Astro2020 Activities and Projects White Paper

CASTOR: A Wide-Field, UV Space Telescope

Thematic Areas: ☒ Space Missions ☐ Ground-Based Activities and Projects
☐ Computation Astrophysics ☐ Theoretical Astrophysics
☐ Laboratory Astrophysics

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Abstract: CASTOR (The Cosmological Advanced Survey Telescope for Optical and UV Research) is a proposed Canadian-led mission that would provide high-resolution imaging and spectroscopy in the UV/optical (0.15–0.55 μm) spectral region. The imager covers a 0.25 deg^2 field of view simultaneously imaged in three bands, a capability that is $\sim$ 100x that of HST in terms of survey speed. In addition, a multi-object Digital Micro-mirror Device (DMD) spectrograph covering an adjacent field of view could provide moderate to high-resolution UV spectroscopy and a grism could provide wide-field low-resolution spectroscopy. The UV imaging and spectroscopic capability would enable a wide range of science in the post HST era including understanding the physics of star formation from our galaxy to the distant universe, the atmospheres of exoplanets, the properties of the outer solar system, as well as improving dark energy constraints. The data would far surpass any current or past UV surveys in terms of sensitivity and angular resolution and would provide complementary capabilities to the longer-wavelength data from the Euclid and WFIRST missions as well as the ground-based Large Synoptic Survey Telescope.

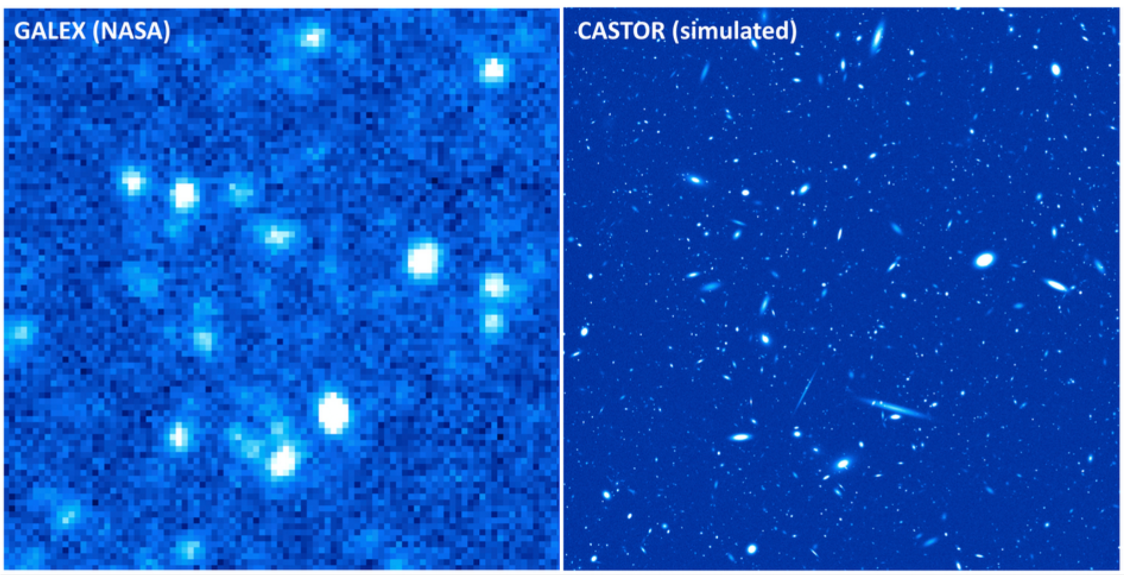

Figure 1: CASTOR will produce an ultra-deep, sharp, and wide field view of the universe in ultraviolet light, allowing studies of star formation in our galaxy and over cosmic timescales. (Left) A region of COSMOS survey field as observed by the GALEX satellite. (Right) View of this same region in a deep (100-hr) simulated observation with CASTOR.

1 Key Science Goals and Objectives

CASTOR[1] (The Cosmological Advanced Survey Telescope for Optical and UV Research; Côté et al. 2012) is a proposed mission from the Canadian Space Agency (CSA) that would provide wide-field high-resolution imaging and spectroscopy in the UV/optical (0.15–0.55 μm) spectral region. The CASTOR facility is designed to fill a gap in observational capability at these wavelengths which will become critical as HST ages. Similar to WFIRST, CASTOR would operate as a joint general observer (GO) and survey mission with $\sim$60-70% of the time dedicated to surveys and the remainder for GO science. As outlined in this white paper, the science enabled by CASTOR

[1]https://www.castormission.org

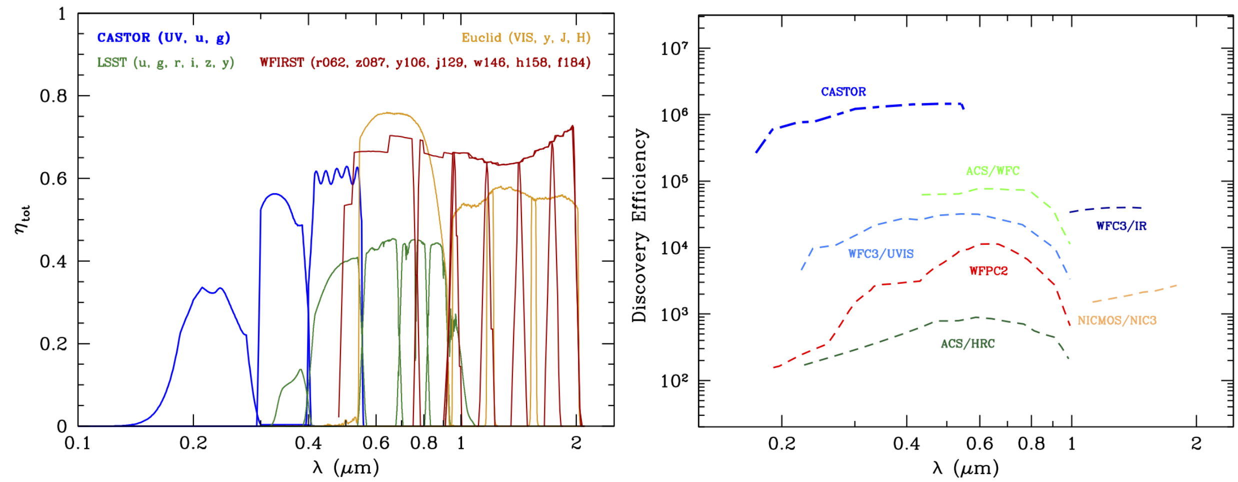

Figure 2: *(Left)* Passbands for CASTOR, shown in blue, compared to those of Euclid (orange), WFIRST (red) and LSST (green), illustrating the CASTOR's uniqueness and synergy with these next generation imaging facilities. *(Right)* Discovery efficiency of CASTOR compared to UVOIR imaging instruments on HST plotted as a function of wavelength. Discovery efficiency is defined here as total system throughput, $\eta_{\rm tot}$, multiplied by telescope collecting area and instantaneous field of view. This comparison neglects the fact that CASTOR images in three bands, simultaneously.

covers a wide range of topics including studies of star formation across cosmic time, exoplanet atmospheres.

CASTOR's key capabilities for science would include: (1) state-of-the-art image quality (FWHM $\simeq 0.15''$) shortward of 0.55 μm; (2) continued access to the UV region, which is unobservable from the ground; (3) an instantaneous field of view roughly two orders magnitude larger than that of HST; and (4) the low backgrounds, stable point-spread functions and photometric calibrations that are achievable in space environments.

The 2010 decadal survey recommendations, along with the delay of the JWST launch, mean observational capabilities in the 2020's have decidedly shifted to the near-infrared ($\geq$ 0.5 μm) and towards large scale surveys. The ESA *Euclid* (Laureijs et al. 2011) mission will launch in 2022 and perform imaging and grism spectroscopy over an area of $\sim$ 15 000 deg^2 in the IR region ($0.9 < \lambda < 2.0\mu$m), as well as in a single broad filter (`VIS`) at red-optical wavelengths ($0.55 < \lambda < 0.9\mu$m). Subsiquently, in 2026 NASA's *WFIRST* mission (Spergel et al. 2015), will carry out red-optical/IR imaging and spectroscopy ($0.5 < \lambda < 2.1\mu$m) over large areas of the sky. On the ground, the Large Synoptic Survey Telescope (LSST) (Ivezić et al. 2008, Abell et al. 2009) is expected to begin its decade-long survey operations in 2021, imaging 20,000 square degrees of sky in six optical bands covering $0.35 < \lambda < 1.0\mu$m, but with most of the observing time focused on red bands. Finally, starting in 2021 JWST, will provide imaging and spectroscopic with unprecedented sensitivity, but at $\lambda > 0.6\mu$m and with an HST like field of view.

As these facilities come online, the aging Hubble Space Telescope (HST) will be one of the only UV facilities, but will likely be nearing the end of its mission. The inevitable failure of a critical HST subsystem will leave astronomers without an UV/blue-optical instrument to complement the new facilities; and even if HST continues to operate nominally, its field of view is far too small for optimal synergy with the new facilities. Furthermore, its observing capabilities in the UV will continue to degrade due to radiation damage to the detectors.

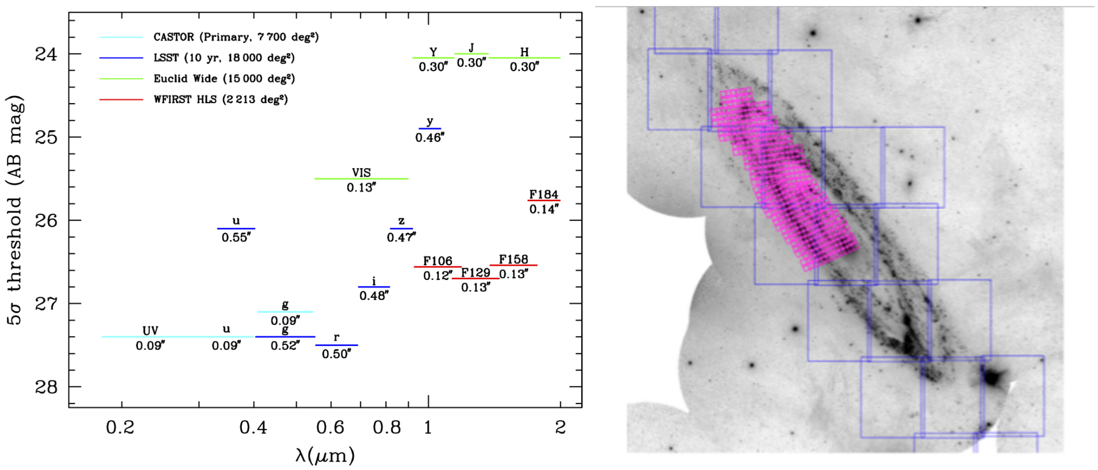

Figure 3: *(Left)* Depth of wide-field UVOIR imaging surveys plotted as a function of wavelength. Results are shown for LSST, Euclid-Wide, WFIRST-HLS and CASTOR. For CASTOR, we show preliminary results for a primary science survey that covers the 7687 deg^2 region defined by the overlap between the LSST and the Euclid-Wide surveys. The labels under each filter indicate the approximate image quality (i.e., EE50 radius) for each survey. *(Right)* Potential CASTOR mosaic for the M31 galaxy overlaid on GALEX NUV imaging. Also shown is the footprint of the Panchromatic HST Andromeda Treasury survey (PHAT; Dalcanton et al. 2012).

CASTOR is designed to provide a new wide-field space telescope that will provide the crucial short-wavelength imaging and access over the UV-optical-infrared (UVOIR) region (e.g. Heap et al. SWP). In the following sections, we outline the diverse science drivers for the UV and CASTOR in particular.

1.1 Galaxies and Cosmic Star Formation

Star formation drives the evolution of normal matter in our universe. It serves as the primary regulator of galaxy evolution, and governs the gas content within galaxies through feedback that propels metals, energy, and momentum into interstellar and intergalactic space. It is thus a visible tracer of the history of the universe and central to studies of the physical mechanisms that drive, regulate and quench galaxy evolution over cosmic timescales.

UV light is our primary probe of star formation and its effects on galaxies (e.g. SWP from Gordon, Hagen, Martin, Paladini, Thilker, & Tumlinson). To study star formation, we either observe UV light directly, or UV light that has been absorbed by dust and gas and re-emitted as far-infrared (FIR) light and/or emission lines such as H_α. In practice, all of these wavelengths are required to form a complete picture of how stars form, but direct observations of UV light provide the highest spatial resolution combined with high sensitivity given current technology.

The proposed CASTOR science is not possible with existing facilities such as the HST that lack the survey speed, or past facilities like GALEX, Herschel, or Spitzer that lacked spatial resolution (see Figure 1). Future facilities such as LSST, Euclid, and WFIRST are optimized for cosmology which is better done at near-IR wavelengths and do not cover the UV or FIR wavelengths needed to probe star formation.

Empirically, the average star formation processes are remarkably synchronized on gigaparsec scales (i.e., degrees on the sky) over the whole universe and on parsec scales ($\sim 0.1''$) within individual, nearby galaxies. Yet, the details of star formation vary widely from galaxy to galaxy (e.g. Peng et al. 2014, Gabor & Dave 2015). We believe the differences are driven by interactions between galaxies and their dark matter halos, but have little quantitative evidence to support this picture because no existing data set brings together the required measurements.

To understand this dichotomy, we need to build a star-formation physics ladder linking the parsec (pc) scale physics in local galaxies (Paladini SWP) with the kilo- (kpc) and giga-parsec (Gpc) scales observable in more distant galaxies at earlier cosmic epochs. These measurements then must be linked to the dark matter skeleton we believe defines the evolution of structure in the universe. In practice, this link is achieved through statistical methods such as weak lensing which are also used for cosmology.

Locally, we wish to constrain star formation timescales, efficiencies, the evolution of multi-scale structure, and enable systematic study of the dependence on key galaxy-scale properties such as ISM phase balance, gas mass, star formation rate, surface densities, and galaxy morphology (Thilker SWP). These constraints are needed to inform a unified theory of star formation, to gain insight into galaxy scaling relationships such as the Kennicutt-Schmidt star formation law, and to bridge the detailed study of star formation in Milky Way and select nearby galaxies, to the field of galaxy evolution.

1.2 Extrasolar Planets

Transmission spectroscopy of exoplanet atmospheres is an incredibly powerful characterization tool. The James Webb Space Telescope is poised to construct exquisite spectra at near- and mid-infrared wavelengths. Unfortunately, interpretation of spectra at these wavelengths is currently stymied by the degeneracy in the (mostly featureless) spectra between atmospheres with high mean molecular weight, or atmospheres with clouds and/or hazes.

However, transmission spectra in the UV and near-optical can be used to break this degeneracy (e.g. SWP from Christiansen, Lisman, Lopez, Reinhardt, Youngblood). If the muted spectral features are caused by small scattering particles (e.g. hazes), then the UV and near-optical wavelengths will show signatures of Rayleigh scattering (e.g. Sing et al. 2016). CASTOR will allow for both UV, u, and g channel transmission spectra, as well as detailed measurements of flux variations from exoplanets as a function of orbital phase around their parent stars. These UV phase curves contain information on the distribution of condensates such as water vapour droplets, water ice, or any cloud or haze particle that is liquid or solid, and will show a dependence on angle of incident intensity to the outgoing scattered intensity. Thus, CASTOR measured UV transmission spectra and phase curves will be a powerful tool for extracting the physical properties of atmospheric condensates in exoplanets.

1.3 Time Domain Astrophysics

With the successful detection of gravitational waves (GWs) by the LIGO/Virgo Collaboration (LVC) in 2015 (Abbott et al. 2016) and the identification of the first electromagnetic (EM) counterpart to a GW source in 2017 (Abbott et al. 2017b), multi-messenger astrophysics (MMA) is set to become a major focus of transient astronomy in the coming decades. UV emission from these transients is uniquely valuable and is predicted to be both prompt and fast evolving — predominantly observable in the first ~ 1 week post-merger — highlighting the need for rapid localization and follow up of UV counterparts (e.g. Metzger SWP).

UVOIR emission from the compact object mergers though to create gravity waves primarily probes material ejected from the system, and thus offers critical constraints on the energetics, mass, and nucleosynthetic yield of the explosion. In particular, these mergers were long theorized to produce kilonovae (KN) — transients powered by the radioactive decay of unstable r-process nuclei synthesized in the merger ejecta (Li & Paczynski 1998). The predicted observational signatures of KN depend sensitively on the opacity of the material, and hence its composition (Kasen et al. 2015; Metzger & Fernandez 2014). Observations of GW170817 revealed thermal emission that initially peaked in the UV, rapidly cooled from a temperature of $>$10,000 K to 3,000 K over 5 days, and was followed by a longer-lived IR transient (Drout et al. 2017). Modeling confirmed that this emission was dominated by a KN, and the large inferred r-process yield (0.05 $M_{\odot}$) now suggests that neutron star mergers may be responsible for producing a large fraction of the heavy elements in the Universe (Cote et al. 2017; Kasen et al. 2017; Rosswog et al. 2018).

1.4 Stellar Astrophysics

CASTOR's wide field of view and exceptional image quality in the UV will transform the study of resolved stellar populations in nearby galaxies. Figure 3 right illustrates this potential by showing how only three CASTOR fields (squares) could fully cover the M31 disk region that was mapped at UV, optical and IR wavelengths by the Panchromatic Hubble Andromeda Treasury (PHAT) survey (pink squares)— one of the largest programs ever approved on HST (828 orbits; Dalcanton et al. 2012). Observations of this quality make it possible to reconstruct the detailed history of star formation and chemical enrichment in nearby galaxies.

In such studies, the power of UV and blue filters lies in their sensitivity to the hottest stars, which can include young massive stars and stars nearing the end of their lives, such as white dwarfs, post-AGB stars, and binaries containing fainter, hot components (i.e., accreting binary systems involving degenerate components, such as cataclysmic variables, novae of various kinds, and X-ray binaries involving neutron stars and black holes). UV/blue-optical data from CASTOR will be a powerful complement to IR imaging from Euclid or WFIRST, allowing a complete picture of the star formation and chemical enrichment histories in nearby galaxies. Note that Euclid and WFIRST alone will be severely limited in their ability to measure ages and abundances for resolved stellar populations due to their restricted wavelength coverage (Figure 2). And, in this context, LSST will be of little use since crowding effects will be prohibitive in ground-based imaging.

1.5 Active Galactic Nuclei

AGN spectra have dominant features in the UV/blue-optical region: e.g., Lyman alpha in emission and absorption, plus broad and narrow emission lines of NV, Si IV, C IV, He II, [C III, Mg II, [O II]. CASTOR imaging will detect AGN at the centers of galaxies and resolve the associated star formation that surrounds them along with the ionization of gas and triggered star-formation and AGN jets. This will be done for vast numbers of galaxies at redshifts out to a few tenths, thus sampling the full range in host environment, from isolated galaxies to rich clusters, where interactions and cooling flows affect the processes significantly.

An exciting recent development in AGN physics has been the discovery of so-called "changing look" quasars, whose origins are being actively debated. Deep imaging from CASTOR, when combined with results from previous surveys, will make it possible to identify and study these rare systems. Nearly simultaneous coverage at multiple wavelengths provide the best way of measuring AGN energy budgets and emission mechanisms, and provides key information for reverberation mapping studies of 1000's of objects (e.g., Chelouche et al. 2014). In particular, CASTOR will enable UV reverberation mapping, directly probing the primary ionizing continuum that originates in the inner region of the accretion disk providing constraints on its structure and size. In the local universe, the relationship between nuclear star clusters and SBHs in low- and intermediate-mass galaxies (Seth et al. 2014) has emerged as an important question for galaxy evolution and feedback models, and UV imaging and spectroscopy will play a critical role in this area (Spengler et al. 2017).

1.6 Near-Field Cosmology

The identification of stellar streams in the Galactic halo, and the mapping of stellar density fluctuations along these streams, can be used to measure the potential of the Milky Way and the number of low-mass DM perturbers (Carlberg 2009; Erkal et al. 2017). UV/blue-optical imaging, particularly when combined with red/IR imaging, can be used to measure the spatial and chemical structure of the Galaxy through photometric parallaxes (Jurić et al. 2008; Ibata et al. 2017), identify multiple populations in Galactic substructures (Renzini et al. 2015), and probe the ultra-metal-poor tail of the Galactic metallicity distribution function, including the identification of the most chemically pristine stars. Proper motion measurements for streams and satellites can be used to measure the mass and shape of the Galaxy's dark halo (Bovy et al. 2016) while the internal motions of satellites (deduced from ground-based spectroscopy or space-based proper motions) can be used to measure the DM power spectrum (Simon & Geha 2008) and/or test modified theories of gravity. The ability to find the faintest and most distant streams from the ground is limited by confusion with faint galaxies, so a space based facility is essential to mapping these structures.

1.7 Cosmology

The accelerated expansion of the universe due to dark energy was the focus of the 2010 decadal survey and has resulted in a number of major projects including Euclid, DESI, LSST, and WFIRST. These studies are using a number of probes, most notably: weak lensing (WL), supernovae (SNIa), galaxy clustering (as traced by baryon acoustic oscillations, BAO), strong lensing (SL) and galaxy cluster counts. It is abundantly clear that the combination of these missions is far more powerful in constraining DE than any individual one (see, e.g., Jain et al. 2015). This is because each mission and observational probe comes with its own systematic errors, which are dictated by differences in image resolution, photometric stability, and wavelength coverage.

CASTOR will significantly mitigate the known technical and systematic risks in these missions by providing photometric stability, homogeneity, and high-resolution imaging in the UV/blue-optical bands. In particular the blue imaging will improve photometric redshifts, provide an independent weak lensing shape measurement, mitigate the risks of PSF chromaticity and directly measure color gradients in galaxies that are a key systematic in weak lensing measuremetns. The importance of this contribution cannot be overstated as it is a capability that is presently lacking in the portfolio of international facilities planned for the 2020s. It will also be possible, with CASTOR alone, to directly probe DE with WL to an accuracy comparable to the WFIRST mission, thus significantly boosting the level of redundancy among independent DE probes.

1.8 Outer Solar System

UV imaging and spectroscopy provides a host of information on solar system objects (e.g. SWP from Clarke, Jean-Yves). Very recently, we have begun to recognize that the measurement of accurate surface compositions of solar system objects requires extending surface reflectance measurements into the blue, where silicate features dominate the spectra (Fraser et al. 2017). Based on recent u-band observations from CFHT — taken as a part of the ColOSSOS project (Marsset et al. 2019) — we are now seeing surfaces in the Kuiper belt that are similar to the thermally processed c-type asteroids (i.e., depleted in H, He and other volatiles). CASTOR will enable studies of smaller, fainter bodies enabling comprehensive studies of the outer solar system.

2 Technical Overview

The key aspect of CASTOR is a wide-field imaging and multi-object spectroscopy capability in the ultraviolet (UV) and blue-optical region. This will be achieved with a 1 meter space telescope operating close to its diffraction limit. A wide-field camera will image a 0.25 deg^2 field of view in three bands ($0.15 \leq \lambda \leq 0.55 \mu$m) simultaneously using dichroics. An optional grism could be inserted in the UV channels to enable low-resolution wide field spectroscopy. In a parallel filed of view to the wide field imager, a Digital Micro-mirror Device (DMD) spectrograph would provide multi-object moderate to high-resolution spectroscopy.

The key technical parameters of the mission are described in Table 1 with a more detailed technical design study available from the CSA (Cote et al. 2019, in preperation). The vast majority of the required technology has been previously flown and is well within the mass, power, and technical margins for the proposed platform.

CASTOR has been designed to fit the mass and size constraints for the ISRO PSLV rocket for a polar orbit. This will also allow it to be the payload on a number of other vehicles with similar capability.

2.1 Technology Drivers

In order to achieve sensitivities comparable to Hubble with a smaller telescope, CASTOR will use large format 2D-doped CMOS arrays with customized filter coatings deposited on the detectors. 2D-doping is a passivation technique developed by JPL that yields 100% internal quantum efficiency (QE) in silicon detectors, allowing an enhanced, stable UV QE to be defined by the custom coating. UV-enhanced CCDs have been demonstrated on various sub-orbital missions such as FIREBall-2 (balloon), and they will be flown on the upcoming SPARCS cubesat. The baseline detector for CASTOR is the SRI Mk x Nk CMOS, a scalable architecture which can produce detector sizes up to 10k x 10k pixels. The 4k x 2k version of this detector will be used on the Europa Imaging System (EIS), and JPL is using EIS CMOS wafers to demonstrate 2D-doped CMOS for a NASA research and development project. Demonstration of the specific CASTOR filters on SRI

Table 1. CASTOR Mission Specifications

Primary aperture	1m off-axis, unobscured, light-weighted Zerodur
Lifetime	5 years minimum, with possible extended lifetime.
Orbit	Low-earth, sun-synchronous, polar terminator, Dawn-Dusk orbit (circular, ~800 km, 98° inclination)
Operational modes	(1) wide field imaging in three channels simultaneously. (2) slit-less spectroscopy in UV and u channels, simultaneously (full field). (3) multi-slit, medium resolution UV spectroscopy in parallel field.
	wide-field imaging
Imaging field of view	0.44° x 0.56° = 0.25 deg^2
Image quality	FWHM = 0.15" in all channels
Detector pitch	10 um pixels (where 0.1" = 10 um).
Photometric channels	UV (150-300 nm), u (300-400 nm), g (400-550 nm).
Spacecraft orientation	Telescope is always pointed > 90° away from the sun. Long duration, continuous observing fields pointed in the anti-sun direction.
Data volumes	~200 GB/day with 10-min exposures in legacy survey mode
Downlink	High-speed optical downlink (~10 Gbps)
	Slit-less spectroscopy in UV and u imaging channels (single grism option)
Spectroscopic field	0.44° x 0.56° = 0.25 deg^2 [full imaging field of view]
Spectroscopic channels	1. UV (150-300 nm) 2. u (300-400 nm)
Resolving power	1. R~300 in UV channel, Δλ over 2 px, 1 px = 10 μm 2. R~420 in u channel, Δλ over 2 px, 1 px = 10 μm
Point Spread Function (PSF)	FWHM < 0.3" in both channels
	Multi-slit, UV spectroscopy in parallel field
Spectroscopic field	207" x 117".
Spectroscopic channels	UV (150-300 nm) at R=1000; or UV (180-300 nm) at R=2000.
DMD	TI 4K Ultra-HD DLP660TE DMD with 5.4 um pixels.
Spectrograph detector	10 um pixels (where 0.1" = 10 um).
Spectral dispersion	14 nm/mm at R=1000 with a 0.2" slit; or 7 nm/mm at R=2000 with a 0.2" slit
PSF in spatial direction	<0.30"
Spectral multiplexing	~600 maximum (i.e., 2 pixels height per spectrum, with 2 pixel gap between spectra)

detectors is currently being planned between JPL and NRC with the goal of raising the CASTOR devices to TRL-6.

The development of an optical communications link is considered a compelling technology for the CSA to develop for science missions and is currently considered part of the baseline mission development.

Another key technology for the multi-object spectrograph is the DMD. Work is underway for the Atlas Probe project that will bring these devices to TRL-6 (Wang et al. 2018).

2.2 Organization and Partnerships

The Canadian Science Maturation Study (SMS, pre Phase-A study) funded by CSA envisions CASTOR as a CSA lead project with major contributions from the Indian Space Agency (ISRO)

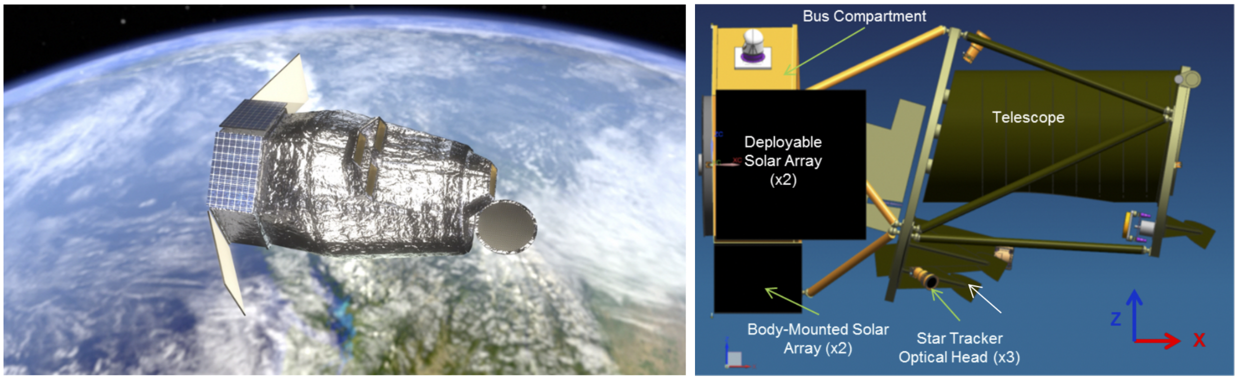

Figure 4: *(Left)* Visualization of CASTOR in its dawn-dusk, sun-synchronous, low Earth orbit (at an altitude of 800 km). *Right:* CASTOR spacecraft shown in its stowed position. The payload and bus package measures 4.4m in its longest dimension and has a total spacecraft mass of 1063 kg.

and the US via a mission of opportunity proposal. Under this partnership Canada would be responsible for development of the mission and operations when the mission launches. The Ottawa office of Honeywell carried out the technical and budgetary studies for the SMS and it is likely they would continue on for full development.

From the CSA side, it is clear that a major partnership is highly desirable in moving forward with committed mission funding and resources. It is expected that Canada will continue a leadership role in the mission but with considerable savings over the cost of the entire mission. As noted elsewhere, this requires a high ranking in the Canadian decadal LRP as well as direct approval by the federal government.

In response to an ISRO competition to develop concepts for an ‘Astrosat 2’ mission, the CASTOR team has worked with a team at the Indian Institute of Astrophysics (IIA) to propose a mission closely resembling CASTOR. This concept has received approval and funding through March 2020 for technical and design development. CSA and ISRO are current partners in the operating Astrosat mission, with many of the same personnel. ISRO expects that Canada and India will be major partners in a joint mission. The division of hardware and operational shares in this are currently under study as of this white paper. However, as it stands ISRO will provide the launch and has expressed interest in several of the major spacecraft components and the multi-object spectrograph instrument.

The US contribution is envisioned as a Mission of Opportunity (MoO) proposal. To date this has been a close and detailed cooperation between NRC of Canada and Caltech/JPL that is continuing with further plans to develop, test and characterize optimized detectors for CASTOR. The SMS envisions the US contributing three wide-field focal planes including flight electronics and software along with ground software development for the level 2 (detector de-trending) processing of the devices and a US science team. This contribution is at the right scale for the MOO cost cap based on a preliminary comparison of the CASTOR focal plane to other focal planes (such as the one for Kepler) along with ground software and science team costs for explorer missions (WISE, SPHEREx).

There is also significant interest among UK scientists, who are engaging with their relevant agencies (UKSA, STFC) to find an appropriate route to join the CASTOR mission. The UK team has been involved in the CASTOR SMS and discussions are continuing on what partnership may emerge (currently envisaged at the level of 10%).

2.3 Status and Schedule

The notional mission concept, which was first described in in the 2010 Long Range Plan (LRP) for Canadian Astronomy, was studied in detail in 2011–2012. A series of Space Technology Development Program (STDP) contracts were then sponsored by Canadian Space Agency (CSA) between 2013 and 2017; these STDP studies focused on critical mission components such as focal plane technologies, large format CMOS detectors with enhanced UV response, anti-reflection/filter optical coatings, pass band filtering options using broadband filters and dichroics, and end-to-end performance comparisons of optical designs. Following a positive review in 2016 from the Midterm Review of the Long Range Plan, a comprehensive science maturation study was carried out in 2018 and 2019. This study updated the mission science case and defined the primary mission survey, revised the mission architecture and technical design, and delivered improved estimates for cost and schedule. At the time of writing, the 2020 LRP is just underway, with final recommendations expected in the autumn of 2020.

If the project receives community endorsement in late 2020 and government approval in 2021, then a 12-month Phase A study (establishing system requirements) could begin as early as mid-2021. Phase B and C studies (i.e., preliminary and critical design reviews, respectively) would require 30 months and could be completed by early 2025. Fabrication, integration and testing (Phase D) could be completed in early 2027, followed by launch later that year. The 60-month Phase E (operations) would begin thus begin in 2027. This operational period would overlap with both LSST and WFIRST, and possibly the final years of the Euclid mission.

2.4 Cost Estimates

The original CASTOR mission concept was re-costed in April 2019 (FY2019 dollars) following the conclusion of the science maturation study and using latest mission design information. The costing exercise was carried out by in collaboration with the CSA and included payload and bus hardware, software development and system engineering, launch, assembly integration and testing, operations support, project management, science support (including data archiving, processing and distribution) and decommissioning, with a 20% contingency on appropriate components. The launch cost was not included in the estimate.

This costing exercise was done in the context of the Canadian funding system so it is not directly translatable to the US funding structure due to differences in how overheads and labor is treated. However, within the criteria defined by the decadal survey, the total mission cost is the small (<$500 million) range.

Links To Relevant Science White Papers (SWP)

Christiansen, J., "Understanding Exoplanet Atmospheres with UV Observations I: NUV and Blue/Optical"
Clarke, J., "Solar System Science with a Space-based UV Telescope"
Gordon, K.D., "Interstellar Dust Grains: Ultraviolet and Mid-IR Extinction Curves"
Heap, S., "Understanding Cosmic Evolution: The Role of UV Spectroscopic and Imaging Surveys"
Jean-Yves, C., "UV Exploration of the solar system"
Hagen, L., "Spatially Resolved Observations of the Ultraviolet Attenuation Curve"
Lisman, D. "Surveying the solar neighborhood for ozone in the UV at temperate rocky exoplanets"
Lopez, E.D., "Understanding Exoplanet Atmospheres with UV Observations II: The Far UV and Atmospheric Escape"
Martin, C., "IGM and CGM Emission Mapping: A New Window on Galaxy and Structure Formation"
Metzger, B., "Kilonovae: nUV/Optical/IR Counterparts of Neutron Star Binary Mergers with TSO"
Paladini, R., "On the Origin of the Initial Mass Function"
Reinhardt, C. T., "The remote detectability of Earth's biosphere through time and the importance of UV capability for characterizing habitable exoplanets"
Thilker, D. "The Nature of Low-Density Star Formation"
Tumlinson, J. "The Baryon Cycle, Resolved: A New Discovery Space for UV Spectroscopy"
Youngblood, A., "EUV influences on exoplanet atmospheric stability and evolution"

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