observing strategy to plan for.

[It is allowed to add <u>two additional pages</u> with figures, tables, or references, as needed to support the preceding answers. This can include any past/planned white papers, community building/engagement activities, working groups, workshops, or cross-project/cross-mission planning relevant to the survey.]

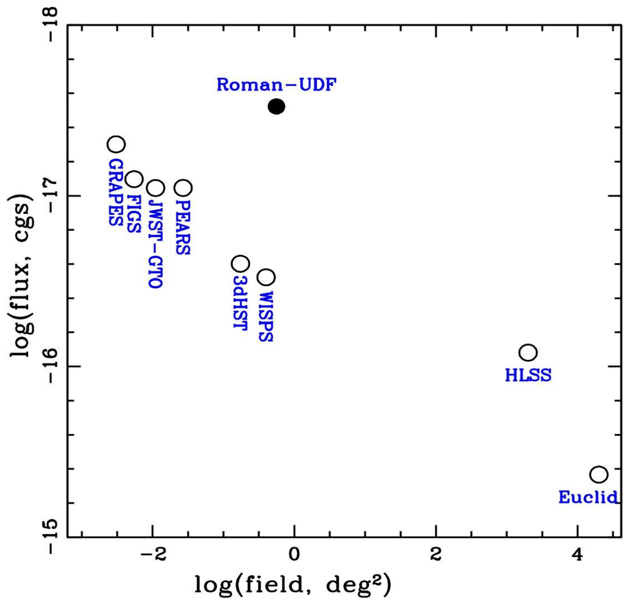


Figure 1: Comparison of the proposed survey (labeled "Roman-UDF") with other space-based slitless spectroscopic surveys. We show five HST programs (GRAPES, PEARS, FIGS, 3dHST, and WISPS), the spectroscopic component of JWST GTO-1176; the projected *Roman* High Latitude Spectroscopic Survey (HLSS); and the *Euclid* spectroscopic survey.

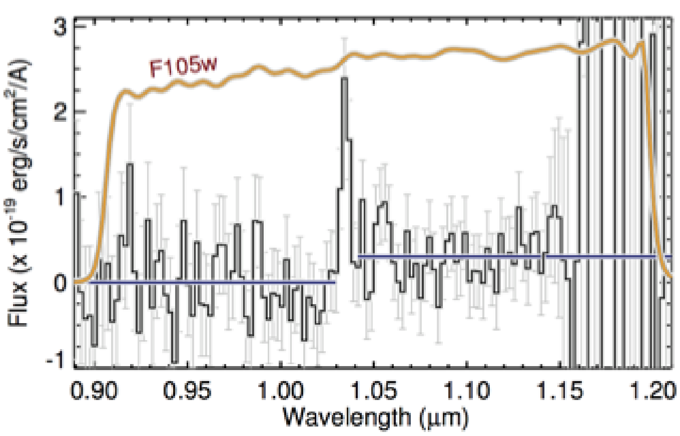
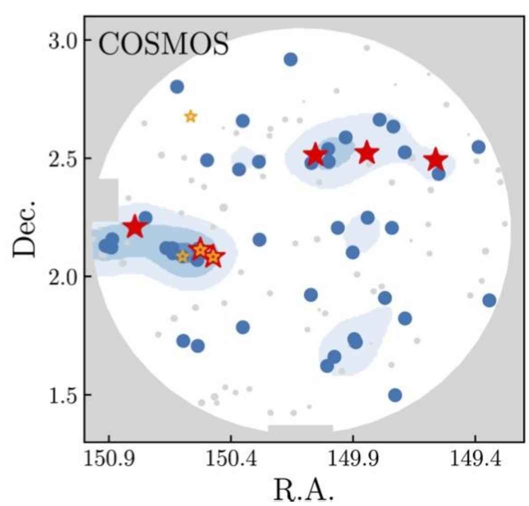


Figure 2: Spectrum of a z=7.5 galaxy, from HST FIGS (the Faint Infrared Grism Survey) (Tilvi et al 2016). This demonstrates identification of both Lyman alpha and the Lyman break in the epoch of reionization using deep slitless grism data (40 *HST* orbits, ~ 35 hours). The suggested *Roman* survey will be ~ 4 times deeper.

Figure 3: Lyman alpha emitters in the epoch of reionization show considerable large scale density variations, as seen in this redshift 7 map from narrow bandpass imaging by the LAGER (Lyman Alpha Galaxies in the Epoch of Reionization) survey (W. Hu et al 2019, fig 3). *Roman* will be the only mission in space able to map comparable areas to comparable sensitivities, and will add the advantage of continuous wavelength coverage thanks to its grism and prism.



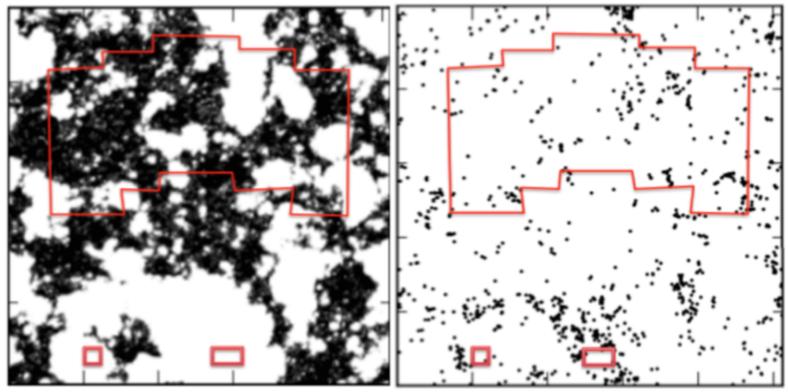


Figure 4: Left: Maps of ionized (white) and neutral (black) gas in the reionization simulation of H. Jansen et al (2012). Right: map of detectable Lyman alpha galaxies, given this IGM ionization state. This snapshot shows expectations for the IGM ionization topology around the midpoint of reionization (z ~ 7 or 8). Superposed fields of view (WFC3-IR, bottom left; JWST NIRCam, bottom right; *Roman* WFI, top) illustrate how only *Roman* will easily cover enough sky to identify the visible Lyman alpha galaxies and so map these extended ionization bubbles.

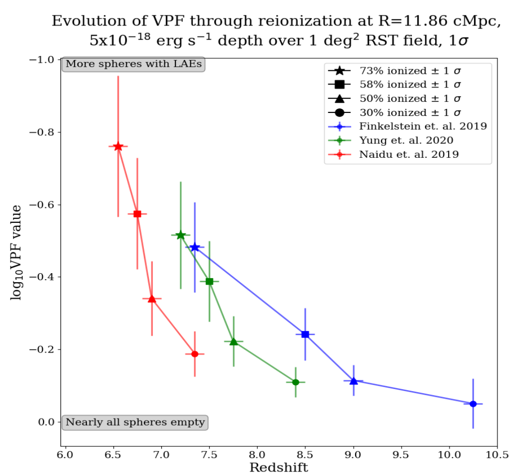


Figure 5: Void Probability Function predictions for Lyman-alpha in a spectroscopic deep field from *Roman*. Different reionization models can be distinguished based on a survey like the one proposed here. (From Perez et al 2021, in prep.)

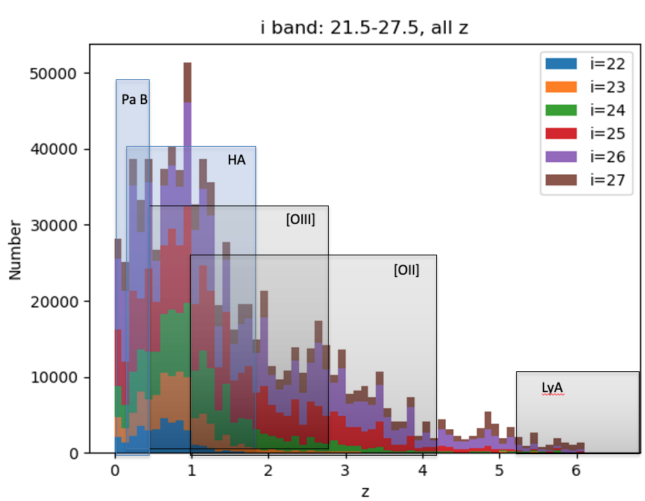


Figure 6: This figure shows the redshift distribution of sources in the COSMOS field as a function of i-band magnitude. The redshift ranges where selected emission lines fall in the joint coverage of the *Roman* prism+grism are overplotted, illustrating how this program will offer nearly complete coverage for emission line redshifts as well as an extensive selection of emission lines for galaxy astrophysics throughout the history of the universe.