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Executive Summary of White Paper (5000 character limit)

CASTOR (The Cosmological Advanced Survey Telescope for Optical and UV Research) is a proposed Canadian-led flagship mission designed to provide high-resolution imaging and spectroscopy in the UV/blue-optical spectral region (0.15-0.55 microns). In the current design, the imager will cover a 0.25 sq. deg. field of view simultaneously in three bands, providing a hundred-fold improvement in survey speed over the legendary, but aging, Hubble Space Telescope (HST). In addition, a multi-object Digital Micro-Mirror (DMD) spectrograph, covering an adjacent field of view, will provide moderate- to high-resolution UV spectroscopy, while a wide-field, low-resolution spectroscopic capability will be provided by a grism. CASTOR's UV imaging and spectroscopic capabilities will enable a vast range of science in the post-HST era, including the physics of star formation from our galaxy to the distant universe, exploring the atmospheres of exoplanets, improving constraints on dark energy, and studying the properties of the outer solar system. CASTOR's data will far surpass any previous UV/blue-optical surveys in terms of sensitivity and angular resolution and will provide complementary capabilities to longer-wavelength data from the Euclid and WFIRST missions, as well as the ground-based LSST. CASTOR will be a strategic asset for Canadian astronomy in the coming decade, showcase the capabilities of Canadian aerospace companies on a global stage, and provide unprecedented opportunities for education and public outreach. A series of CSA-sponsored scientific and technical studies carried out during the past decade have advanced the mission concept to a mature state, and international partners are now waiting for a commitment by Canada.

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CASTOR: A Flagship Canadian Space Telescope

I. Background and Context

The 2010 Long Range Plan identified the top priority for Canadian space astronomy as “significant involvement in the next generation of dark energy missions — ESA’s Euclid, or the NASA WFIRST mission, or a Canadian-led mission, the *Canadian Space Telescope*”. Despite considerable effort, and Canada’s long-term leadership role in wide-field and high-resolution imaging, Canada was unable to negotiate either a hardware or software contribution to Euclid; in the end, very limited involvement ($\sim$ 20 people) was obtained through the contribution of CFHT data to Euclid’s ground segment. Similarly, a protracted series of hardware studies and partnership negotiations failed to produce any Canadian involvement in the WFIRST mission. Ten years on, LPR2010’s highest recommendation for space astronomy remains unfulfilled.

However, since 2011, a consortium of Canadian scientists and engineers based in industry, academia and government has developed a compelling design for a Canada-led mission, CASTOR, that would fulfill the LRP2010 recommendation and revitalize Canada’s flagging space astronomy sector. A series of Canadian Space Agency (CSA) studies during the past decade have advanced this mission concept to a mature state and attracted the attention of prospective international partners. *A strong, final endorsement by the community through the LRP2020 process is now needed to seek approval and funding from the Government of Canada, secure the participation of international partners, and move aggressively towards a launch in the 2026–2027 time frame.*

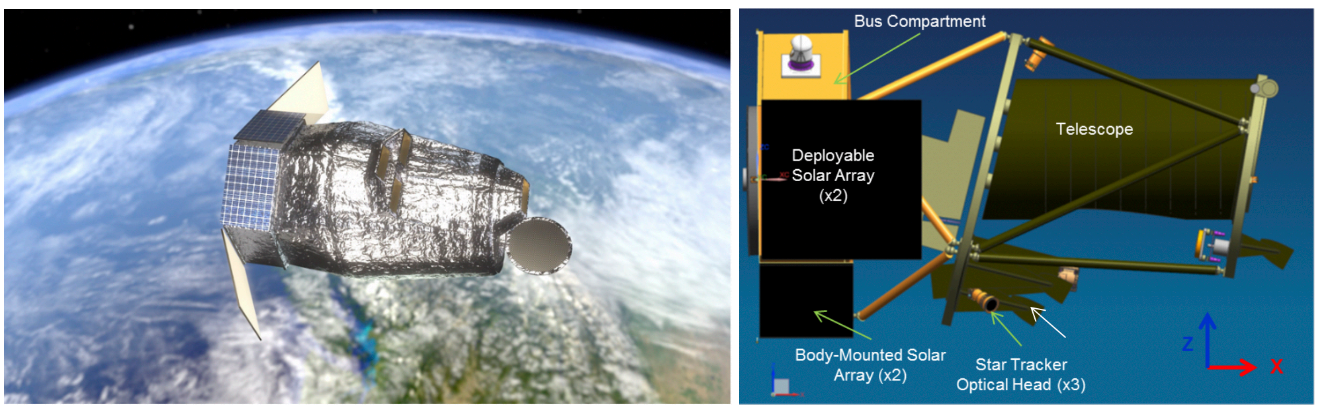

Figure 1: *(Left)* Visualization of CASTOR in its sun-synchronous, low Earth orbit (altitude $\simeq$ 800 km). *(Right)* The CASTOR spacecraft in its stowed position. The payload and bus package measures 4.4m along its longest dimension and has a total spacecraft mass of 1150 kg — suitable for launch in a Polar Satellite Launch Vehicle (PSLV).

II. Technical Design and Mission Architecture

The current CASTOR design was established during the recent CSA-sponsored Science Maturation Study (SMS; Côté et al. 2019, in preparation), and was driven by a fresh consideration of scientific opportunities in the coming decade. A visualization of CASTOR in orbit, and an illustration of the spacecraft in its stowed configuration, are shown in Figure 1.

The 1m-diameter (off-axis and unobscured) CASTOR telescope uses a Three Mirror Anastigmat (TMA) design to deliver Hubble-quality images (FWHM $\approx 0.15''$) over an instantaneous 0.25 deg^2 field of view. High-efficiency beamsplitters and state-of-the-art multi-layer coatings are used to define the photometric passbands — UV (0.15–0.30μm), u$'$ (0.30–0.40μm) and g (0.40–0.55μm) — and deliver images to three focal plane arrays, simultaneously (see Figure 2). Thanks to its combination of sensitivity, field of view and image quality, CASTOR will exceed the legendary (but aging) Hubble Space Telescope in “discovery efficiency” by roughly *two orders of magnitude*. The extraordinary power of CASTOR lies in its three, 320-megapixel cameras and state-of-the-art detectors: i.e., large-format, back-illuminated CMOS arrays that achieve unprecedented sensitivity at these wavelengths thanks to JPL’s customized “delta-doping” process. Lightweighted Zerodur optics, integrated into a low-CTE carbon fibre

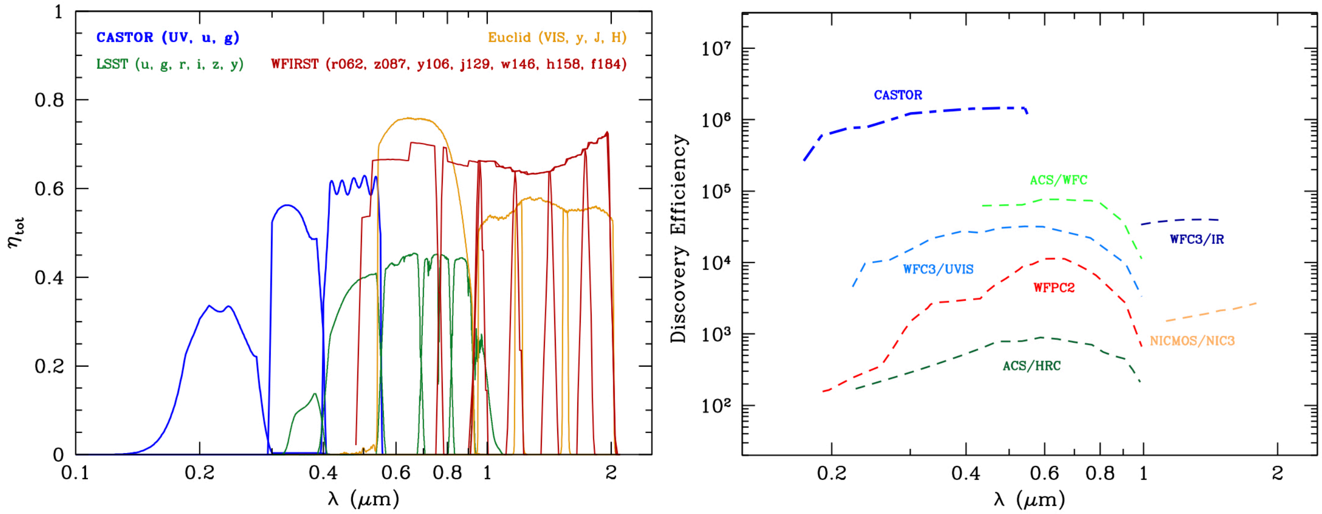

Figure 2: *(Left)* Passbands for CASTOR, shown in blue, compared to those of Euclid (orange), WFIRST (red) and LSST (green), illustrating CASTOR's uniqueness and synergy with these next generation imaging facilities. *(Right)* Discovery efficiency of CASTOR compared to UVOIR imaging instruments on HST 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.

reinforced polymer truss structure with an active M2 fine adjustment mechanism, ensure sharp and stable images at comparatively low mass and low cost.

In addition to its (baseline) wide-field imaging capability, a multi-object Digital Micro-Mirror (DMD) spectrograph covering an adjacent field could provide moderate to high-resolution (R=1000–2000) UV spectroscopy while a grism mechanism could provide full-field, low-resolution (R=300–420) spectroscopy in the UV and u′ channels. A single detector placed in each of CASTOR's focal planes, with transmissive diffuser plates located in converging space above the detectors, would allow *ppm* photometric monitoring of bright exoplanet hosts.

Baselined to a minimum five-year lifetime, the spacecraft would operate in a low-earth, sun-synchronous, dawn-dusk orbit, at an altitude of 800 km. In this orbit, the Sun would be continuously visible on three solar panels, providing spacecraft power, as the telescope points in the anti-Sun direction. Over the course of a year, CASTOR would have access to every region of the sky. Producing an average of $\sim$ 200 GBytes of data per day, a 10-Gbps optical downlink would be used for data transmission. The spacecraft uses Magellan's MAC-200 small-SAT bus, and weighs in at a modest 1150 kg — suitable in mass and volume for launch in an Indian PSLV vehicle.

III. Scientific Goals and Objectives

The recent SMS has updated and refined the science drivers for CASTOR, identifying a wide range of timely and exciting science programs. Designed to operate as both a survey and a guest observer (GO) facility, CASTOR has the flexibility to make transformational advances across a wide ranges of fields.[1] A 1.8-year "primary survey" has been identified as a potentially transformational contribution to astrophysics. This survey — covering the $\sim$7700 deg^2 region defined by the overlap of the LSST, Euclid and WFIRST footprints — would reach the unprecedented depth of $m_{\rm AB} \sim 27.2$, providing the "widest, deepest and sharpest" view of the Universe at UV and blue-optical wavelengths (see Figure 3). Below, we briefly summarize the broad research potential of this mission.

a) Cosmology and Dark Energy. The discovery of dark energy was a milestone event in modern cosmology, and prompted the development of several major facilities that will begin operations in the 2020s: e.g., Euclid, LSST and WFIRST. Such "Stage IV" dark energy experiments seek to combine wide-field, high spatial resolution, broad wavelength coverage, and high cadence to explore the nature of dark energy. In practice, however, no single experiment satisfies all of these criteria, and CASTOR would play an important role in this landscape

[1]The SMS recommended $\sim$30% of the observing time be reserved for GO programs, to ensure access for all members of the community.

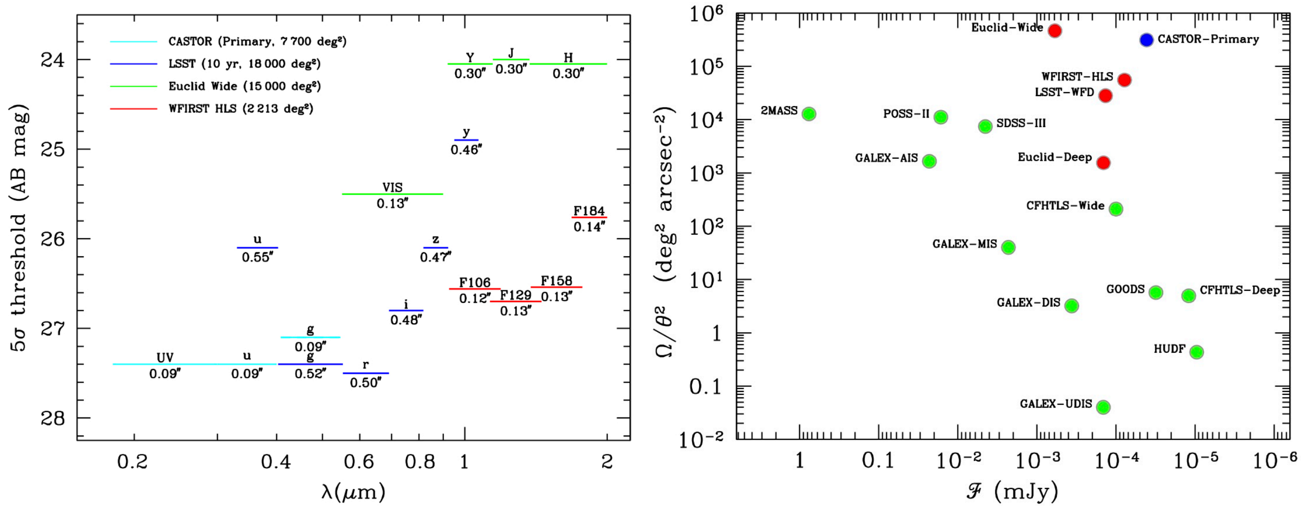

Figure 3: *(Left)* Depth of wide-field UVOIR imaging surveys plotted as a function of wavelength. Results are shown for LSST, Euclid-Wide, WFIRST-HLS and CASTOR. For CASTOR, we show preliminary results for a primary science survey that covers the 7687 deg^2 region defined by the overlap between the LSST and the Euclid-Wide surveys. The labels under each filter indicate the approximate image quality (i.e., EE50 radius) for each survey. *(Right)* "Information content" for wide-field, imaging surveys in the UVOIR spectral region. Information content in this diagram increases diagonally toward the upper right corner. CASTOR's Primary Science Survey (shown in blue) would be uniquely powerful among past (green) and planned (red) imaging surveys, combining depth, areal coverage and angular resolution.

by adding wide-field and high-resolution imaging in the UV/blue-optical region (currently a "missing capability" for the 2020s). Within this landscape, CASTOR will make several critical contributions to cosmology. It will significantly lessen the technical and systematic risks in Stage IV experiments by providing photometric stability, homogeneity, and high-resolution imaging at UV/blue-optical wavelengths. This expanded SED coverage will greatly improve the precision of photometric redshifts, provide independent weak lensing shape measurements, mitigate the risks of PSF chromaticity, and directly measure colour gradients in galaxies (currently a key source of systematic error in planned weak lensing measurements). The importance of this latter 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 dark energy with weak lensing to an accuracy comparable to the WFIRST mission, thus significantly boosting the level of redundancy among independent dark energy probes.

b) Time Domain and Multi-Messenger Astronomy. With the detection of gravitational waves by LIGO/Virgo in 2015, and the identification of the first electromagnetic counterpart to a gravitational wave source in 2017, multi-messenger astronomy is poised to become a major focus of research in the next decade. UV emission from these transients is particularly valuable for understanding the properties of the explosions (i.e., energetics, progenitor masses, and nucleosynthetic yields) and is predicted to be both prompt and rapidly evolving (i.e., observable only during the first ~ 1 week; Figure 5). The need for rapid localization and follow-up of counterparts is thus clear, and a number of small UV satellites designed to localize transients are currently under consideration by international space agencies. Within this landscape, CASTOR will be unique in having unrivalled UV sensitivity and angular resolution, and thus complementary to any small, rapid-response mission. Indeed, during the post-HST era, CASTOR will be the only facility capable of following the early UV/blue-optical variations to ultra-low levels, and though CASTOR's design has been optimized for wide-field surveys, it will also be possible to mount an unprecedented, multi-band photometric and spectroscopic monitoring program for multi-messenger events. Furthermore, CASTOR will boast powerful time-domain synergies with LSST thanks to its unique UV capabilities, angular resolution, and superior point-source sensitivity. One obvious legacy survey would be a wide-field, time domain UV survey (probing $>$ five times the volume of any previous UV survey) that focuses on high-cadence monitoring of LSST deep drilling fields.

c) AGN and Supermassive Black Holes. Because accretion disk power peaks in the UV, AGN spectra have dominant features at the short wavelengths that CASTOR is sensitive to: e.g., Lyman alpha in emission and absorption, plus broad and narrow emission lines of NV, SiIV, CIV, HeII, CIII, MgII, [OII]. With an ambitious reverberation mapping campaign, combining multi-band imaging and low-resolution slit-less UV spectroscopy, CASTOR will yield masses for thousands of supermassive black hole — ten times more than all previous AGN studies — over an unprecedented redshift range ($0.0 \lesssim z \lesssim 2.5$). CASTOR's Primary Survey will also detect AGN at the centers of galaxies and resolve the associated star formation, the surrounding ionized gas, and the AGN jets. This will be possible for huge 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 origin is 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. Finally, in the local universe, the relationship between nuclear star clusters and supermassive black holes in low- and intermediate-mass galaxies has emerged as an important question for galaxy evolution and feedback models, and CASTOR's UV imaging and spectroscopy will play a critical role in this area.

d) Galaxies and Star Formation. Star formation drives the evolution of baryonic matter in our universe and serves as the primary regulator of galaxy evolution. The evolution of star formation rate, as a function of environment and over cosmic timescales, is central to our understanding of the physical mechanisms that drive, regulate and quench the evolution of galaxies. Previous studies established that star formation processes are, on average, remarkably synchronized on Gpc scales over the entire universe, and on parsec scales within individual, nearby galaxies. Yet, mysteriously, the specifics of this star formation vary widely, from galaxy to galaxy. It is suspected that these differences are driven by interactions between galaxies and their dark matter halos, but we have little quantitative evidence to support this picture as no existing dataset brings together the essential measurements. What is required is a star formation physics "ladder" that links the parsec-scale physics in local galaxies to the much larger scales observable in galaxies at earlier cosmic epochs. In addition, this ladder must be linked to the underlying dark matter structure (derived from, e.g., weak lensing measurements) that we believe governs the evolution of cosmic structure. Because UV light is our primary probe of star formation, such an ambitious program requires a wide-field, high-resolution UV telescope.[2] With a discovery efficiency that is $\sim 100\times$ greater than HST, CASTOR will open a new era in the study of cosmic star formation (see Figure 4). CASTOR is uniquely positioned to address this fundamental question because existing facilities, such as HST, lack survey speed, while past facilities (e.g., GALEX, Herschel, or Spitzer) lacked spatial resolution. Future facilities such as LSST, Euclid, and WFIRST are optimized for cosmology questions better conducted at near-IR wavelengths and thus do not cover the UV or FIR wavelengths needed to probe star formation.

e) Near-Field Cosmology. The numbers and properties of low-mass stellar substructures in the Local Universe (such as ultra-faint galaxies and stellar streams in galactic halos) can provide powerful tests of cosmological models on small spatial scales (i.e., $\lesssim 1$ Mpc). CASTOR will excel in the identification and study of such substructures thanks to its combination of HST-like image quality, wide field of view, and superb point-source sensitivity. At ultra-faint magnitudes — a domain where confusion from faint galaxies can be severe — CASTOR will outperform all ground-based telescopes in star-galaxy separation. It will map density fluctuations along stellar streams, making it possible to measure both the gravitational potential of the Milky Way and the number of low-mass, dark matter perturbers. UV/blue-optical photometry from CASTOR will greatly expand the SED coverage possible with Euclid and WFIRST, providing much-improved age and metallicity sensitivity, and allowing astronomers to measure the spatial and chemical structure of the Galaxy through photometric parallaxes, characterize multiple populations in Galactic substructures, 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 beyond the reach of Gaia would be used to measure the space velocities and internal motions of satellites which, when complemented by ground-based spectroscopy, can be used to measure the dark matter power spectrum, and/or test modified theories of gravity.

[2]We can also observe UV light that has been absorbed by dust and gas and re-emitted as far-infrared light and/or emission lines such as Hα. In practice, direct UV observations provide the best combination of spatial resolution and sensitivity with current technology.

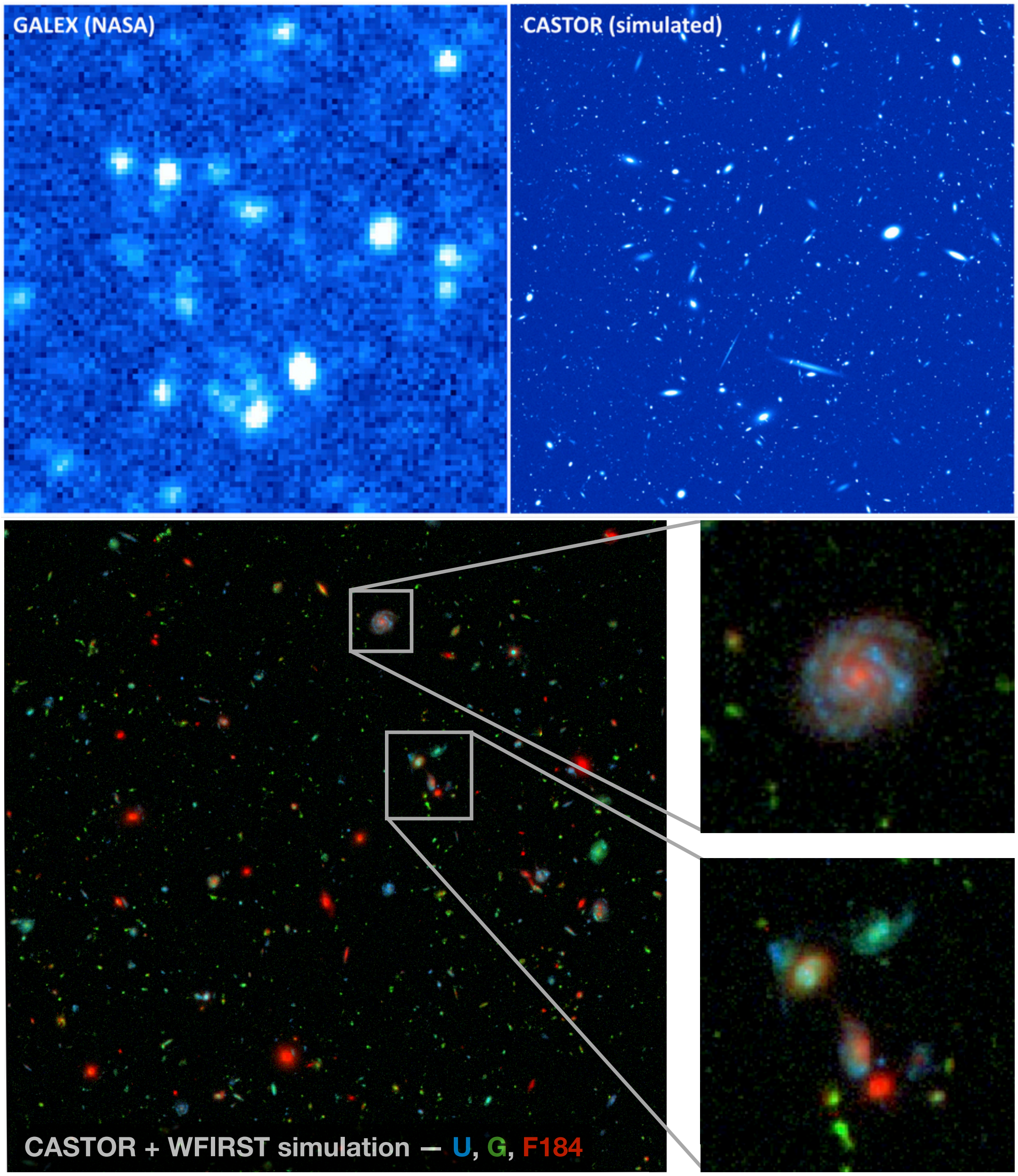

Figure 4: CASTOR will produce an ultra-deep, sharp, and wide-field view of the universe in ultraviolet light, allowing for studies of star formation in our Galaxy and in distant galaxies over cosmic timescales. *(Top left)* A region of the COSMOS survey field as observed by the GALEX satellite. *(Top right)* The same region in a deep (100-hr) simulated observation with CASTOR. *(Bottom panels)* Simulated CASTOR+WFIRST image based on spatially-resolved galaxies in the Hubble XDF: 100 hrs with CASTOR in U (blue) and G (green), and 10 hrs with WFIRST in F184 (red).

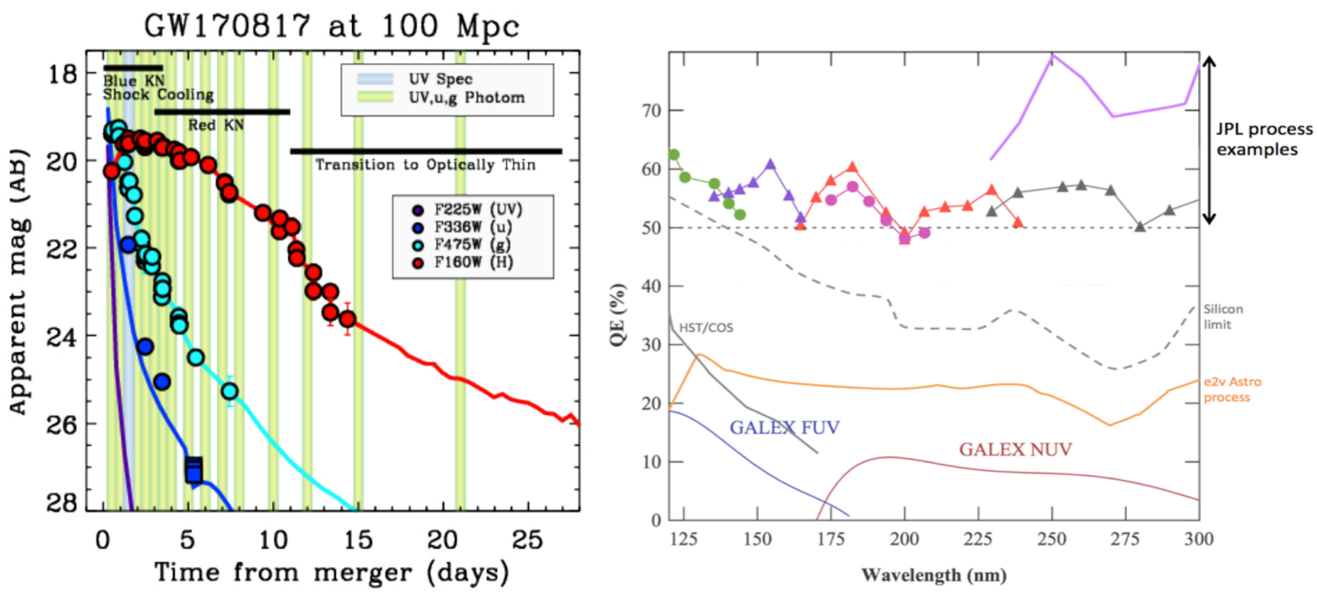

Figure 5: *(Left)* Nominal early phase observing strategy for a CASTOR legacy survey of multi-messenger events, illustrated using models for GW170817 shifted to a distance of 100 Mpc. The shaded vertical lines represent the timing and type of observations for our fiducial observing strategy during the first 3 weeks post-merger.. *Right:* Quantum efficiency (QE) as a function of wavelength for various detector options. JPL delta-doped silicon detectors are shown above the 50% mark with each color corresponding to different anti-reflective (AR) coatings. The dashed grey line shows the bare silicon limit, i.e. the maximum possible QE for any Si device without AR coating. The e2v Astro process was used on HST/WFC3, which requires periodic ”flashing” to mitigate unstable QE. For reference, we also show QE curves for GALEX and the HST Cosmic Origins Spectrograph, which used microchannel plates. The expected performance of CASTOR is 5-7 times that of GALEX with 60 times the spatial resolution.

f) Stellar Astrophysics. The UV holds a special significance for stellar astronomy. This region — observable only from space — is highly sensitive to hot continuum sources (such as high mass stars that are disproportionately responsible for most element synthesis, ionization, dissociation, and kinetic energy input to galaxies), and contains an abundance of atomic and molecular spectral features, including numerous resonance transitions. The UV continuum is highly sensitive to the integrated light of young stellar populations, making it a powerful diagnostic of star formation on timescales of $10^{7.5}$–$10^{8.5}$ yr. CASTOR, with its wide field and excellent image quality, will open a new era in the study of 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. CASTOR will, in particular, reveal Galactic white dwarfs in profusion, including the rare and almost entirely unexplored population of halo white dwarfs. UV/blue-optical data from CASTOR will also 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 both Euclid and WFIRST will be severely limited in their ability to measure ages and abundances for resolved stellar populations due to their restricted wavelength coverage, and LSST will be of little use in this context since crowding effects will be prohibitive in ground-based imaging.

g) Exoplanets. Understanding the internal structure and atmospheric properties of extra-solar planets will be a top priority for astrophysical research in the coming decade. UV/blue-optical observations will be critical for progress in this area, as this spectral region provides a unique window into the structure and composition of planetary atmospheres via Rayleigh scattering and molecular absorption: i.e., photometric monitoring can reveal the presence of both hazes (which are, in turn, the result of photo-chemical reactions related to the formation of clouds) and ozone produced by lighting. UV phase curves contain information on scattering from 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. Using optimized detectors in each of its three focal planes (and an optical design that de-focuses the light from bright targets in order to achieve the highest possible photometric precision), CASTOR will use transit spectroscopy and scattering angle measurements to probe the composition of exoplanet atmospheres, and to search for possible Earth analogues. Additionally, in its wide-field imaging mode, transit surveys in the UV, u, and g bands targeting dense star fields (i.e., bulge fields or star clusters) would provide a window into the number and properties of exoplanets in new or underexplored environments and metallicity regimes.

h) Solar System. Small bodies in the outer solar system hold clues to the formation of the Sun and its planets. Their observed properties help put our solar system into the broader context of protoplanetary systems and debris disks observed around other stars. In the coming decade, CASTOR will play an important role in exploring the outer fringes of our solar system, complementing and extending the work of LSST while opening new regions of discovery space. Thanks to its nearly diffraction-limit image quality, CASTOR's point-source sensitivity far surpasses that of LSST: i.e., a 45-minute exposure with CASTOR reaches $g \sim 27.5$, nearly a half magnitude deeper than the 10-year depth of LSST, and a full 2.5 mags deeper than LSST's single-visit depth. This exceptional sensitivity — combined with high angular resolution and UV/blue-optical response — makes CASTOR a powerful tool for finding and studying small bodies in the solar system, and addressing key open questions in this field. A deep, multi-epoch survey of selected regions along the ecliptic plane will produce a state-of-the-art census for small bodies in the outer solar, including low-mass and/or very distant objects beyond the reach of LSST. Pointed observations for hundreds of Kuiper Belt binaries will allow a full characterization of their orbits, providing constraints on the past dynamical evolution of the population. As a byproduct of CASTOR's Primary Survey, u' and g photometry for thousands of Kuiper Belt objects with red-optical fluxes from LSST will open a window into the mineralization properties and surface chemistries of these remote objects.

IV. Organization and Partnerships

Although conceived and developed as a CSA-led project, international contributions are highly valued as they strengthen Canada's international ties, bring additional scientific and technical expertise to the project, and reduce the cost to Canada, making it possible to consider a mission of greater scope. A detailed costing analysis has been delivered to CSA as part of the recent SMS, demonstrating that this MIDEX-scale mission could be undertaken by Canada in a leadership role for roughly the same level of investment as Canada's contribution to JWST. A number of possible CASTOR partnerships and collaborations are taking shape, which we now summarize.

India/ISRO. In the current development plan, ISRO (Indian Space Research Organization) is identified as providing a PSLV launch and has expressed interest in several of the major spacecraft components, including the DMD spectrograph. However, it must be noted that, in response to a recent ISRO competition to develop concepts for a new astronomy satellite, the CASTOR team has worked with a group at the Indian Institute of Astrophysics (IIA) who are proposing a mission (INSIST) that closely, and intentionally, resembles CASTOR. This concept has received approval and funding from ISRO through March 2020 for technical and design development, and while ISRO expects that Canada and India will be major partners in a joint mission, the division of hardware and operational shares are not yet defined. Note that CSA and ISRO are current partners in the operating Astrosat mission, with many of the same personnel and a strong heritage in UV astronomy.

JPL/Caltech/NASA. JPL and Caltech have contributed substantially to the current mission concept and science plan. A JPL/Caltech-led US contribution is envisioned as a NASA Mission of Opportunity (MO) proposal that capitalizes on JPL's world-leading capabilities in UV/optical detector technologies.[3] CASTOR's wide, high-resolution UV imaging will be enabled by mosaics of CMOS detectors, totaling about 960 megapixels. JPL's delta-doping and integrated filter processes can enhance the UV sensitivity of these silicon devices by boosting quantum efficiency (QE) in UV bands while suppressing it at longer wavelengths. This not only increases the signal-to-noise in UV exposures, it also improves image quality (PSF) by eliminating the need for standalone (glass) infrared blocking

[3] An Astro2020 white paper — "*Surveying the Solar Neighborhood for Ozone in the UV at Temperate Rocky Exoplanets*" from a JPL team — shows how CASTOR could be further leveraged to image exoplanets and search rocky planet atmospheres for the potential biosignature gas Ozone (Lisman et al 2019). This would require operating CASTOR at Earth-Sun-L2 in formation with a separate starshade spacecraft used to suppress starlight. These authors recommendeded further study of a joint NASA mission, whereby NASA notionally provides the starshade spacecraft and co-launches it with CASTOR.

filters in the optical design. Figure 5 shows examples of QE performance achieved by JPL's process as compared to other options. With detectors customized for its bands, CASTOR could achieve UV sensitivities similar to Hubble WFC3 (and reaching shorter wavelengths) despite its much smaller 1m primary mirror. Note that the "leading alternative" – the e2V Astro process – was used on WFC3, which exhibits unstable QE and requires periodic "flashing" to restore nominal operation.[4] By contrast, JPL-processed detectors have stable QE. Preliminary estimates based on the JPL-produced Kepler focal plane indicate that the CASTOR focal planes would fit within a NASA MO budget. The next opportunity to propose for MOs is anticipated in 2021, and happens every 2-3 years, so *it is imperative that CSA commits to CASTOR by mid-2020 for a NASA contribution to this CSA-led mission.*

Other Partners. There is significant community interest in joining the CASTOR mission within the UK, whose government and space agency have a renewed interest in bilateral ventures with Canada (and India). A UK team was involved in the CASTOR SMS and discussions are ongoing on possible partnerships. Contributions could take the form of detectors, opto-mechanics, electronics, thermal analysis, data processing and archiving, performance simulation software, stray light analysis, radiation environment, qualification and shielding, instrument calibration or ground segment support. There is also interest from Laboratoire d'Astrophysique de Marseille (LAM) in both scientific and hardware contributions, with the latter likely centred on DMD and/or grism spectroscopy, where significant LAM expertise exists (e.g., GALEX, BATMAN). At the time of writing, Japan is also exploring possible scientific and/or hardware contributions to the mission.

V. Status and Schedule

If CASTOR receives a strong community endorsement through the LRP2020, followed by 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 thus begin in 2027. This operational period would overlap with both LSST and WFIRST, and possibly the final years of the Euclid and JWST missions. *To secure the participation of key international partners (e.g., ISRO, and NASA through its MO framework), a strong LRP endorsement by mid-2020 is absolutely essential.*

VI. CASTOR and Canada's Space Plan

In its *Space Policy Framework* (2014) and *Canadian Space Strategy* (2019), the Government of Canada has established the framework for future endeavours in space. CASTOR aligns perfectly with these principles and priorities. As a flagship mission with unparalleled public visibility, it would be a cornerstone in a balanced space portfolio, inspire Canadians of all ages, and help to "reverse the decline in Canada's space capacity before it is too late". CASTOR has been a centrepiece in the Coalition for Canadian Astronomy's lobbying activities and has already gained good traction with the general public via a Twitter account, a very successful logo competition open to all Canadians and inclusion in public outreach talks. The realisation of CASTOR would be an unparalleled opportunity for astronomy EPO in Canada and surely become a landmark in Canada's astronomy heritage. As the 2010 LRP stated, Canada has "reached the point that we could now lead a large space astronomy mission" and leadership on CASTOR would bolster ties with some of our most important international partners.

Moreover, CASTOR would "strengthen excellence in key capabilities" and "position the private sector at the forefront of space activities". It would showcase Canada's aerospace and engineering capabilities to a global audience and advance transformative technologies with vast export potential in high-tech markets that are poised to grow ten-fold in the coming decades. These technologies include low-cost and lightweight optical components, high-speed laser links, state-of-the-art optical communications hardware, massive data processing and archiving capabilities, and spacecraft bus platforms and subsystems. Potential commercial applications could include optical sensing, high-speed communications, precision agriculture, disaster monitoring, and high-resolution Earth observations. In addition, CASTOR has been specifically designed for implementation on the Canadian (Magellan) MAC-200 small-Sat spacecraft bus, thereby securing a long-term national strategic capability to design, build, and operate satellites that was established with the launch of Alouette 1 in 1962.

[4]Astro process QE data is provided by e2v.

VII. A Strategic Contribution to International Astronomy:

CASTOR has been designed to provide critical "missing" capabilities that will be needed by the international astronomical community in the 2020s and 2030s: i.e., access to the UV region, high blue sensitivity and observing efficiency, and superb angular resolution over a large instantaneous field of view. It would thus be a *strategic Canadian asset* that might be used to negotiate access to upcoming projects (LSST, WFIRST, etc) in exchange for international involvement in CASTOR.

1: How does the proposed initiative result in fundamental or transformational advances in our understanding of the Universe?

With its hundred-fold improvement in discovery efficiency over HST, CASTOR would be the world's preeminent wide-field telescope at UV/blue-optical wavelengths. As such, it will have a *transformational impact* in Canadian and international astrophysics, from cosmology to exoplanets. See §III.

2: What are the main scientific risks and how will they be mitigated?

Given the very diverse science drivers, these must be assessed on a case-by-case basis. However, in a general sense, CASTOR's uniqueness as a wide-field, UV/blue-optical space telescope mitigates scientific risk. See §III.

3: Is there the expectation of and capacity for Canadian scientific, technical or strategic leadership?

Beginning with the initial LRP2010 recommendation that Canadian astronomers "should explore the possibility of a Canadian-led UV/optical wide-field imaging satellite as a complement to Euclid/WFIRST", CASTOR has been *specifically* developed as a strategic contribution by Canada to international astronomy in the 2020s and a vehicle for scientific and industrial leadership on a global stage. See §I, §III, §VII.

4: Is there support from, involvement from, and coordination within the relevant Canadian community and more broadly?

It is a *sine qua non* condition that a mission like CASTOR must appeal to a broad segment of the Canadian astronomical community. The latest CSA study was carried out by a team of $\sim$100 scientists, 72 of whom are based at Canadian universities and institutes. The industrial effort is being spearheaded by Honeywell Aerospace, ABB Inc. and Magellan Aerospace — three of Canada's most capable and internationally respected aerospace companies — but would ultimately involve dozens of Canadian sub-contractors, geographically distributed from coast to coast. See §VI.

5: Will this program position Canadian astronomy for future opportunities and returns in 2020-2030 or beyond 2030?

CASTOR would revitalize key Canadian aerospace companies, which have been under severe threat for more than a decade, and instantly re-establish Canadian leadership in space sciences and wide-field/UVOIR astronomy. As the world's premier UV/blue-optical telescope in the 2020s, and a pathfinder opportunity for technologies needed for future (i.e., post-2030) flagship missions (HabEx, LUVOIR, Starshade), CASTOR would open many scientific and technical opportunities for Canada over the next two decades. See §III, §VI, §VII.

6: In what ways is the cost-benefit ratio, including existing investments & future operating costs, favourable?

By focusing on high-resolution imaging in the UV/blue-optical bands, CASTOR would fill a critical "missing capability" within the international portfolio of astronomy facilities in the 2020s; at the same time, it would build on past Canadian investments in this area: e.g., CFHT, Astrosat, Dragonfly, SuperBIT. It would also leverage past investments that have helped establish unique Canadian aerospace capabilities, such as fine guidance systems, high-speed optical satellite communications and the MAC-200 small-SAT bus. For an investment comparable to Canada's contributions to JWST, CASTOR would help Canada and its aerospace companies make key contributions to future NASA flagship missions (e.g., HabEx, LUVOIR). See §VI.

7: What are the main programmatic risks and how will they be mitigated?

As a CSA-led mission, the key programmatic risk facing CASTOR is *the uncertain development path within Canada*. As is well known, there is no predictable and well-defined process for selecting and maintaining a portfolio of CSA missions. This presents a challenge to the leadership role that Canada must play to secure the backing of international partners, whose interest in the mission is high but will soon need a clear commitment from Canada (i.e., no later than $\sim$ mid-2020 for both JPL/NASA and IIA/ISRO). If a committment is not forthcoming by this time, then it is conceivable these agencies will move forward without Canada. See §IV.

8: Does the proposed initiative offer specific tangible benefits to Canadians, including but not limited to interdisciplinary research, industry opportunities, HQP training, EDI, outreach or education?

As the world's preeminent UV/blue-optical imaging telescope, CASTOR would combine the wide-field and high-resolution elements of HST and CFHT imaging that have been so effective in capturing the imagination of the public. It would open countless opportunities for HQP training, education and public outreach, while showcasing Canadian industrial technologies with high export potential. See §VI,VII.