Roman CCS White Paper

Optimizing Science Return with Synergy Between Roman's Core Community Surveys and the High-Resolution, UV-Optical CASTOR Mission

Roman Core Community Survey:

High Latitude Wide Area Survey, High Latitude Time Domain Survey

Scientific Categories:

large scale structure of the universe; galaxies; stellar physics and stellar types

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Relevance to the Roman White Paper Process

The Roman Space Telescope team has requested community input on science drivers and observing strategies for maximizing the scientific return from Roman's planned Core Community Surveys (CCSs). The information collected in this consultation process will be used to carry out trade studies on the design and implementation of each CCS.

This white paper is being submitted as an update to the Roman Space Telescope team on the CASTOR mission (see below, and https://www.castormission.org/), which is tentatively scheduled to launch at the end of this decade. CASTOR's scientific capabilities are highly complementary to those of Roman as it will probe the UV-optical sky at high resolution comparable to Roman's NIR view, and its science mission features several "Legacy surveys" that strongly leverage Roman's CCSs. CASTOR's capabilities and data products may thus be of interest to the Roman team when optimizing the design and return of the Roman CCSs and science investigations.

Overview of the CASTOR Mission

The *Cosmological Advanced Survey Telescope for Optical and ultraviolet Research* (CASTOR; Côté et al. 2019ab) is Canada's highest priority in space astronomy for the 2020s (Barmby et al. 2021). A Canadian Space Agency (CSA) Phase 0 study (2022-2023) is underway including the participation of international scientists, including US researchers, with the goal to define the science mission and secure partnerships.

- ***Design and Capabilities***

CASTOR is a 1m, UV/blue-optical telescope designed for efficient imaging and spectroscopy surveys. Its three-mirror anastigmat design combines a wide field of view (0.24 deg^2) with nearly diffraction-limited image quality (FWHM ≈ 0.15″). Two high-efficiency beam-splitters and state-of-the-art multi-layer coatings are used to define three photometric passbands — *UV* (0.15–0.30 μm), *u* (0.30–0.40 μm) and *g* (0.40–0.55 μm) — and deliver images, simultaneously, to three focal plane arrays. Each focal plane is covered with a 2×2 mosaic of delta-doped, AR-coated BICMOS detectors. A filter wheel can deploy either a grism— which will provide full-field, low-resolution (R=300-420) slit-less spectroscopy in the *UV* and *u* channels — or a broadband filter that splits the *UV* and *u* channels for better SED sampling at short wavelengths. A multi-object Digital Micro-Mirror (DMD) spectrograph covering an adjacent (3.4′ × 2.0′) field offers medium-resolution (R≈1500) spectroscopy in the 0.15–0.30 μm range. Finally, a single BICMOS placed in each of CASTOR's focal planes will allow ~10 ppm photometric monitoring of bright exoplanet hosts.

- ***Synergies with Roman***

CASTOR will operate in a "dawn-dusk", sun-synchronous, low-earth orbit that allows high-efficiency mapping of large regions of the sky, like Roman, but in a spectral range (0.15–0.55 μm) that is inaccessible to Roman. The field of view and image quality of the two facilities are similar: 0.28 deg^2 and 0.2″ for Roman, vs. 0.24 deg^2 and 0.15″ for CASTOR. These similarities make CASTOR an ideal complement to Roman. It is unsurprising that several of the Legacy

Surveys being planned for CASTOR will leverage UV-blue observations to *enhance existing* planned Roman science and to *enable new* Roman investigations that are uniquely possible with CASTOR data. The scientific synergy between Roman and CASTOR will be analogous to the many demonstrated constructive collaborations stemming from availability of Spitzer in the IR and GALEX in the UV, though accomplished at dramatically higher resolution and sensitivity.

CASTOR Intersection with Roman CCSs

In the spirit of this call for white papers, we briefly highlight the anticipated intersection between two of the Roman CCSs and the CASTOR Legacy Surveys.

- ***High Latitude Wide Angle Survey (HLWA Survey)***

The ***CASTOR Wide Survey*** will cover Roman's HLWA Survey footprint to 5-sigma depths of ~26.4–27.4 ABmag in the UV/blue-optical spectral region. The final survey will provide deep, high-resolution imaging and photometry in five passbands covering the 0.15 to 0.55 μm wavelength range, matching the final (10-year) depth of Rubin-LSST in the *g*-band (27.4) and exceeding its final *u*-band depth by ~1.3 mags (see Figure 1). A wide range of science will be enabled by the survey. In cosmology, CASTOR will contribute to the study of dark energy by breaking key degeneracies in photo-z measurements, performing independent shape measurements for cosmic shear studies, and mitigating the problem of blending among faint galaxies, which is known to introduce a correlated bias between local density, shear and redshift measurements. Owing to their high-resolution, broad wavelength coverage, and unbiased wide-field nature, the combined CASTOR and Roman data will open a new era in the study of galaxy evolution, providing an unprecedented view of how galaxies form and evolve, including when, where and how their star formation unfolds over cosmic times. The UV-optical-NIR imaging will resolve individual stellar clusters/associations in all nearby galaxies within the HLWA survey (Fig. 2) plus map recent star formation in statistical samples of distant galaxies (Fig. 3), whereas the grism survey will yield samples of Lyα and Lyman continuum emitters up to 100x larger than currently exist. Additional studies enabled by the combination of CASTOR-Roman data include strong lensing, the tomography of the UV background, the identification of massive quiescent galaxies, characterization of the hosts of extragalactic transients, the chemical evolution of the Milky Way, and stellar and planetary evolution from massive stars to white dwarfs. The wide-field and grism offered by both Roman and CASTOR will support massively multiplexed, highly efficient studies of AGN triggering and quenching mechanisms.

- ***High Latitude Time Domain Survey (HLTD Survey)***

Three CASTOR Legacy Surveys aim to carry out deep UV/blue imaging and slit-less spectroscopy in extragalactic survey fields that will be targeted by the next generation of ground- and space-based telescopes in optical and IR wavelengths: i.e., Rubin-LSST, Euclid and Roman. Indeed, Roman's HLTD Survey field will be an inviting target for one of these CASTOR fields given its extreme depth and high imaging cadence (Figure 4), which overlays a grid of CASTOR pointings on an illustrative HLTD Survey field). The pertinent CASTOR Legacy Surveys, observing plans and data products are as follows: (1) The ***CASTOR Deep Survey*** will perform five-band imaging to a (5-sigma point-source) depth of ~29 ABmag to measure the evolution of the spatial distribution of star formation in galaxies out to approximately z=2.5. (2) The ***CASTOR Grism Survey*** will use Lyα emitters and Lyman break galaxies to map the cosmic web at $1 < z < 3$ and examine cosmologically important starbursts and their luminosity functions at these redshifts. (3) The ***CASTOR Cadence Survey*** will monitor several fields with a frequency of roughly one observation per day for six months to reveal shock breakouts from infant supernovae and their immediate environments, probe the early emission from super-luminous supernovae and tidal disruption events, carry out reverberation-mapping of AGNs, and amass large samples of the poorly-studied UV light curves for core-collapse and Type Ia supernovae.

Note that, like Roman, a fraction of CASTOR's observing time (25-33%) will be reserved for Guest Observer and Target-of-Opportunity programs; other synergistic opportunities will therefore exist beyond these two CCSs.

Summary

As is the case with Roman's CCSs, observing plans for CASTOR's Legacy Surveys will continue to be refined as the mission development proceeds towards an anticipated launch around the end of this decade. Given the many synergies between the two missions some coordination to optimize scientific return is advisable and could be facilitated by a joint working group of US/Canadian astronomers having scientific investment in both missions.

References:

Barmby et al. 2021, Discovery at the Cosmic Frontier: Canadian Astronomy Long Range Plan 2020-2030.

Côté et al. 2019a, Final Report on the Wide-Field Space Astronomy Study: Science Maturation Study for the CASTOR Mission

Côté et al. 2019b, CASTOR: A Flagship Canadian Space Telescope (LRP2020 White Paper)

Williams et al. 2021, ApJS, 253, 53

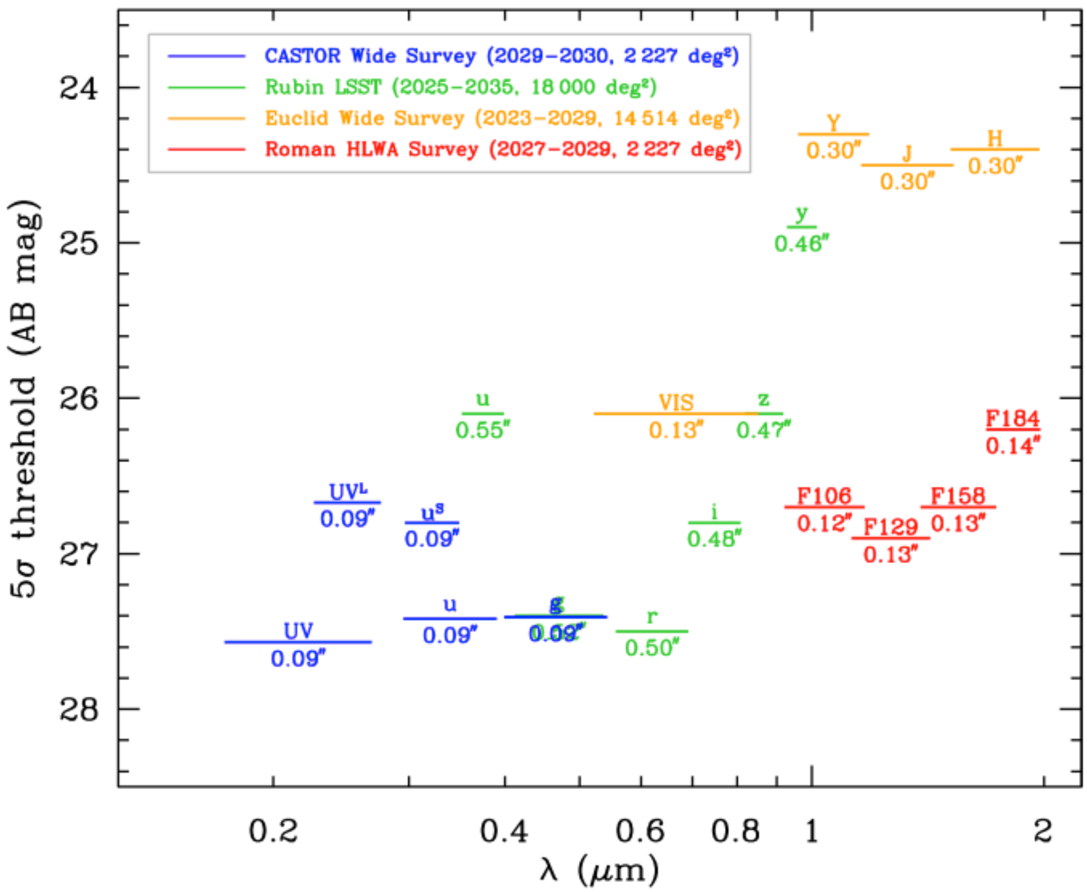

Figure 1. ***Final depths for the proposed CASTOR Wide Survey (shown in blue) which aims to cover the Roman HLWA Survey footprint*** *(shown in red). For comparison, we also show the final depths of the Rubin-LSST 10-year survey (green) and Euclid Wide Survey (orange) which will cover this same region. The labels associated with each filter indicate the approximate image quality (i.e., EE50 radius) for each survey.* ***The CASTOR Wide Survey would complement the Roman HLWA Survey to ultimately provide deep, high-resolution imaging over the entire UVOIR region, from 0.15 to 2 µm.***

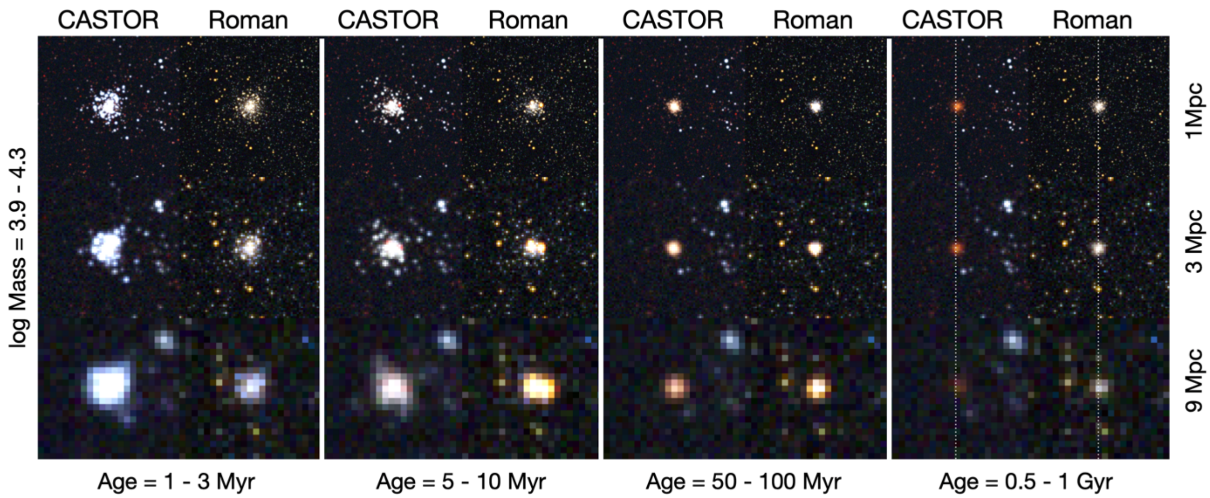

Figure 2. ***Four synthetic stellar clusters generated to match their expected appearance when observed by CASTOR and Roman*** *at planned* ***CASTOR Nearby Galaxy Survey*** *(UV, u, g) and Roman HLWA Survey depth. Cluster realizations were inserted in a field star population based on UV-NIR photometry of M33's southern disk (PHATTER, Williams+2021). (left to right) Representatives of various age bins are shown. In the oldest bin, we add a thin line to guide the eye to faint simulated clusters. We show the cluster (and field) appearance in each telescope at distances of 1, 3, and 9 Mpc. When simulating each cluster, member stars were drawn in a stochastic manner from the IMF, and placed randomly in accord with a Moffat profile.*

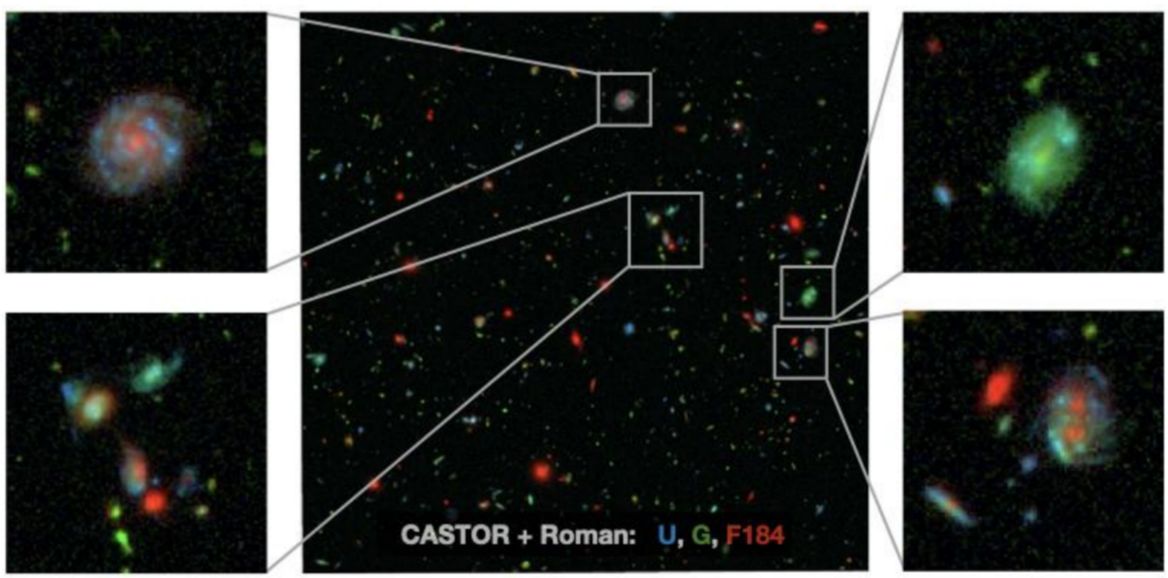

Figure 3. ***A simulation of the Hubble Ultra Deep Field (UDF) in filters from CASTOR (u, g) and Roman (F184).*** *This image shows a ~1.5'×1.5' field, or just ~0.06% of the area that will be covered by the* ***CASTOR Ultra-Deep Survey****. While Roman's IR imaging (red) is sensitive to existing stellar mass, CASTOR picks out regions of ongoing star formation.* ***With comparable spatial resolution from the ultraviolet to the near-infrared it will be possible to map stellar populations and other physical parameters*** *across galaxies, out to cosmic noon.*

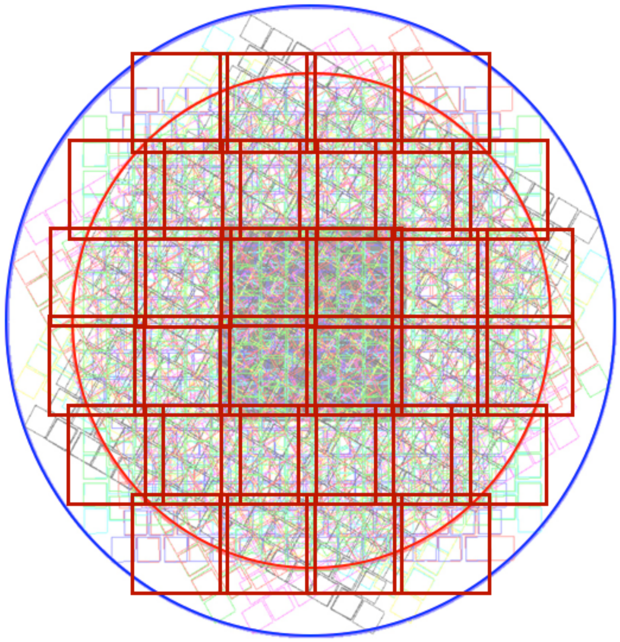

Figure 4. ***Layout of a nominal supernovae survey region*** *(courtesy D. Scolnic & C. Baltay)*[1]*. The red and blue circles encompass areas of 5 deg^2 and 8 deg^2, respectively. The red polygons show individual CASTOR pointings, which will each provide simultaneous UV, u and g imaging over an area of 0.24 deg^2.* ***Three CASTOR surveys will provide deep UV/u/g imaging and slit-less spectroscopy in six carefully selected extragalactic fields — one of which may be the Roman HLTD Survey field.***

[1] https://roman.gsfc.nasa.gov/high_latitude_time_domain_survey.html