Roman CCS White Paper
Subaru-Roman Synergistic Galaxy Survey-I: Overview

Roman Core Community Survey: *High Latitude Wide Area Survey, High Latitude Time Domain Survey*

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Abstract

The combination of joint Subaru and Roman observations has the potential to enable transformative science that cannot be done by either telescope alone. The wide field of views of Subaru/Hyper Suprime-Cam (HSC), Prime Focus Spectrograph (PFS), and ULTIMATE have excellent synergies with Roman's wide-field instruments. The director of the Subaru Telescope and Subaru Advisory Committee already agreed with NASA to commit 100 Subaru nights to the Roman-Subaru synergistic observations.

To enable the Roman and Subaru synergistic observations, **we propose that a significant fraction of the Roman survey fields should be accessible from the Subaru Telescope in the northern hemisphere** (e.g., >~100 deg^2 and ~10-20 deg^2 in the High Latitude Wide Area and Time Domain Surveys, respectively). By taking advantage of the unique capabilities of Subaru's instruments, the Roman and Subaru synergistic observations will allow us to investigate various important science cases to understand galaxy formation and evolution. Choosing fields that can be accessible from Subaru as the core community survey field will maximize the scientific outputs from Roman.

1. Introduction:

One of the goals of modern astronomy is to understand the formation and evolution of galaxies across cosmic time (c.f. the Cosmic Ecosystems theme of Astro2020). So far, synergistic observations between different telescopes hold great importance in advancing our understanding of galaxy formation and evolution. For example, observations by ground-based telescopes (e.g., Subaru, Keck, VLT) in the Hubble legacy fields such as COSMOS and GOODS have provided crucial datasets useful to understand galaxy properties (e.g., Taniguchi et al. 2007, Kriek et al. 2015).

The synergy between Subaru and Roman offers unprecedented opportunities for transformative science that cannot be done by either telescope alone. Subaru, with its advanced instruments especially with wide field-of-views (FoVs) like the Hyper Suprime-Cam (HSC) and Prime Focus Spectrograph (PFS), uniquely complements the wide field instruments of Roman (**Figures 1&2**).

Subaru/HSC has a 1.7 deg^2 wide FoV and provides deep 5 broad-band and unique 18 narrow-band (NB) and 16 medium-band (MB) images at 0.4-1.0 um that complement Roman's broadband imaging observations in the 0.6-2.1um range. Some deep imaging data have already been taken in the HSC-SSP survey and the H20 survey (see Section 3).

Subaru/PFS can conduct massive spectroscopic observations with its wide FoV (1.3 deg^2), utilizing 2394 fibers per pointing and medium resolution (R~3000), covering the 0.38-1.26um range. This complements Roman's grism and prism spectroscopy at 0.8-1.9um with low resolution (R~100-900). A large PFS-SSP survey is planned to start in 2024 (see Section 3).

ULTIMATE-Subaru is a project to develop a next-generation, wide-field adaptive optics system (GLAO) and a new NIR wide-field imager (14'x14'), with its expected first light in 2028. ULTIMATE can add special scientific values on top of Roman's survey with a suite of NB and MB filters at >2um, whereas Roman has only a single broad-band filter in this wavelength range.

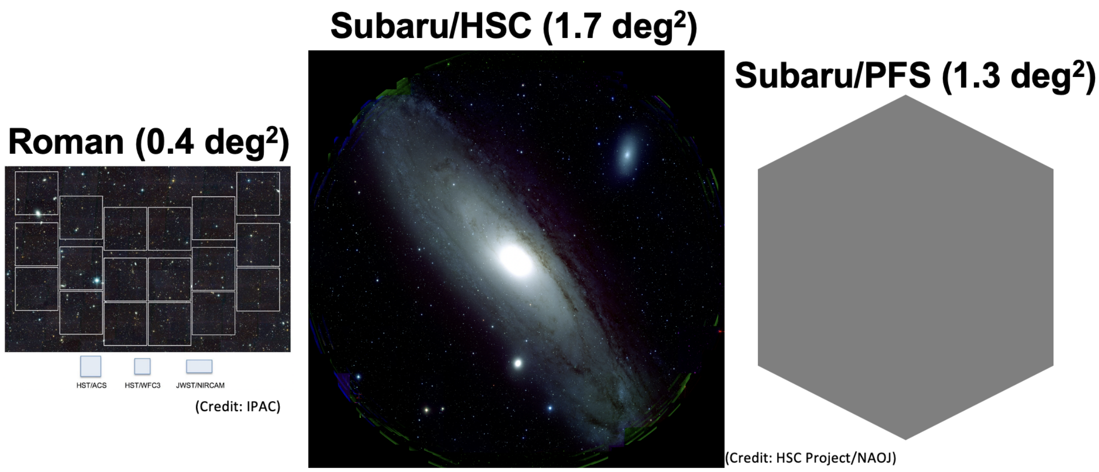

Figure 1: Comparison of FoVs of Roman (0.4 deg^2), Subaru/HSC (1.7 deg^2), and Subaru/PFS (1.3 deg^2). The wide FoVs of HSC and PFS have an excellent synergy with Roman.

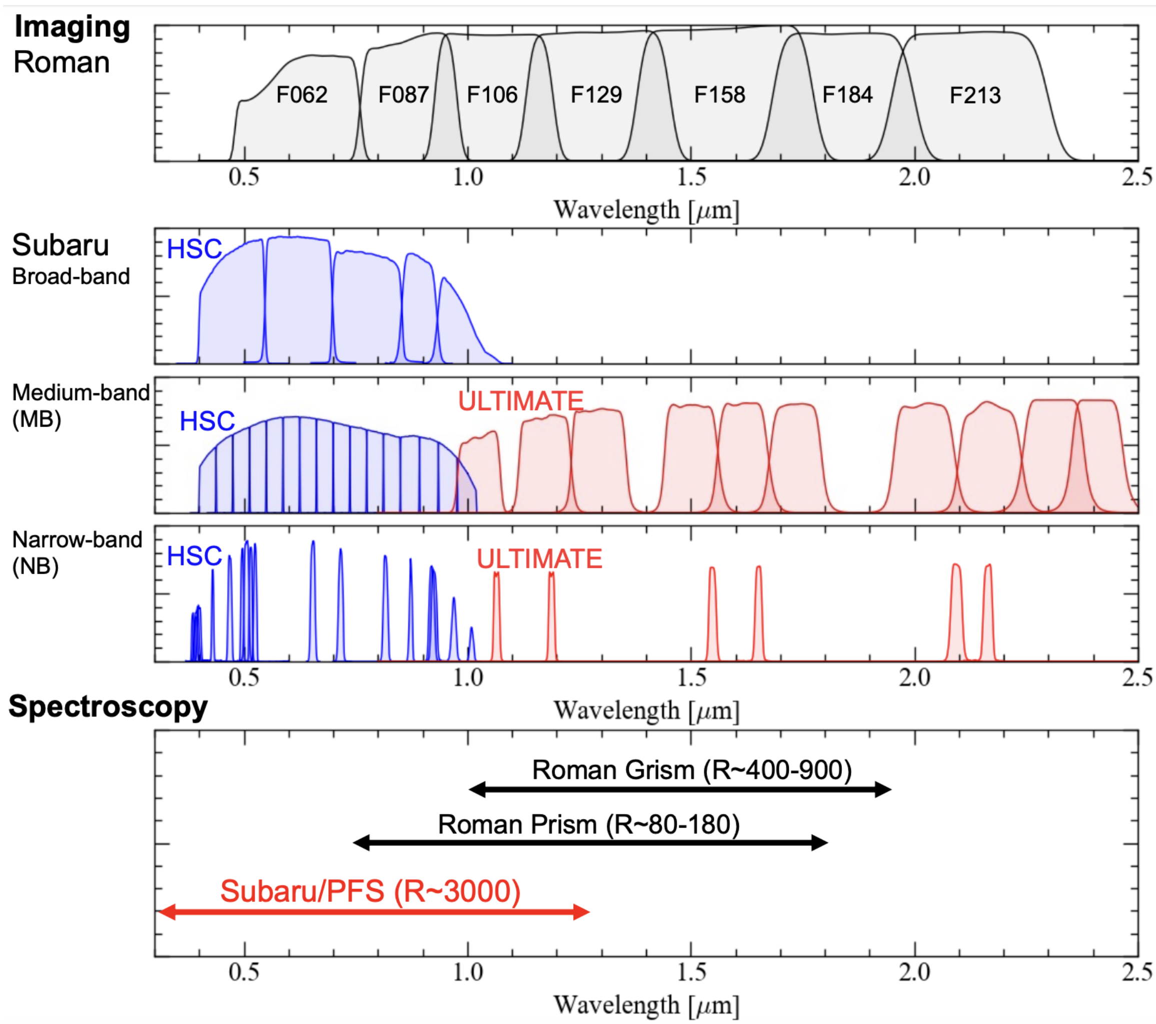

Figure 2: Overview of the imaging (top) and spectroscopic (bottom) capabilities of Roman and Subaru. Subaru/HSC, PFS, and ULTIMATE uniquely complement Roman's observing capabilities. See White Papers IV (Nishizawa et al.) and V (Koyama et al.) for details of HSC MBs and ULTIMATE.

The combination of Subaru (HSC, PFS, and ULTIMATE) and Roman will be incredibly powerful. FoVs of these Subaru's wide-field instruments enable unique synergy with Roman; such combinations of wide-field multi-wavelength imaging and spectroscopy observations are crucial to garnering full physical information about galaxies. Such Subaru-Roman synergistic observations are in great demand and have been intensively discussed, as shown in some white papers (e.g., paper).

To enable synergistic observations, **we propose that a significant fraction of the Roman Survey fields should be accessible from the Subaru Telescope in the northern hemisphere**, e.g., >~100 deg^2 and ~10-20 deg^2 in the High Latitude Wide Area and Time Domain Surveys, respectively. In the context of Roman mission objectives, this can be achieved either by including the fields already observed with Subaru/HSC (and PFS in the future) as part of the Roman High Latitude Surveys or by ensuring that the survey fields are otherwise accessible to the Subaru in the northern hemisphere. Promising candidate fields include the Chandra Deep Field South (CDFS), North Ecliptic Pole (NEP), COSMOS, and XMM-LSS for the High Latitude Time Domain Survey, and HSC-W-HectoMAP for the High Latitude Wide Area Survey (see **Table 1** for details). The advantages of the Roman Surveys are myriad because it will guarantee the ability to efficiently coordinate ground-based precursor *or* follow-up observations with a large-aperture telescope spanning optical through near-infrared wavelengths. By leveraging the unique capabilities of Subaru, the joint Roman and Subaru observations will enable investigations into crucial aspects of galaxy formation and evolution, as described below.

2. Example Science Cases Enabled by the Subaru-Roman Synergy:

Here we describe example cases enabled by the Subaru-Roman synergistic observations. Details of some cases are described in a series of white papers (papers II-V).

- Mapping Cosmic Reionization with Lyman-Alpha Emitters

Lyman-alpha emitters (LAEs), galaxies with a strong Lya emission line, offer a unique opportunity to probe the process of cosmic reionization, by which the hydrogen in the intergalactic medium was reionized, completing at the redshift around z~5-6. Roman's grism/prism spectroscopic survey will provide a large sample of LAEs at z~5-9, but their low spectroscopic resolutions (R~100-900) hamper analyses of the Lya line profile and its velocity offset, useful to study the neutral hydrogen fraction and the size of the ionized HII bubble. The Subaru/PFS medium-resolution (R~3000) spectra will allow us to conduct detailed analyses of the Lya line profile and velocity offsets (with systemic redshifts from HeII, CIV, and CIII]). The combination of the wide-field Roman and Subaru/PFS observations in the 10-20 deg^2 survey field (including several ionized bubbles) will map the growth of large ionized bubbles late in the process of cosmic reionization, on scales too large to be observed with telescopes with a narrow FoV (e.g., JWST).

- Intergalactic Medium Tomography Across Cosmic Time

Mapping the intergalactic medium (IGM), which contains more than 95% of the cosmic baryons in the universe, is critical for understanding how early galaxies formed in the context of the cosmic web, as predicted by ΛCDM cosmology, and how they drove cosmic reionization. The unique deep

Subaru/HSC NB imaging capability enables us to photometrically detect faint Lyman alpha forest flux along background galaxies and reconstruct the tomographic map of the IGM from z~6 to z~3. The Subaru/PFS redshift survey will provide hundreds of background galaxies per 1.3 deg^2 FoV suitable for IGM tomography. Roman's multi-band infrared imaging at 1-2 microns is crucial for fully characterizing the spectral energy distribution of background galaxies, breaking the degeneracy between intrinsic UV continuum slope, dust, and age, to precisely determine the Lyman-alpha forest transmission of the IGM. By combining Subaru NB and Roman infrared imaging, we can map the evolution of the large-scale structure of the IGM from the tail end of reionization to cosmic noon. The IGM tomographic maps over 10-20 deg^2 will have significant value for the scientific community, enabling a wide range of extragalactic science, including constraints on the ionizing leakage of early galaxies, the search for ionized bubbles and protoclusters, and understanding the emergence of a diverse range of galaxies in the context of the large-scale cosmic web environment across cosmic time.

- Census of Galaxy Evolution at Cosmic Noon

During the period from z~2 to z~0.5, many galaxies not only assembled a significant fraction of their present-day stellar mass but also transitioned from highly star-forming to relatively quiescent. Consequently, studying galaxies at these redshifts is crucial to understanding the physics that drives galaxy quenching. Ambitious programs using Subaru/HSC and Subaru/PFS have already been designed to study galaxies at these redshifts in detail, leveraging the wide FOVs of both instruments to place galaxies in the larger context of the evolving cosmic web.

Combining HSC and PFS data with wide-field imaging and grism observations from Roman provides significant added value to observations from both facilities. Specifically, (1) the higher spectral resolution afforded by PFS observations will assist in deblending the H-alpha+[NII] feature in Roman’s grism observations of $0.7<z<0.9$ galaxies, thereby improving galaxy redshift measurements, and (2) the addition of blue rest-optical observations from HSC and PFS to any photometric or spectroscopic observations with Roman will allow those galaxies to be studied in comparable detail to large surveys at z~0 and z~2-3. In other words, not only does the ability to combine Subaru and Roman observations advance the cosmology science goals of the Roman mission, but it also transforms the already-planned observations into a revolutionary galaxy evolution survey as well. In the same galaxies, we can study morphology, mass, star-formation rate, chemistry, and even outflow properties. One of the primary goals of PFS is to spectroscopically map the backbone of the evolving cosmic web. Combining this map with photometric information from HSC and Roman will provide the highest fidelity, detailed 3D distribution of galaxies at Cosmic Noon and beyond, thus enabling unparalleled tests of the role of large-scale (PFS + HSC) and small-scale (HSC + Roman) environment in driving galaxy evolution.

- Early Galaxy Formation Probed with Extremely Metal-Poor Galaxies

To comprehensively study galaxy evolution, it is crucial to investigate galaxies in the low-mass, low-metallicity regime at high redshifts, as they represent a population of young galaxies that likely serve as the building blocks for massive galaxies observed in later epochs. We propose that Roman’s infrared bands provide an opportunity to perform systematic searches for low-mass, extremely metal-poor galaxies up to z=2 by capturing the intense optical emission lines such as H-alpha imprinted on the broadband photometric spectral energy distributions. We have demonstrated the technique in the local universe using SDSS and Subaru/HSC photometric data with a dedicated machine-learning classifier (e.g., Kojima et al. 2020).

To obtain a complete suite of rest-frame optical emission lines, including [OIII]4363 crucial for precise metallicity measurements, we argue that a synergistic survey with Subaru/PFS covering the optical-NIR wavelength range with the medium-resolution is highly valuable. The Subaru+Roman observations over ~100 deg^2 will provide a large sample of 800 extremely metal-poor galaxies at z~2, allowing us to conduct a statistical analysis. Such a collaborative effort would enable conclusive investigations into the properties of galaxies during the early stages of galaxy evolution, specifically targeting the Roman-selected extremely metal-poor galaxies.

- Galaxy Clusters and Large-Scale Structures at z>2 (See **White Paper II** by Kodama et al.)

Growth of large-scale structures (LSS) including galaxy clusters and the formation and evolution of galaxies therein, and the interplay of the two, are the key subjects in modern extragalactic astronomy. The Subaru Telescope and its unique suite of wide-field instruments (e.g., HSC) have been playing key roles in mapping the LSS in the early Universe and the characterization of global/statistical galaxy formation and evolution as a function of time and environment. The wide-field survey of HSC is conducted at optical wavelengths, thus limiting the redshift range that we can probe with rest-frame optical light to z<1.2. We propose to largely expand the survey of LSS to higher redshifts (z>2), to small mass systems (groups and filaments) and to small mass galaxies therein, with the deep and wide Roman High Latitude Wide Area Survey. The combination of Subaru and Roman in a large survey area will enable us to trace the LSSs and will provide hundreds of galaxy clusters/groups in each redshift interval (delta_z=1) out to z~4, by capturing the 4,000A/Balmer break feature. The planned slitless (grism) spectroscopy is also essential to trace emission line galaxies, such as H-alpha and [OIII] emitters out to z~3 along the structures. We will be thus able to quantify the history of galaxy formation, evolution, and eventually quenching as a function of time and environment in much greater detail.

- Cosmology with Large-scale Structure Measurements at z>4 using CMB Lensing (See **White Paper III** by Miyatake et al.)

In the late 2010s, possible evidence for the breakdown of ΛCDM emerged. One of the cosmological parameters in the ΛCDM model, S_8, which quantifies the clumpiness of the Universe at present inferred from the LSS at z<1 through weak lensing and galaxy clustering measurements by various galaxy imaging surveys is coherently lower than S_8 predicted from the primary fluctuations in cosmic microwave background (CMB) (Abdalla et al., 2022). One approach to investigating the S_8 tension is by measuring LSS at high redshifts to probe the evolution of S_8, Miyatake et al. (2022) demonstrated this approach at z~4, measuring S_8 using clustering of high redshift galaxies selected as HSC g-dropouts and CMB lensing caused by them. With Roman, to obtain robust cosmological constraints, we will reduce contamination from low-redshift interlopers using F213 observations in the overlapping region between the Roman High Latitude Wide Area Survey and HSC. We can also use

HSC g-band and Roman F062 and F087 in the overlapping region to identify galaxies at z~5, thereby constraining S_8 at z~5. In addition, follow-up observations by PFS and MB imaging with HSC will enable us to further reduce contamination in the sample. The combination of Subaru and Roman will allow us to obtain S_8 constraints across z~0 to z~5 seamlessly.

- HSC MB Filters for Precise Photometric Redshift (See **White Paper IV** by Nishizawa et al.)

MB filters on HSC divide the optical wavelength range from 400 to 1000 nm into 16 distinct bands. The depth of the sample is planned to go down to 26 AB magnitude at the r-band equivalent wavelength range with 1-hour exposure. According to the simulated data, the accuracy of the photometric redshift can reach <1% both for outlier rate and scatter. We will collect the data over a 25 deg^2 sky of the HSC-SSP Deep layer to fully utilize the existing broadband data. The data will be particularly useful for calibrating the photometric redshift of the Roman photometric sample particularly for the weak lensing sample at the fainter end of the sample. It is also worth noting that the combination of the HSC MB filters with ULTIMATE MB filters may broaden the well-calibrated redshift ranges in the future.

- ULTIMATE-Subaru (See **White Paper V** by Koyama et al.)

We emphasize that ULTIMATE has great synergy with Roman. In particular, NBs and MBs at >2um will be the most important components in the context of the Roman-ULTIMATE synergy, as Roman has only a single broad-band filter in this wavelength range (F213). For example, we can provide a spatially resolved H-alpha map for thousands of galaxies at the cosmic noon (z=2-2.5) with various NB(K) filters. Also, ULTIMATE has the potential to detect rare, Roman “F213-dropout” galaxies with MB(K3)/MB(K4) filters (Balmer break at z>4, or potentially Lyman break at z>15).

3. Subaru Observations:

Given the excellent synergies described above, **the director of the Subaru Telescope and Subaru Advisory Committee already agreed with NASA to commit 100 Subaru nights to the Roman-Subaru synergistic observations.** In addition, the following datasets are available in some fields (see also **Table 1**).

1. HSC-SSP Survey

The Subaru/HSC SSP Survey has obtained deep optical images over ~1100 deg^2. The survey has three layers, Wide, Deep, and UltraDeep. In the Wide layer (r~26 mag, 5sigma, 1100 deg^2), broad-band grizy images are taken in the fields of HSC-W-HectoMAP, HSC-W-Spring, and HSC-W-Autumn, which can be candidates of the survey field for the High Latitude Wide Area Survey. The typical seeing size is about 0.6 arcsec in the i-band. The Deep (r~27 mag) and UltraDeep (r~28 mag) layers are composed of COSMOS, XMM-LSS, ELAIS-N1, and DEEP2-3, which can be candidates for the High Latitude Time Domain Survey. In addition to the broad bands, there are data taken with the three NBs (NB387, NB816, and NB921), deep U-band data over the full area (~27 mag, with 350h of CFHT time), decent J-band data to J~23 mag, and deep Spitzer IRAC coverage (depth 23.1 mag; PI: Lacy and Sajina). Further details can be found in Aihara et al. (2017, 2021).

2. H20 Survey

The H20 Survey is a 20 deg^2 deep Subaru/HSC imaging (r~28 mag) and Keck/DEIMOS spectroscopic survey targeting two primary Euclid Deep Calibration Fields (NEP and CDFS). The survey has currently 90% and 60% completion rates in NEP and CDFS, respectively.

3. PFS-SSP Survey

The PFS-SSP survey is a large spectroscopic survey in the HSC-SSP Survey footprint currently planned to start in 2024, and will dedicate 120 nights for the PFS Galaxy Evolution (PFS-GE) survey to an ambitious array of targets from 0.7<z<6.6 over a total footprint of 13 deg^2 within the HSC SSP Deep/UltraDeep Survey (see Greene et al. 2022). At the lowest redshifts (0.7<z<2.3) we will measure accurate redshifts and spectroscopic properties of ~300k galaxies at >L*, allowing a wide range of studies including the environmental dependence of galaxy quenching and evolution in the mass-metallicity relation. We will also perform an IGM tomography survey of 2<z<3.5 dropouts, with the goal of dynamically mapping the 3D cosmic web using novel reconstruction techniques. Finally, at the 5<z<7 Epoch of Reionization, we will target LAEs selected from the HSC-SSP NB images, which will allow the 3D mapping of ionized HII bubbles.

Comparison with LSST/Rubin: Although LSST/Rubin is a powerful facility that can take deep broad-band images in wide sky areas, for single pointing depths, Subaru/HSC is 1.5 times faster than LSST due to the larger mirror area. In addition, Subaru/HSC, PFS, and ULTIMATE can provide deep NB+MB images and spectra of a large number of galaxies from optical to near-infrared, which cannot be obtained by other 8m-class telescopes including LSST.

Summary

The synergy between the Roman and Subaru telescopes offers a unique opportunity to address fundamental questions related to galaxy formation and evolution. By combining their wide field observations, advanced imaging capabilities, and spectroscopic instruments, the joint observations have the potential to deliver transformative scientific breakthroughs that would be unattainable with either telescope alone. **Choosing fields accessible to Subaru as the core community survey field will maximize the scientific outputs from the Roman and Subaru synergistic observations.**

Table 1: Possible survey fields that can be observed from Subaru (c.f., Table in Koekemoer et al. 2019)

Field	R.A.	Decl.	Ecl. Lat.	E(B-V) (mag)	Rel. Zodi.	Days (/yr)	Subaru/HSC exist?	HSC Area (deg^2)
CDFS	03:32	-27.48	-45	0.008	1.4	229	H20	~5-10
NEP	18:00	+66:33	+86	0.042	1.0	365	H20	~5-10
COSMOS	10:00	+02:12	-9	0.018	6.0	148	SSP-Deep (+PFS-GE)	~5
XMM-LSS	02:31	-04:30	-18	0.024	3.2	155	SSP-Deep (+PFS-GE)	~5
ELAIS-N1	16:11	+55.00	+73	0.008	1.0	365	SSP-Deep (+PFS-GE)	~5
DEEP2-3	23:30	+00:00	+3	0.044	1.4	229	SSP-Deep (+PFS-GE)	~5
EGS	14:17	+52:30	+60	0.009	1.2	365	SSP-Wide	~1
GOODS-N	12:36	+62:13	+57	0.012	1.2	365	-	-
ELAIS-N2	16:46	+41:01	+63	0.014	1.1	365	-	-
IRAC-Dark	17:40	+69:00	+87	0.043	1.0	365	-	-
HSC-W-HectoMAP	13:20-16:40	+42:00-+44:00	~+60	~0.01	~1	~365	SSP-Wide	~50
HSC-W-Spring	08:30-15:00	-02:00-+05:00	~0	~0.03	~4	~150	SSP-Wide	~500
HSC-W-Autumn	22:00-02:40	-07:00-+07:00	~0	~0.03	~3	~150	SSP-Wide	~550

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