Roman CCS White Paper

Subaru-Roman Synergetic Galaxy Survey-V: Synergy between Roman and ULTIMATE-Subaru

Roman Core Community Survey: *High Latitude Wide Area Survey, High Latitude Time Domain Survey, (Galactic Bulge 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; Galaxy evolution; Galaxy formation; High-redshift galaxies; Galaxy clusters; Large-scale structure of the universe; Reionization*

Submitting Author:

Name: Yusei Koyama
Affiliation: Subaru Telescope, National Astronomical Observatory of Japan
Email: koyama@naoj.org

List of contributing authors (including affiliation and email):

Yosuke Minowa (NAOJ, minoways@naoj.org)
Tadayuki Kodama (Tohoku Univ, kodama@astr.tohoku.ac.jp)
Kentaro Motohara (NAOJ, kentaro.motohara@nao.ac.jp)
Yoshito Ono (NAOJ, ono@naoj.org)
Masayuki Akiyama (Tohoku Univ, akiyama@astr.tohoku.ac.jp)
Akio Inoue (Waseda Univ, akinoue@aoni.waseda.jp)
Tomoko Suzuki (Kavli IPMU, tomoko.suzuki@ipmu.jp)
Ken-ichi Tadaki (Hokkai Gakuen Univ, tadaki@hgu.jp)
Takashi Moriya (NAOJ, takashi.moriya@nao.ac.jp)
Takahiro Morishita (Caltech, takahiro@ipac.caltech.edu)
Yuichi Harikane (Univ. of Tokyo, hari@icrr.u-tokyo.ac.jp)
Mariko Kubo (Tohoku Univ, m.kubo@astr.tohoku.ac.jp)
Atsushi J. Nishizawa (Gifu Shotoku Gakuen Univ, atsushi.nishizawa@iar.nagoya-u.ac.jp)
Tsutomo T. Takeuchi (Nagoya Univ, tsutomu.takeuchi.ttt@gmail.com)
Michitoshi Yoshida (NAOJ, michitoshi.yoshida@nao.ac.jp)

Subaru-Roman Synergetic Galaxy Survey-V: Synergy between Roman and ULTIMATE-Subaru

Abstract: This White Paper discusses a potential science synergy between Roman and "ULTIMATE-Subaru". ULTIMATE is a project to develop a wide-field adaptive optics (GLAO) system and a new wide-field imager (WFI) for the Subaru Telescope. ULTIMATE can deliver a high-quality GLAO-assisted (FWHM~0.2 arcsec) image over a wide FoV (14'x14'), and the availability of a suite of narrow-band (NBs) and medium-band (MBs) filters can complement the Roman's surveys. By targeting the Roman's deep survey field with ULTIMATE NB/MB filters, we can detect extremely faint emission lines with NBs (Lyα emission at z~8-9, and Hα/[OIII] lines at z~2-3), and also detect "break" features situated in λ>2um with MBs (e.g. Balmer break at z>4, Lyman break at z>15). We therefore request that at least a part of Roman's deep survey fields (*High Latitude Time Domain Survey)* will be placed in the northern sky, where the Subaru Telescope can access.

1. ULTIMATE-Subaru – an introduction

ULTIMATE-Subaru – *Ultra-wide Laser Tomographic Imager and Multi-object spectrograph with AO for Transcendent Exploration by Subaru* – is a project to develop a next-generation, wide-field adaptive optics system (GLAO) and a new wide-field NIR imager (WFI; 14' x 14', see Fig.1) for the Subaru Telescope. We expect the first light of ULTIMATE in ~2028 – i.e., during the period of Roman operation. The ULTIMATE GLAO system can uniformly improve the image quality over ~20-arcmin FoV in diameter. We can achieve an image quality of FWHM~0.2-arcsec in K-band at the moderate conditions, thanks to the good atmospheric conditions on Maunakea site. We note that the GLAO image quality is comparable to that of Roman (in K-band), and therefore we can expect great synergy between Roman (space) and ULTIMATE (ground).

In particular, the most unique feature of ULTIMATE, in terms of the Roman-ULTIMATE synergy, is its availability of a suite of narrow-band (NB) and medium-band (MB) filters which are not available for Roman (see Fig.2-left). Our current plan is to perform a deep (~25-mag) and wide-field (a few to ten square degree scale) imaging survey using the ULTIMATE NB/MB filters, to search for faint emission lines (Lyα emission at z~8-9 and Hα/[OIII] lines at z~2-3), as well as the "break" features at high redshifts situated in K-band (Balmer break at z>4, or potentially Lyman break at z>15).

We note that the improved image quality will also improve the point source sensitivity (by a factor of ~1.5-2.0x). In Ks-band, ULTIMATE will reach 5σ~25mag in 1-hour observing time in moderate conditions, or 5σ ~25.4 mag in the top 25% conditions. In fact, the latter is comparable to the sensitivity of Roman in F213 band, according to the latest version of the sensitivity estimate in "Roman Science and Technical Overview (Summer 2023)". While Roman has a wider FoV, it is important to recognize that ULTIMATE can be a good alternative choice for many of the Roman science cases which request Ks-band observations.

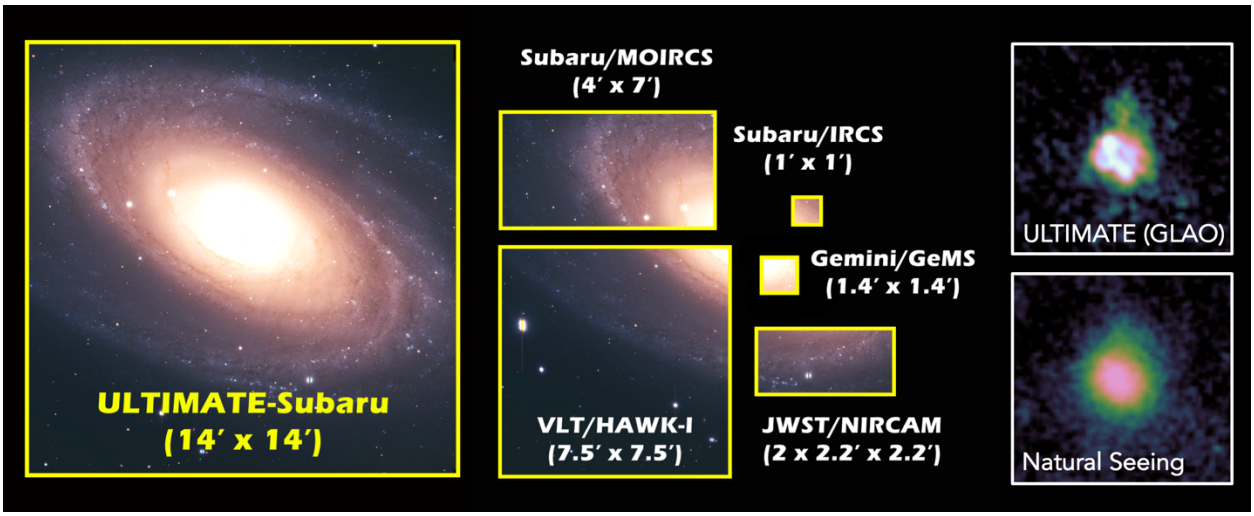

Fig.1: Comparison of the FoVs of ULTIMATE and other facilities which can perform wide-field NB/MB observations in NIR. ULTIMATE is standing at a unique position with its largest FoV among these facilities. The right panels demonstrate simulated observations of clumpy star-forming galaxies at z~2 with/without GLAO. We emphasize that the image quality achieved by ULTIMATE (GLAO on Maunakea) is comparable to that of Roman at 2um.

2. Expanding our science potential with Roman-ULTIMATE synergy

The key science goal of the ULTIMATE-Subaru is to reveal the *birth*, *growth*, and *death* of galaxies in the context of the structure formation of the universe. More specifically, we will (1) unveil the cosmic reionization history by searching and detecting Lyα emitters at highest redshifts ($z \gg 7$); (2) reveal the origin of galaxy morphologies (Hubble sequence) by spatially resolving star-forming regions (via Hα and/or [OIII] lines) of thousands of galaxies located in a wide environmental range (from rich clusters to voids) at the peak epoch of galaxy formation ($1 < z < 4$); and (3) identify when, where, and how the massive/quiescent galaxies appear in the universe by constraining the stellar mass function (and the number density of very massive galaxies) in the universe, by tracking down the Balmer-break feature of galaxies out to $z \sim 5$. All these key science goals require deep and wide-field NB and MB imaging observations in NIR (1um-2.5um), while all these observations also require deep broad-band imaging data as well, to determine the faint continuum levels of individual high-redshift sources.

(1) ULTIMATE NB(Y)/NB(J) survey: We aim at detecting Lyα emitters at z=8-9 – i.e. in the epoch of cosmic reionization – by performing an unprecedentedly deep NB(Y) and NB(J) imaging survey (~26mag) over >4-deg^2 field. This observation requires extremely deep broad-band imaging in Y and J-band, and thus the deep broad-band data to be obtained by Roman's deep imaging survey will be extremely helpful. By constraining the bright end of the Lyα luminosity function at z~9, and by measuring the neutral fraction of hydrogen gas in the inter-galactic medium (IGM) of the universe via the ratio between the number

density of Lyα emitters (LAEs) and UV-selected galaxies (LBGs, with Roman) over a wide area, we will unveil the cosmic reionization process. Roman's grism spectroscopy can also search for high-z LAEs, but an advantage of NB imaging survey is that it does not suffer from spectral overlap.

(2) ULTIMATE NB(K) survey: We aim at revealing the origin of the morphologies of galaxies (i.e. Hubble Sequence) by studying the detailed stellar build-up processes inside the galaxies at the "cosmic noon" epoch ($1 < z < 4$), where most stars in the present-day universe are formed. This goal can be achieved by spatially resolving star-forming regions (via Hα and/or [OIII] emission lines) of high-redshift galaxies residing in a wide variety of environment from rich clusters to void regions. We will perform a ~4-deg^2 scale, NB imaging survey in K-band (down to ~24-25mag). The proposed unprecedentedly deep, sharp, and wide-field NB(K) imaging survey is truly unique—no other telescope can do this (Fig.2-right). Roman's grism spectroscopy has a capability to deliver the spatially resolved emission line, but the Roman grism does not have access to λ>2um. The proposed ULTIMATE NB(K) imaging survey can extend the Roman grism survey to λ~2.5um. Again, deep broad-band (Ks-band) data is needed for this science. We will target the Roman's deep F213 imaging field with many ULTIMATE NB(K) filters, allowing us to compare the emission-line map (with ULTIMATE NB) and stellar continuum map (with Roman broad-band).

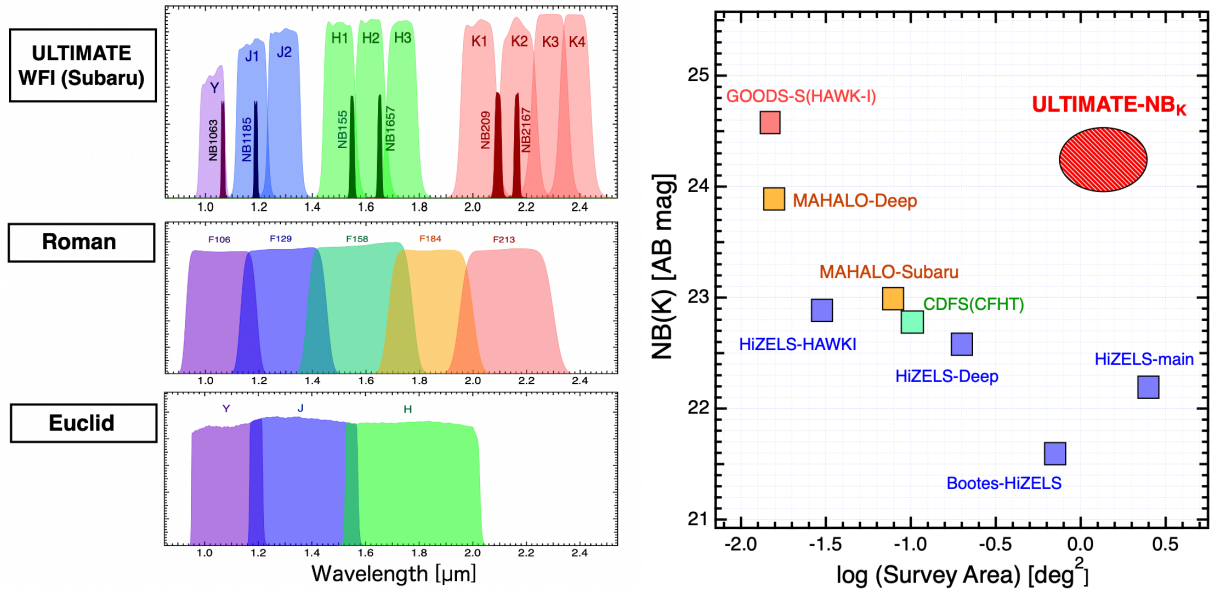

Fig.2: (Left): NIR imaging filters to be installed on ULTIMATE (top), Roman (middle), and Euclid (bottom), demonstrating that ULTIMATE can offer a unique set of NB and MB filters. **(Right):** Limiting magnitudes and survey area sizes of deep/wide NB imaging surveys ever performed in K-band. ULTIMATE can perform a much deeper and wider NB survey with a reasonable (~20-nights) observing time.

(3) ULTIMATE MB(K) survey: We will identify the first emergence of massive/quiescent galaxies in the universe, by tracking down the "Balmer break" feature of galaxies out to z ~ 5 with a few to ten square degree scale MB imaging survey in K-band. We aim to quantify the number density of rare, very massive quiescent galaxies ($M\star >\sim 10^{11}$Msun) back into z~5 to put strong constraints on the formation timescale of massive galaxies and the star formation in the earliest Universe. This is another key component of the proposed Roman-ULTIMATE synergy – we can straddle the Balmer break at z~4-5 with F213 (Roman) and K3/K4 filters (ULTIMATE), and again, it is very important to overlap our MB survey with Roman's deep survey field.

(4) ULTIMATE time domain survey: As already mentioned above, ULTIMATE can achieve the comparable depth to Roman in Ks-band (broad-band), both Roman and ULTIMATE can be powerful tool for NIR transient search (e.g. high-redshift supernovae). Roman will do a blind survey taking its wide FoV, but by considering the limited life time of Roman, and by carefully targeting overdense regions of high-z galaxies selected by Roman, Roman-ULTIMATE collaboration can boost the supernovae detection rate.

3. Summary (requirements)

We believe that ULTIMATE-Subaru will greatly enhance science outputs from the Roman mission. Our goal is to perform a deep (down to ~25mag levels) and wide (a few to ten square degrees scale) imaging survey with ULTIMATE NB/MB filters *on top of* the Roman's deep extra-galactic survey fields. Our only requirement is therefore that at least a part of Roman's deep surveys (*High Latitude Time Domain Survey)* will be placed in the northern sky, where the Subaru Telescope can access with reasonably good visibility. The depths and excellent data quality provided by Roman (in Y/J/H/F184 (+Ks)) will be extremely helpful for ULTIMATE to detect faint emission lines with NBs (Lyman-a emission at z~8-9,or Ha/OIII lines at z~2-3), and to detect "break" features situated in λ>2um (Balmer break at z>4, Lyman break at z>15).