Roman CCS White Paper

Title: Deep-Wide Spectroscopy for Galaxy Evolution and Reionization

Roman Core Community Survey: High Latitude Wide Area Survey   (also High Latitude Time Domain Survey)

Scientific Categories: Galaxies; the intergalactic medium and the circumgalactic medium; supermassive black holes and active galaxies; large scale structure of the universe

Additional scientific keywords: Emission line galaxies, Reionization, Large Scale Structure of the Universe, Supernovae

Submitting Author:
Name: James Rhoads
Affiliation: NASA GSFC
Email: James.E.Rhoads@nasa.gov

List of contributing authors (including affiliation and email):
James Rhoads (NASA GSFC/James.E.Rhoads@nasa.gov), Isak Wold (NASA GSFC/Isak.G.Wold@nasa.gov), Tri Astraatmadja (STScI/tastraatmadja@stsci.edu), Jean-Gabriel Cuby (CFHT / cuby@cfht.hawaii.edu), Pratika Dayal (Groningen U./pratika24@gmail.com), Susana Deustua (NIST), Xiaohui Fan (U. Arizona / fan@as.arizona.edu), Yuichi Harikane (U. Tokyo / hari@icrr.u-tokyo.ac.jp), Anne Hutter (U. Copenhagen./anne.hutter@nbi.ku.dk), Rolf A. Jansen (Arizona State U. / rolfjansen.work@gmail.com), Ali Ahmad Khostovan (Rochester / akhostov@gmail.com), Anton M. Koekemoer (STScI / koekemoer@stsci.edu), Garrelt Mellema (Stockholm U./ garrelt.mellema@astro.su.se), Masami Ouchi (NAOJ/U. Tokyo / ouchims@icrr.u-tokyo.ac.jp), Lucia Perez (Princeton U. / lucia.perez.phd@gmail.com), Andreea Petric (STScI / apetric@stsci.edu), Benjamin Rose (Duke / benjamin.rose@duke.edu), David Rubin (U. Hawai`i / drubin@stsci.edu), Rachel Somerville (Flatiron Institute / rsomerville@flatironinstitute.org), Wei Leong Tee (U. of Arizona / wltee@arizona.edu), Vithal Shet Tilvi (Goa), Feige Wang (U. of Arizona / feigewang@arizona.edu), Rogier Windhorst (Arizona State U. / Rogier.Windhorst@asu.edu), L. Y. Aaron Yung (NASA/GSFC / l.y.aaronyung@gmail.com), Erik Zackrisson (Uppsala U. / erik.zackrisson@physics.uu.se).

Abstract: Roman's capability for slitless spectroscopy over wide fields of view will be revolutionary for studies of galaxy evolution and reionization. In this white paper, we underscore the case for a deep+wide spectroscopy component to the Core Community Surveys, primarily the High Latitude Wide Area Survey.   Covering ~ 10-20 square degrees to an emission line sensitivity of of 10-17 erg cm-2 s-1 will enable (a) multiple reionization tests, (b) charting star formation rate density across cosmic noon, (c) identification of rare and interesting objects, (d) redshifts for supernova hosts, and (e) photometric redshift training, all studied with large samples and over a range of environments.

Insert your white paper content here. The suggested length is 2 or 3 pages of text, plus figures, tables and references as needed.

Spectroscopy underpins a vast fraction of astrophysical knowledge. The *Nancy Grace Roman Space Telescope* will be capable of previously impossible spectroscopic surveys, thanks to its wide field, excellent spatial resolution, and the relatively low background in orbit.

In this white paper, we advocate for the astrophysical applications of deep-wide fields with *Roman* spectroscopy. Here "Wide" means ~ 10-20 square degrees, and "deep" means line flux limits of $\sim 1 \times 10^{-17}$ erg cm^{-2} s^{-1}. These numbers correspond to the deep fields described in the Reference Survey for high latitude observations in the *Roman* science requirements document (RST-SYS-REQ-0020, Rev C; for spectroscopy, section 3.3.1; and for imaging, section 3.4.4 and requirement HLIS 2.0.5). That reference survey assumes approximately 10% of the total HLWAS time will be spent observing ~ 6 - 20 square degrees with sensitivities 3-5 times deeper than the main survey. These observations are in the reference survey to enable verification of performance requirements over the full HLWAS. On top of that, they will be incredibly powerful surveys in their own right, and suitable optimization of their planning will support a diverse range of science cases.

One key element of optimization is to enable a diverse range of roll angles for at least some of the wide-deep coverage. This means placing ~ half or more of this area in the continuous field of regard, within 36 degrees of the ecliptic poles. A diversity of dispersion directions allows better mitigation of overlap between spectra of unrelated objects.

Another key element of optimization is synergy with the High Latitude Time Domain Survey. A portion of the deep grism observations taken for HLWAS should coincide spatially with prism observations from the HLTDS. Such a data set, combining both *Roman* spectral elements over many epochs and position angles, will be most excellent.
These observations 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. Providing redshifts for a majority of star-forming Supernovae Host galaxies.
E. Providing a large training set for photometric redshifts.
F. 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. Reionization probes depend sensitively on depth at flux levels near 10^{-17} erg cm^{-2} s^{-1}, and Lyman alpha applications would benefit from accentuating depth over area. If such depth can be achieved over ~ 20 square degrees, it will unlock the power of joint Lyman-alpha + redshifted 21cm radio observations (figure 4). Correlating 21cm emission with LAEs will be crucial to validating both methods, and will be the strongest probe of the reionization state of the IGM, and the average ionized region sizes around LAEs. Finally, a survey of this depth and scale will describe in detail the entire reionization history of the IGM using Lyman α galaxy clustering (Perez et al 2023 Fig. 5).

Simulations show high recovery rates for line emitters using more than 24 Position Angles (Wold et al. 2023). 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; cf. figure 2). The spectroscopic detection limits correspond to star formation rates as small as <0.4 Msun/year over the range z=1-2, which is 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 Deep-Wide survey will sample a volume of 150 – 500 million Mpc^3 (for 6-20 deg^2) out 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.

For H-alpha galaxies and sensitivity of 1e-17 we will find ~118,000 sources per deg^2 compared to 8,800 per sq-deg^2 for HLSS survey limit. A prism survey with the same sensitivity will miss about 33% of the sources that have low equivalent width of the H-alpha line, i.e. the massive galaxies (figure 3).

It will also resolve the degeneracies between objects with red colors due to extreme redshift and red colors due to strong line emission that have been seen in some *JWST* studies.

C. 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), and such objects will stand out in direct spectroscopic surveys. Active galactic nuclei (AGN) of various types will also be directly identified. Finally, this survey will identify young metal poor galaxies to investigate the early stage of star formation in galaxies.

D. All core collapse supernovae, and *also* a strong majority of Type Ia supernovae, occur in star forming host galaxies. A Deep-Wide component of the HLWAS will be sensitive enough to detect spectroscopically the strong star-formation emission lines from the hosts of most supernovae detected (or detectable) by *Roman* over the surveyed area, thereby providing redshifts for a majority of these supernovae.

E. Spectroscopic redshifts of essentially all objects at z<4.1 that have emission lines brighter than 10^{-17} erg cm^{-2} s^{-1} over 10 deg^2 will offer ~ 10^6 galaxies with *Roman* emission line detections and *Roman* photometry. This will be an unmatched training set for photometric redshifts.

F. The pace of structure formation depends on local density, and key galaxy properties may do likewise. A Deep-Wide *Roman* spectroscopic survey will cover enough volume to sample cosmic environments from the lowest densities to high peaks. Moreover, it will do so over a wide and continuous redshift range, allowing cross-comparisons of galaxy properties as a function of both local density and redshift.

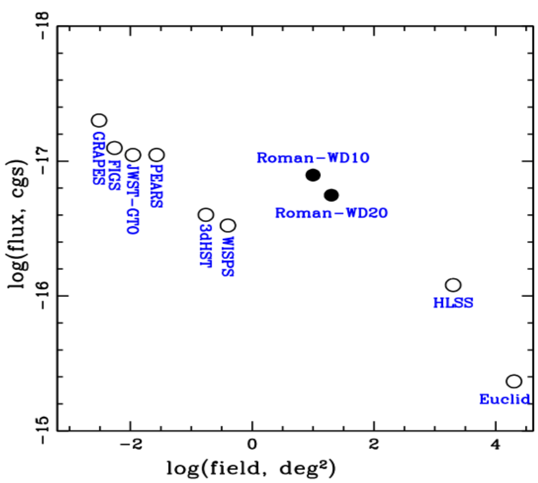

Figure 1: Comparison of the survey described herein (which will lie along or near the line between "Roman-WD10" and "Roman-WD10") with other space-based slitless spectroscopic surveys. We show five HST programs (GRAPES, PEARS, FIGS, 3dHST, and WISPS), the spectroscopic component of JWST GTO-1176; the projected *Roman* High Latitude Spectroscopic Survey (HLSS); and the *Euclid* spectroscopic survey. The proposed survey will fill a large gap in the parameter space.

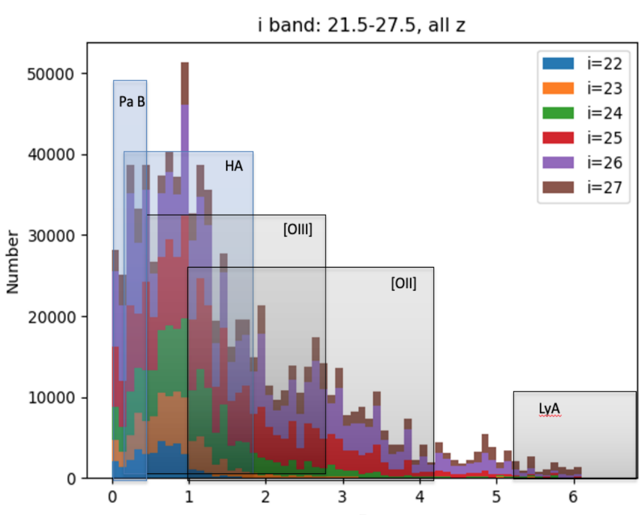

Figure 2: This figure shows the redshift distribution of sources in the COSMOS field as a function of i-band magnitude. The redshift ranges where selected emission lines fall in the joint coverage of the *Roman* prism+grism are overplotted, illustrating how *Roman* Wide-Deep spectroscopy can offer nearly complete coverage for emission line redshifts as well as an extensive selection of emission lines for galaxy astrophysics throughout the history of the universe.

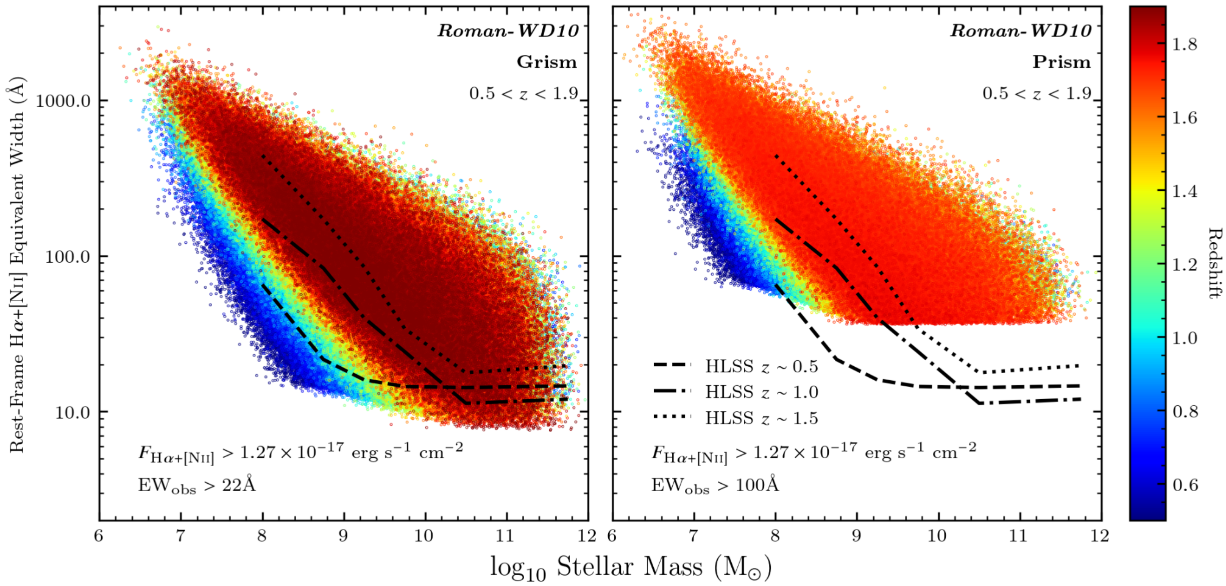

Figure 3: Completeness of *Roman* slitless spectroscopy, as a function of stellar mass and rest-frame equivalent width, for the grism sensitivity expected if the Deep-Wide survey covers 10 square degrees using 10% of the HLWAS time. The left panel shows grism results, and the right panel prism results. Colors indicate redshift. Incompleteness at the low-mass end is due to sensitivity limits, and incompleteness at the low-EW end due to the difficulty of seeing the less prominent emission lines at finite spectral resolution. We see that the strengths of the two elements are complementary.

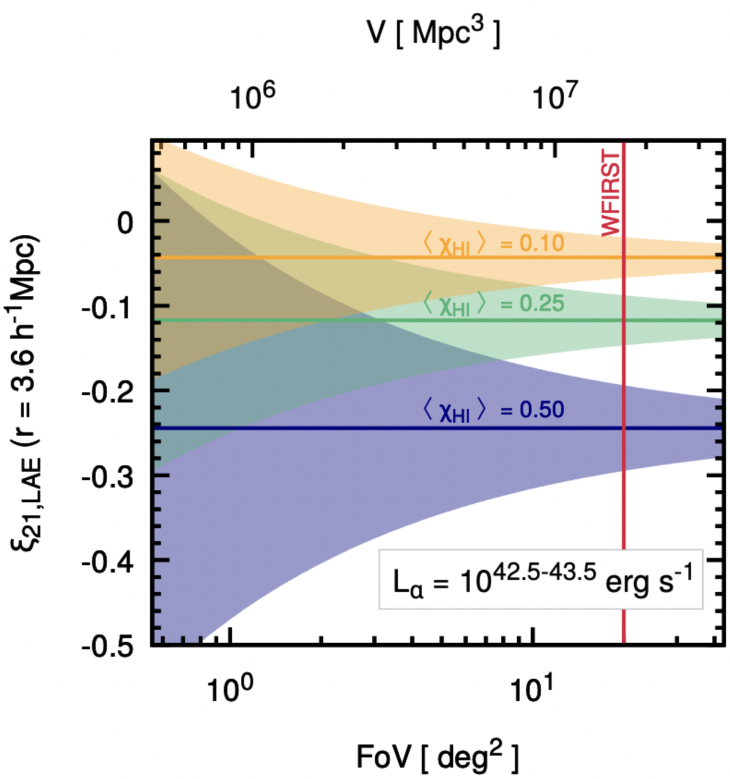

Figure 4: 21cm-LAE cross correlation function at r = 3.6h–1cMpc for a survey Lyα luminosity limit of $L_{Ly\alpha} = 10^{42.5}$erg s^{-1} for 1000h of SKA observations. The orange, green and blue lines represent results for $\langle \chi_{HI} \rangle \simeq 0.1$, 0.25 and 0.5, respectively. The shaded regions show the cross correlation function uncertainties as a function of the survey volume of the SKA and LAE observations. The vertical line shows the survey area for *Roman*. Surveying an area of 20 deg^2 to a depth of $L_{LyA} = 10^{42.5}$ erg s^{-1} will be crucial in shedding light on the reionization state of the IGM.