Roman Early-Definition Astrophysics Survey Opportunity

(1) Submission Title or Survey Name: Roman Ultra Deep Field

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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 support the selection of a Roman Early-Definition Astrophysics Survey. Specifically, we present a **Roman Ultra Deep Field** survey concept, across **7 broadband imaging filters** (F062, F087, F106, F129, F158, F184, and F213), reaching **maximum depth** (**AB~30**, 5σ point-source) in most of these, over a total area **~1 deg^2** (possibly across 3 locations), for ~**700-750h**. Such a survey is motivated by Roman's capability for **Hubble UDF-quality** imaging, to depths approaching **JWST**, over **~100x** larger area, opening up completely new parameter space, and revealing early **faint-end, sub-L* galaxies up to z~15**. Moreover, **early definition is crucial** for this survey, due to necessary preparatory observations, theoretical simulation work and software development, laying the groundwork for future GO proposals with limited-life missions, incl JWST, and enabling follow-on proposals in future Roman cycles, maximizing scientific return.

Key science drivers: First galaxies and Epoch of Reionization to z~15

The Epoch of Reionization is a key frontier: the deepest HST surveys have probed up to z~9–11 to reveal populations of sub-L* galaxies, measure their escape fraction of ionizing photons and constrain their role in reionization, and trace their assembly into more massive galaxies over cosmic time [refs 1–35]. However, only a handful of such sources have been identified to date, primarily limited by the small size of these fields: eg, the HUDF subtends only a few arcminutes, or less than a Mpc at these redshifts, too small to probe large-scale environments or clustering properties of these galaxies, crucial for advancing our understanding of reionization, and also insufficient to provide statistically useful samples. There is also a need to probe to higher z, as the first galaxies may have already formed by z~15 or earlier [1,36]. While JWST programs such as CEERS and JADES [37,38] will extend the redshift range, and cover more area than HUDF, they will likely yield no more than several dozen z~11 sources, and handfuls of sources at higher z. The Roman Ultra Deep Field concept proposed here can potentially provide extensive samples of **faint-end sub-L* galaxies** in this crucial redshift range (Fig 1: eg, up to~6000 galaxies at z~11, up to ~300 at z~13, and up to ~7 galaxies at z~15), and will provide critical discrimination power across z~11–15 to differentiate between different LF evolutionary scenarios [refs 39–44].

Additional breadth of science: LSS, Growth of Galaxies+AGN, SNe, LSB, MW Halo

A rich variety of additional science would be uniquely enabled by a Roman Ultra Deep Field: reaching AB~30 across 1 deg^2 would yield ~3–4×10^6 galaxies, including several ×10^4 at z~8–9, and several ×10^5 at z~6–7, **more than 100×** the current samples at these redshifts, as well as ~10^6 galaxies at each of z~4–6 and z~2–4. This will enable much more detailed studies of the initial stages of the growth of large-scale structure and the relation between environment and galaxy properties, as well as tracking the co-evolution of galaxies and their central supermassive BHs. Obtaining the observations over 3 epochs, separated by 6 months over a 1-year period, will enable deep searches for transients, including variability-selected AGN, and pair-instability supernovae (PISNe) up to z~10. Other science includes low surface brightness (LSB) [45,46], and faint star counts in the Milky Way outer halo, potentially valuable for bulge formation work.

Datasets expected upon survey completion:

Multi-band mosaics in all 7 imaging filter bandpasses, full-depth and per-epoch, photometric galaxy catalogs (including bandpasses from Roman and other facilities observing these fields), catalogs of transient sources (including SNe, AGN), morphological and environmental galaxy parameters, galaxy redshift information (photo-z, and spectroscopic from ancillary data), galaxy physical parameters (incl. SED fits, SFR, SFH, SMF).

Comparison of parameter space with other Roman core surveys:

The key differences between the Roman UDF and the other two Roman core extragalactic surveys (HLS and SN survey) are that the Roman UDF can be considered the deepest layer in a "wedding-cake" strategy, probing a part of parameter space that is fully complementary. Also, compared to state-of-the-art HST and JWST surveys, this survey is ~100× HUDF area, probes to higher redshift (z~15), also ~30× the area of JWST surveys that probe these redshifts, providing crucial targets for JWST followup, and thereby motivating early observations with Roman.

Survey Type	Area	Depth (AB, 5σ pt)
HLS	~2000 deg^2	~27
SN survey	~10-50 deg^2	~28-29
Ultra Deep Field	≲1 deg^2	~30

6) Possible observational outline of the survey *(half a page max)*:
The primary science drivers for the survey lead to a parameter space that is as deep as the HUDF (AB~30), covering an area ~100× larger (~1 deg^2), with the full wavelength range of 7 broadband filters on Roman up to the longest wavelengths (~2μm), probing up to z~15. This uniquely leverages the observing capabilities of Roman, through the combination of wide-field (relative to HST and JWST), depth (comparable to HUDF and JWST surveys) and wavelengths.

Exposure times (in hours) needed to achieve Roman UDF depths in a single WFI pointing

	F062	**F087**	**F106**	**F129**	**F158**	**F184**	**F213**	**Total**
AB (5σ point-source)	**30.0**	**30.0**	**30.0**	**30.0**	**30.0**	**29.6**	**28.6**	
1.2x zodi (|b|>60° / CVZ)	8.0	17.7	20.0	22.9	28.0	38.8	88.5	223.9
1.44x zodi (|b|~45°)	9.2	20.4	23.4	26.5	31.9	41.9	89.0	242.3
2.0 x zodi (|b|<25°)	12.1	26.7	30.5	34.8	41.1	49.2	90.4	284.8

(from tables at https://roman.gsfc.nasa.gov/science/apttables2021/table-exposuretimes.html)

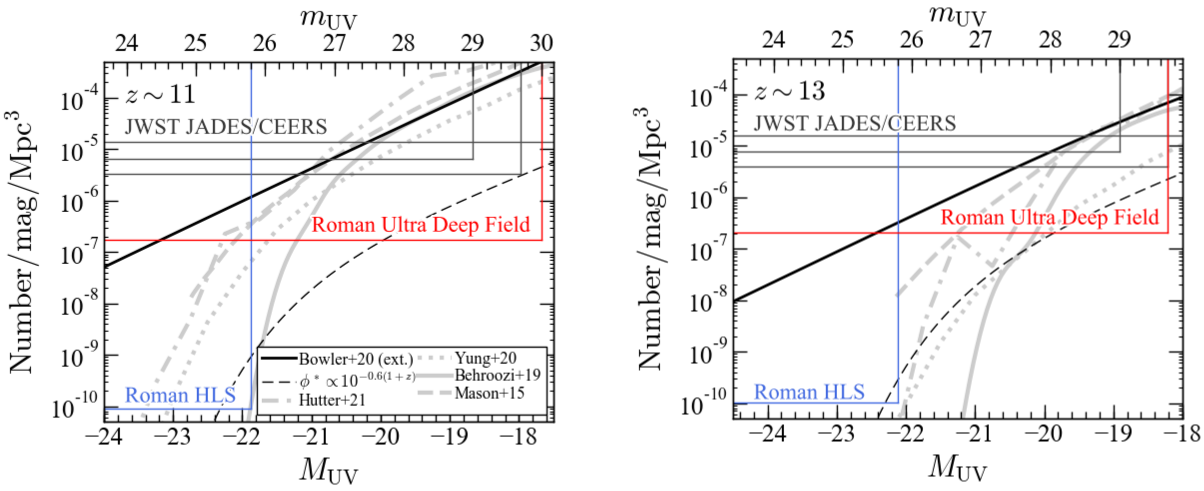
The science drivers lead to ~1 deg^2 to achieve necessary statistical samples, corresponding to 3 WFI pointings, ~700-750 h total (which would cover ~0.81° x 1.26° if contiguous, beneficial for LSS studies). The observations may be cadenced, eg, 3 epochs, 6 months apart, over a 1-year timeframe, for time-domain science. To mitigate cosmic variance, it may instead be desirable to place the 3 WFI pointings at different locations on the sky, chosen for a combined minimization of zodi, AV, cirrus, and NH, ideally also amenable to extensive ancillary data (eg Fig 3). Current examples (see table in https://arxiv.org/abs/1903.06154 for more details) of candidate fields are: |b|>60 (CVZ): EDFN (incl JWST-NEP-TDF); |b|~45: EDFF (incl CDFS); |b|<25: COSMOS.

(7) Specific preparatory activities enabled by early definition *(half a page max)*:
Supporting facility observations would include imaging and spectroscopy, with current facilities (incl. Subaru, VLT, Gemini, Keck, LBT, HST, ALMA, VLA, Chandra, eRosita) and future (incl. Rubin, ELT, GMT, TMT, JWST, Euclid, SKA). Eg, excellent synergy may be provided by Subaru PFS (FOV 1.25 deg^2), where spectroscopy similar to the "deep" tier of the 360-night survey (16 h depth, reaching z=26) could target the several x 10^5 sources to this depth that would be detected in a ~1 deg^2 Roman UDF. Other PFS options could include deeper spectroscopy, incl extending NIR depths. A deep Roman grism program, as a companion to a Roman UDF imaging program, may provide invaluable deep redshifts of sources too faint to reach from the ground.

Theoretical/simulation efforts relevant to Roman deep field science that would be energized by an early selection effort include cosmological simulations of the high-z universe (teams include Bagley, Finkelstein et al.; Bowler et al.; Drakos, Robertson et al.; Peeples, Simons et al.; Wold, Malhotra et al.), simulations of high-z PISNe and SLSNe (Hounsell et al.; Moriya et al.), and simulations of LSB science (Borlaff et al.). Algorithm / Software development efforts would include joint survey processing with existing deep ground-based imaging surveys (incl. Rubin) to improve and calibrate measurements, eg, object detection and high-precision deblending.

Other benefits of conducting these activities early include enabling future Roman observations of these fields (GO proposals), e.g., extend depth or cadence,, and more extensive followup with limited-lifetime missions including HST, JWST, Euclid, Chandra and eRosita.

Supplementary material: figures, community engagement, white papers, refs *(2 pages max)*



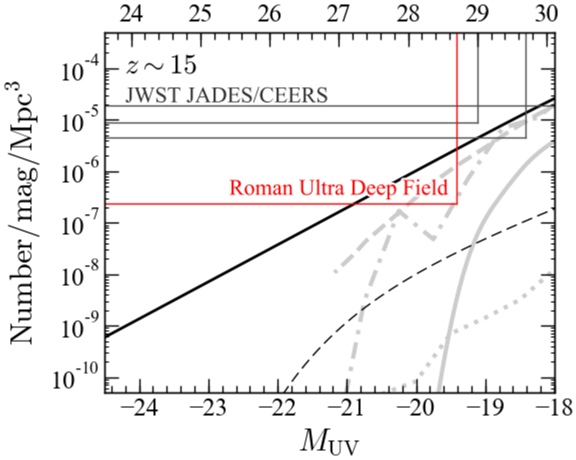


Figure 1: Parameter space probed by a Roman UDF, at z~11, z~13, and z~15 (left, top right, and bottom plots; Harikane et al.) showing the ability to differentiate between UVLF models (Mason et al. 2015, Behroozi et al. 2019. Yung et al. 2020, Bowler et al. 2020, Hutter et al. 2021,,vs a Schechter function with rapid $(1+z)^{-0.6}$ density evolution, Harikane et al. in prep.). The Roman UDF could detect up to ~6000 (z-11), ~300 (z=13), and ~7 (z=15) faint end galaxies (M_{UV} -18 to -20), for the optimistic cases, providing factors of ~1000–100x in discriminating power.

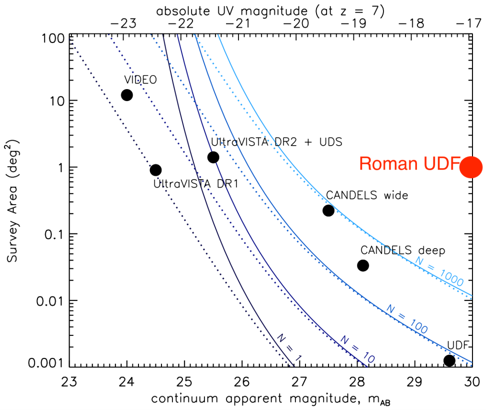


Figure 2: Parameter space for Roman UDF vs other surveys (adapted from Bowler 2021).

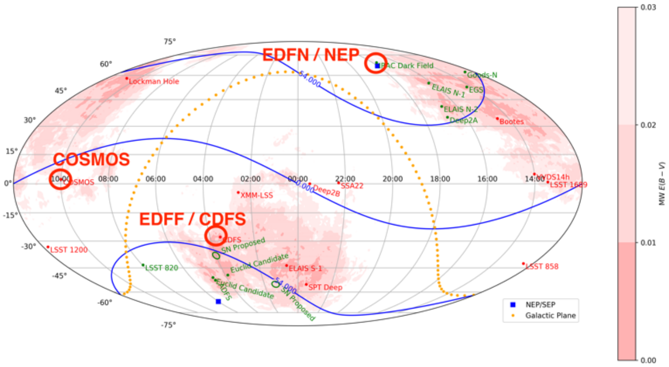


Figure 3. Locations of possible Roman UDF fields (EDFN/NEP, COSMOS, EDFF/CDFS) as examples.

Community workshops with relevant Roman Deep Field presentations:
2018 Aug, Workshop on WFIRST/LSST Deep Fields, Princeton
2019 Jun, AAS 234th Meeting, Special Session on WFIRST Deep Fields (#222, #315), St. Louis
2020 Oct, Galaxy Formation & Evolution in the Era of the Nancy Grace Roman Space Telescope
2021 Feb, Roman-Subaru Synergystic Observation Workshop, JAXA/Japan (virtual)
2021 May, Multi-Object Spectroscopy for Statistical Measures of Galaxy Evolution, STScI

Relevant whitepapers

Borlaff, A. S. et al. 2021, arxiv:2108.10321, “Euclid preparation: XVI. Exploring the ultra low-surface brightness Universe with Euclid/VIS”
Doré, O. et al. 2019, 2019BAAS...51c.341D, “WFIRST: The Essential Cosmology Space Observatory for the Coming Decade”
Foley, R. et al. 2018, arxiv:1812.00514, “LSST Observations of WFIRST Deep Fields”
Foley, R. et al. 2019. 2019BAAS...51c.305F, “WFIRST: Enhancing Transient Science and Multi-Messenger Astronomy”
Hounsell, R. et al. 2018, ApJ, 867, 23, “Simulations of the WFIRST Supernova Survey and Forecasts of Cosmological Constraints”
Koekemoer, A. M. et al, 2019, arxiv:1903.06154, “An Ultra Deep Field survey with WFIRST”
Melchior et al. 2021, https://doi.org/10.1038/s42254-021-00353-y, “The challenge of blending in large sky surveys”
Moriya, T. et al. 2021, arxiv:2108.01801, “Discovering Supernovae at Epoch of Reionization with Nancy Grace Roman Space Telescope”
Rhodes, J. et al. 2019, 2019BAAS...51g..32R, “Subaru and WFIRST: A Partnership for the 2020s”
Ryan, R. et al. 2019. 2019BAAS...51c.413R, “The WFIRST Deep Grism Survey: WDGS”
Windhorst, R. et al. 2021, arxiv:2106.02664, “NASA ORCAS SWG Whitepaper - Galaxy Science with ORCAS: Faint Star-Forming Clumps to AB<31 and re>0.01"

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