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Roman-Subaru Synergy White Paper: Advancing Supernova Ia Cosmology and Time Domain Studies*

The Roman Supernova Cosmology Project Infrastructure Team

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ABSTRACT

The Roman Supernova (SN) Cosmology Project Infrastructure Team (PIT) proposes that **24 nights of Hyper Suprime-Cam (HSC)** imaging and **104,500 fiber hours of Prime Focus Spectrograph (PFS)** be used to observe the Roman High-Latitude Time-Domain Survey (HLTDS) Northern field, ELAIS-N1. These observations will yield substantial improvements in measuring the properties of dark energy. HSC observations are necessary to cover optical bands not observable with the Roman Wide Field Instrument, and will require 24 nights to reach a depth equivalent to that of Roman. The HSC imaging should ideally be taken concurrently with the Roman pre-imaging phase, enabling a photometric redshift catalog to support both a Roman SN program and broader galaxy and cosmology studies. We propose that PFS observations be taken in two phases: the first during the Roman HLTDS for active SNe and galaxy redshifts, and the second after the survey's completion for additional galaxy observations. It is important to observe both host galaxies and nearby field galaxies to estimate the impact of weak gravitational lensing and line-of-sight dust extinction. Although the observing the active SNe at any one time would only use 10–20% of the available PFS fibers, over the two elapsed years of the Roman HLTDS the total density of galaxies of interest will approach using all PFS fibers in a given field. The Subaru time requested here can and should be shared with the RAPID, and HLWA communities in addition to the AGN, high-z galaxy, and epoch of re-ionization study communities at large.

1. SN IA COSMOLOGY PROGRAM SUMMARY

The Nancy Grace Roman Space Telescope (hereafter referred to as Roman), is on track to launch by October 2026 (and required to launch no later than May 2027). With a large field of view (0.281 deg^2) and broadband wavelength coverage of 0.48–2.3 microns[1], this mission will revolutionize our understanding of the near-IR universe for generations to come. The Roman mission is tasked with answering three key questions: (1) what is the nature of dark matter; (2) how many exoplanets are there in our Galaxy; and (3) what is the nature of dark energy. To aid in answering these questions, the mission has devised three Core Community Surveys (CCSs): the High-Latitude Wide-Area-Survey

* March, 14th, 2025
[1] https://roman.gsfc.nasa.gov/science/WFI_technical.html

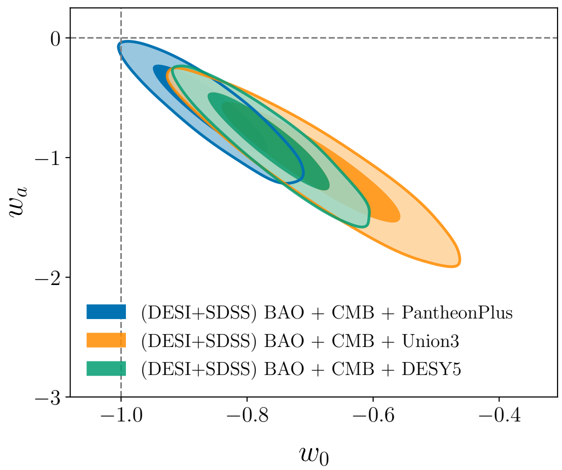

Figure 1. The most recent combined constraints on the dark-energy equation of state parameters w_0 and w_a from baryon acoustic oscillations, cosmic microwave background, and SNe Ia suggest that a constant $w = -1$ model may not be the best explanation. Credit: Adame et al. (2025).

(HLWAS)[2], the Galactic-Bulge Time-Domain Survey (GBTDS)[3], and the High-Latitude Time-Domain Survey (HLTDS)[4]. Maximizing SN Ia cosmology science for the HLTDS is the focus of this whitepaper.

A key component of the HLTDS is to obtain a significant number of well-sampled Type Ia Supernova (SN Ia) light curves and prism spectroscopy. SNe Ia are one of our most mature cosmological probes and were used to discover the accelerated expansion of the universe (Riess et al. 1998; Perlmutter et al. 1999), and as such the possible existence of a new energy density with an effective repulsive force called dark energy. The current baseline model for dark energy is a constant energy density (a "cosmological constant"); but there is significant interest in and recent hints of the possibility of time-dependent dark energy (see Figure 1). Reaching farther back in time by adding high-redshift SNe Ia will significantly improve our sensitivity to evolving dark energy. To date, only a modest number of SNe Ia have been observed at $z > 1$ and only a few of these have had the necessary high-quality observations necessary to use in a cosmological analysis. With a dedicated 6 months of observing time spread over two years, the HLTDS is set to discover $\sim$10,000 SNe Ia over $\sim$25 deg^2 (combined fields) – producing a data set spanning $0.3 < z < 3$ (see for example Hounsell et al. 2018). The quest to understand dark energy remains at the forefront of physics and astrophysics, and the Roman HLTDS will provide an unparalleled view back in time to explore the beginnings of dark energy's affect on the cosmos.

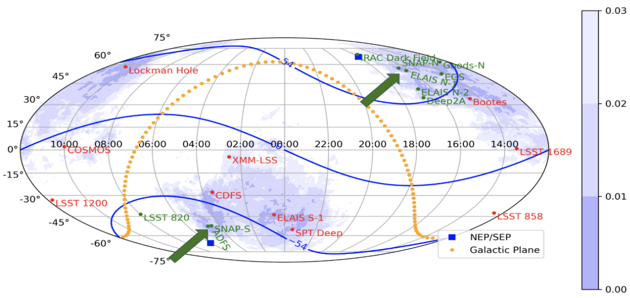

Figure 2. Recommended field selections for the HLTDS-CC (equatorial projection) by the CCS Definition Committee. The fields must reside in the CVZ ($|\epsilon| > 54°$), should have minimal foreground extinction, and maximal pre-existing and contemporaneous multi-wavelength coverage. Credit: David Rubin - Roman SN Cosmology PIT, and the HLTD CCS Definition Committee.

To exploit the full potential of the Roman HLTDS data, key additional information is required in the form of deep optical imaging (g, r, i to 28.0-27.5 mag) and deep spectroscopy (24.5 mag) of many thousands of SNe Ia and host galaxies. The Northern field of the Roman HLTDS, ELAIS-N1, will be 13.95 deg^2. Subaru's large field of view (FoV), 8.2-m aperture, and location at a site with excellent seeing are both well matched and critical to covering this field. Subaru is uniquely poised to obtain high-quality imaging and spectra of SNe Ia, host galaxies, and a wealth of other transient phenomena captured as part of the HLTDS.

In this white paper, we present an overview of the current HLTDS design as proposed by the Core Community Survey team in Section 2 and describe our proposed three-phase Subaru SN Ia Northern Hemisphere program in Section 3.

2. CORE COMMUNITY SURVEY REPORT

The report published by the HLTD Core Community Survey (CCS) Definition Committee[5] recommends a survey strategy that is optimized for SN Ia cosmology while allowing discoveries and studies of other SNe, high-redshift galaxies, and rare phenomena. The HLTDS will target two distinct Roman Continuous Viewing Zone (CVZ) fields in the sky (see Figure 2): (1) a Northern Field centered on ELAIS-N1 (Oliver et al. 2000); and

[2] https://science.nasa.gov/mission/roman-space-telescope/high-latitude-wide-area-survey/

[3] https://science.nasa.gov/mission/roman-space-telescope/galactic-bulge-time-domain-survey/

[4] https://science.nasa.gov/mission/roman-space-telescope/high-latitude-time-domain-survey/

[5] https://asd.gsfc.nasa.gov/roman/comm_forum/forum_17/Core_Community_Survey_Reports-rev03-compressed.pdf

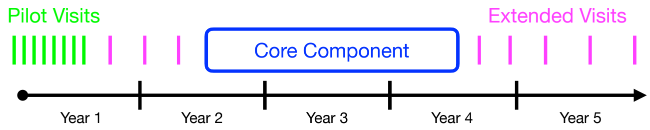

Figure 3. Recommended scheduling of the HLTDS-CC, HLTDS-PC, and HLTDS-EC by the CCS Definition committee. The three components provide: (1) a large sample of high-z SNe Ia, sufficient to meet the Roman cosmology requirements; (2) the opportunity to verify a successful survey design early in the mission lifetime; and (3) coverage of the Deep Imaging Tier during the entire prime phase, for long-duration transients. Credit: HLTD CCS Definition Committee report.

(2) a Southern Field that overlaps with the Euclid Deep Field South (EDFS)[6].

The recommended in-guide survey strategy consists of a total of 180 days of observing time and three components: (1) the Core Component (HLTDS-CC, 158 days) will monitor the HLTDS fields continuously over a 2-year period during the middle of Roman's 5-year mission; (2) the Pilot Component (HLTDS-PC, 15 days) will take place at the beginning of the mission and make 8 visits to each field to collect template images and to estimate the $z > 1$ SN Ia rate – which is currently poorly constrained; and (3) the Extended Component (HLTDS-HC, 7 days) will fill in the gaps before and after the Core Component in the Deep Fields and extend the total duration of observations of the HLTDS to 5 years (see Figure 3).

The Roman observations consist of imaging and prism spectroscopy in two redshift tiers – Wide and Deep. The Wide will target SN Ia at $z = 0.9$ and the Deep at $z = 1.7$. The total Wide imaging area is ~ 18 deg^2 (13.95 in the North and 7.59 in the South) and the total Deep imaging area is 6.5 deg^2 (1.97 in the North and 4.50 in the South). Due to limited observing time, Roman prism spectroscopy will be performed in only the Southern Deep imaging tier. This means that Roman data of the Northern Field will be imaging only and will lack key spectroscopic information.

ELAIS-N1 is observable from Mauna Kea during the months of March through July. We propose to utilize Subaru in ELAIS-N1 for both Wide- and Deep-field HSC imaging and PFS spectroscopy to target transients and their host galaxies.

3. A SUBARU SN IA NORTHERN HEMISPHERE PROGRAM

We propose complementary HLTDS observations in three phases.

[6] https://www.cosmos.esa.int/web/euclid/euclid-survey

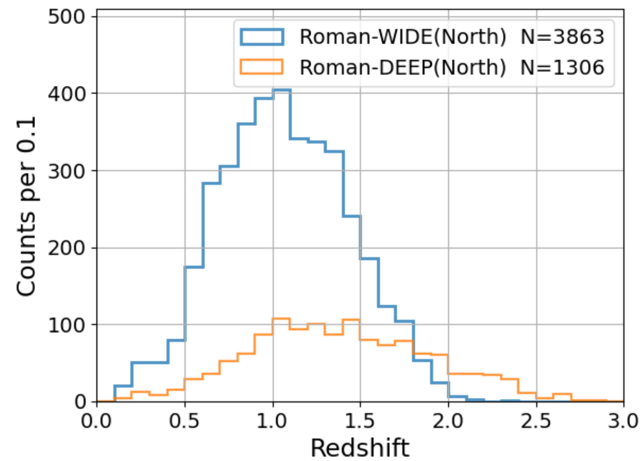

Figure 4. The redshift distribution of high-quality cosmologically-useful SN Ia is shown for Roman WIDE (blue) and DEEP (orange) in the HLTDS Northern Field. These results are based on a SNANA (Kessler et al. 2009) simulation following the in-guide recommendation in the HLTD CCS Definition Committee report. Credit: Rick Kessler - Roman SN Cosmology PIT

I. HSC pre-survey imaging of ELAIS-N1 during initial Roman operations. This pre-imaging will obtain optical data of comparable AB mag depth to Roman NIR and improve the photo-z catalog

II. PFS observations during the Roman HLTDS to obtain spectra of active transients and of galaxies.

III. As the total number of SN Ia discovered increases during the HLTDS, PFS observations will focus less on transients in general and more on galaxies associated with SNe Ia.

3.1. Phase-I: HSC Imaging, 24 nights

For the success of the Roman SN Ia program, accurate photo-z's, high-quality photometry in multiple bands, and sampling strong features such as the Lyman (restframe $\sim$1000 Å) or Balmer breaks (restframe $\sim$4000 Å), are critical. The Roman bands cover the Balmer break objects with $z > 0.6$, but we also need bluer bands for galaxies at $z < 0.6$ and for Lyman Break galaxies at $z > 1.8$ to support the SN Ia program.

The addition of Subaru data results in a significant reduction in the outlier fraction relative to Roman-only photo-z's (left Subfigure 5). This is especially true at high redshift because the lower redshift degenerate solutions to high-z objects can be rejected. There is also a significant reduction in scatter at low-z because of the optical coverage provided by HSC.

ELAIS-N1 has been observed as part of the HSC Subaru Strategic Program (SSP); however, its coverage area

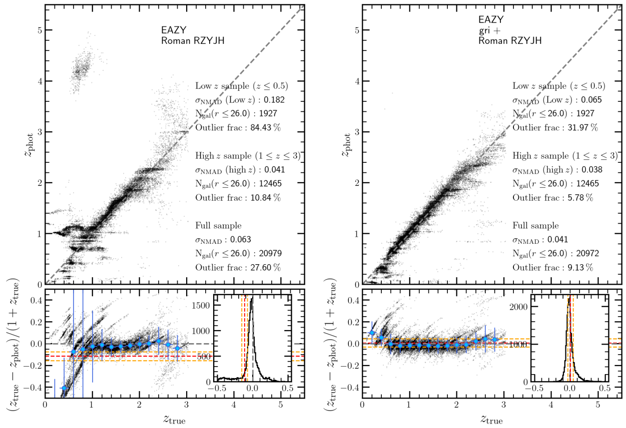

Figure 5. Comparison of $z_{\rm phot}$ vz. $z_{\rm true}$ for synthetic galaxies using only Roman data (left) and Roman+Subaru data (right) for the HLTDS Wide tier. Lower panels show the normalized residual $(z_{\rm phot} - z_{\rm true})/(1+z_{\rm true})$. The histogram shows distribution of $(z_{\rm phot} - z_{\rm true})/(1+z_{\rm true})$. We impose a cut off of 26 AB mag in Roman J (F129) band. Credit: Bhavin Joshi & Russell Ryan - Roman SN Cosmology PIT.

(6.5 deg^2, 4 HSC pointings) is smaller than the target set by Roman (13.95 deg^2, 7 HSC pointings), and its depth is shallower than required for our photometric redshift (photo-z) measurements (Table 1). Ensuring the same depth as Rubin/LSST is also crucial. A large and representative spec-z training set is also necessary to validate and train photo-z's - hence the need for PFS (Section. 3.3).

Phase-I will use **23.7 HSC nights** to obtain (g, r, and i) depths of (28, 28, and 27.5 mag).

3.2. *Phase-II: PFS Active Supernovae : 87,700 fiber hours*

No Roman spectroscopic follow-up is scheduled for ELAIS-N1 during the HLTDS. Ground-based multiplexed spectroscopic follow-up (PFS) is the only opportunity we have to obtain spectra of active transients to secure their identification and redshift. We follow the successful scheme of the Dark Energy Survey whose spectral follow-up was executed by the AAT multiplex spectrograph (OzDES). They simultaneously observed active transients, host galaxies from past events, AGN and other science targets and filled all of the fibers (Lidman et al. 2020). We would like to observe HLTDS fields twice a month for 5-month visibility window from Hawaii and capture active transients as much as possible. Our proposed telescope time allocation scheme is summarized in Table 2, and we made realistic fiber-hour estimates based on our HSC SNIa cosmology program with AAT and OzDES efficiency. We extrapolated the AAT efficiency to PFS, but this estimate can be updated with PFS commissioning data. The estimated spec-z yield is summarized in Table 3.

The set of spectroscopically observed SN Ia will be key in allowing for the full cosmological use of the photometrically-only observed SNe Ia. Because of Roman's unprecendented reach to find SNe Ia at $z \sim 2$, the spectroscopic subset that will be observed will be selected from a representative, volume-limited sample of the diversity of SNe Ia out to $z < 1.2$. The unbiased spectroscopic subset will enable us to develop a redshift-dependent SN Ia light curve model for brightness standardization of the broader SN Ia sample without spectra, and also train a redshift-dependent photometric classifier to make robust and accurate transient and supernova typing. Allocating fibers for the active transients at any given observation will use 10–20% of fibers; the remaining fraction will be unused at the beginning and then gradually filed by SN Ia host galaxy targets toward the end.

Phase-II is the most important and time critical part of this program and will require **87,700 PFS fiber hours**.

3.3. *Phase-III: PFS Host Galaxy Follow-up: 16,800 Fiber Hours*

The HLTDS will yield an overwhelming number of transient discoveries, significantly exceeding the capacity for spectroscopic follow-up. Consequently, we are unable to obtain spectroscopic redshifts for the majority of active transients (Table 3).

We will thus rely on the spectroscopic redshifts of SN Ia host galaxies for a substantial fraction of the HLTDS SNe Ia. While HLTDS is running, we will allocate PFS fibers to the host galaxies of known transients at the time of PFS observations (Phase-II). The PFS fiber configuration is complicated, and even if we prioritize our targets, the observation may not be executed during Phase-II. We aim to have a dedicated time for faint host galaxies in Phase-III.

The host galaxies play an important role in SN Ia cosmological analysis. It is not just about redshifts; the brightness of SN Ia is correlated with the properties of their host galaxies. Therefore, we need to determine the stellar mass and star formation rate of the host galaxies, and high-quality galaxy spectra are the key to calibrating this process. The IR component of PFS is essential for the study of z>1 host galaxies. Phase-III will be a small finishing stage to this program with **16,800 PFS fiber hours**.

Table 1. HSC Exposure Time Estimate (Phase-I)

Survey	Area	HSC	Filters			Total
	deg^2	Pointings	g	r2	i2	
HSC SSP Depth (mag 5σ)	6.7	4	27.5	27.1	26.8	
Exp Time (hrs)			4.8	4.2	9.4	
Roman Depth (mag 5σ)	13.95[a]	7 (total)	28.0	28.0	27.5	
Additional Exp Time on SSP Fields (hrs)		4	7.2	18.0	24.7	
Exp Time on New Fields (hrs)		3	9.0	16.7	25.6	
Total Hours (including overheads 15%)			18.6	39.9	57.8	116.3
Total Nights : Weather Factor included (30%)			3.8	8.1	11.8	**23.7 Nights**

[a]The total of 45 Roman pointings is multiplied by 0.31 deg^2 of Roman FoV which includes chip gap

Table 2. Telescope Time Allocation Scheme (Phase-II and Phase-III)

Survey	Exp Time	SN Ia	CCSN	Host Galaxies	Pointings	Epochs	Fiber
	(hrs)	per epoch	per epoch	per epoch			Hours
Phase-II: Active Supernovae (Core Survey)	3.0[a]	~ 100	~ 100	400–2,400	7	20[b]	**87,700**
Phase-III: Host Galaxy Spec-z	6.0			$\sim 2,400$	7	1	**16,800**
Total							**104,500**

[a]Exposure Time for the active supernovae is based on PFS ETC for $z = 1$ SNe Ia at maximum (S/N$\sim$5).

[c]ELAIS-N1 is visible for at least 3 hours/night from Subaru for 5 months of the year, and we would like to observe twice a month for 2 years

Table 3. PFS Fiber Allocation Scheme

Phase	Target	Total	Visible	Total Fiber	Fiber	Expected	Fibers/epoch	Redshift
		Number[a]	from Subaru[b]	Numbers[c]	Hours[d]	Spec-z Yield[e]	/pointing	Range
Phase-II	Active SNIa	6,186	2,570	970	2,910	679	~ 15	0.1< z <1.2
Phase-II	Active CCSN	26,966	11,235	723	2,169	506	~ 10	0.1< z <0.7
Phase-II/III	SNIa Host Galaxies	6,186	6,186	6,186	18,558	2,881	400-900	0.1<z<2.0
Phase-II/III	CCSN Host Galaxies	26,966	26,966	26,966	80,898	11,290	400-2400	0.1<z<2.0
Sub Total	SNIa Program				21,468	679+2881		
	Core-Collapse SN				83,067	506+11290		
Total	SNIa PIT Request				**104,535**	1185+14171		

[a]Total number of supernovae (DEEP+WIDE) Roman will find in ELAIS-N1 based on the Core Community Survey Report

[b]ELAIS-N1 is only visible for 5-month a year from Hawaii which reduces the number of observable active supernovae

[c]We target all of the active transients brighter than 24th mag while we target all of the galaxies regardless of the magnitudes in case we catch emission lines.

[e]We budget 70% efficiency of PFS configuration

4. SUMMARY AND RELATION TO OTHER PITS

The proposed 105,000 fiber-hours of PFS and 24 nights of HSC observations would be beneficial not just for SN Ia cosmology, but also for time domain and host galaxy studies in general - with applications to the RAPID, and HLWA PIS, and the AGN, high-z galaxy, and epoch of re-ionization study communities at large.

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REFERENCES

Adame, A. G., Aguilar, J., Ahlen, S., et al. 2025, JCAP, 2025, 021, doi: 10.1088/1475-7516/2025/02/021

Hounsell, R., Scolnic, D., Foley, R. J., et al. 2018, ApJ, 867, 23, doi: 10.3847/1538-4357/aac08b

Kessler, R., Bernstein, J. P., Cinabro, D., et al. 2009, PASP, 121, 1028, doi: 10.1086/605984

Lidman, C., Tucker, B. E., Davis, T. M., et al. 2020, MNRAS, 496, 19, doi: 10.1093/mnras/staa1341

Oliver, S., Rowan-Robinson, M., Alexander, D. M., et al. 2000, MNRAS, 316, 749, doi: 10.1046/j.1365-8711.2000.03550.x

Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, ApJ, 517, 565, doi: 10.1086/307221

Riess, A. G., Filippenko, A. V., Challis, P., et al. 1998, AJ, 116, 1009, doi: 10.1086/300499