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Executive Summary of White Paper (5000 character limit)

Euclid is an ESA-led medium class space mission selected in October 2011, with launch planned for 2022. The Euclid mission aims at understanding why the expansion of the Universe is accelerating and what is the nature of the source - commonly called dark energy - responsible for this acceleration. Dark energy represents around 75% of the energy content of the Universe today, and together with dark matter it dominates the Universe's matter-energy content. Understanding dark energy is one of the key goals of physics over the next decade. The imprints of dark energy and gravity will be tracked by Euclid using two complementary cosmological probes to capture signatures of the expansion rate of the Universe and the growth of cosmic structures: weak gravitational lensing; and galaxy clustering (both through baryonic acoustic oscillations and redshift-space distortions).

Although low-redshift cosmology is the primary driver of the mission, a wide range of science will be possible with the Euclid data. The Euclid Mission aims to survey over 15,000 deg^2 of the extragalactic sky with imaging in a wide visible (riz) band at 0.1" resolution, near-infrared photometry (Y, J, and H) and near-infrared spectroscopy. As a result, the Euclid Mission will generate a vast data set for legacy science, including broadband visible images and near-infrared photometry of roughly 1.5 billion galaxies and near-infrared spectroscopy of roughly 25 million galaxies. Such a large data set will touch on many aspects of astrophysics, on many different scales, from the formation and evolution of galaxies down to the detection of brown dwarfs.

In 2016, Canada joined the Euclid Consortium when CFHT approved the Canada-France Imaging Survey (CFIS) as a Large Program. CFIS, along with other ground-based surveys, will be used by Euclid to measure photometric redshifts in the northern sky. 27 faculty-level astronomers in Canada are members of the Euclid Consortium. In this white paper, we present a status update for Euclid, and a request that the committee make a strong recommendation that funds be allocated to support the exploitation of the Euclid data by Canadian researchers.

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1 Introduction to Dark Energy

The accelerating expansion of the Universe, first realised 20 years ago, has been confirmed by numerous observations. It is the primary driver of the dynamical evolution of the Universe in the present epoch. That we do not know the nature of this so-called dark energy is one of the most important puzzles in modern fundamental physics. Although the behaviour, as tested to date, matches Einstein's cosmological constant (Λ), it is a factor of 10^{120} smaller than the "natural" quantum vacuum energy density, suggesting that unknown physics, commonly known as dark energy, lies at the heart of the acceleration. Possible explanations include a new scalar field with an effective negative pressure, modifications of general relativity (GR) such as scalar-tensor theories or $f(R)$ theories, or the acceleration could be the signature of extra dimensions, as proposed in the brane-world picture. Observational cosmology is becoming the foremost way of exploring fundamental physics beyond the standard model, and physicists and astronomers are convinced that pinning down the nature of this mysterious component of the Universe will lead to a revolution in physics.

Many types of cosmological measurement are possible, with different observables being sensitive to different physics. Consequently, having multiple measurements is extremely beneficial. Type 1a supernovae and baryon acoustic oscillations (BAOs) are very good probes of the expansion rate, for instance, while gravitational lensing and the peculiar velocities of galaxies (as revealed by their redshifts) are very good probes of gravity and the growth rate of structures. It is only by combining several complementary probes that the source of the acceleration of the Universe can be understood.

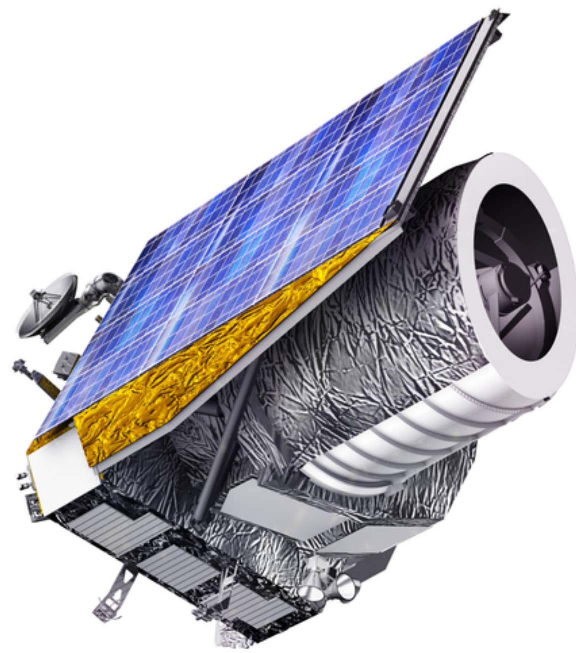

Figure 1: An artist's view based on industry drawings of the *Euclid* spacecraft showing the large sunshield covered by solar cells and the telescope baffle on the payload module containing the cold parts of the instruments. Also visible is the K-band antenna to transmit the large amount of data from the second Earth–Sun Lagrangian point, located 1.5 million kilometres from Earth. The spacecraft measures approximately 4.5 m tall and will have a launch mass of around 2100 kg. (Image credit: ESA/C Carreau.)

2 The Euclid Mission

Euclid is a space-based mission, under development led by the European Space Agency (ESA), to which Canada is making a significant contribution. It is a medium-class mission, selected by ESA in October 2011 as the first-priority cosmology mission of the next decade. The spacecraft (shown in Fig. 1) comprises a service module supporting the telescope and instruments, which form the payload. Details are given in Laureijs et al. (2011); Racca et al. (2016). *Euclid* will be equipped with a 1.2-m diameter Silicon Carbide (SiC) mirror telescope made by Airbus (Defence and Space), feeding two instruments, VIS and NISP, built by the Euclid Consortium: a high quality panoramic visible imager (VIS), a near infrared 3-filter (Y, J, and H) photometer (NISP-P) and a slitless spectrograph (NISP-S). The satellite will be launched by a Soyuz ST-2.1B rocket and then travel to the L2 Sun-Earth Lagrangian point for a 6-year mission.

Euclid will be launched at the end of 2022 and will observe 15,000 deg^2 of the darkest sky that is free of contamination by light from our Galaxy and our Solar System. Three "Euclid Deep Fields" covering around 40 deg^2 in total will be also observed, extending the scientific scope of the mission to the high-redshift Universe.

The mission is designed to allow low-redshift cosmological measurements: sets of galaxies selected from these data will be used to measure the behaviour of the low redshift Universe using multiple cosmological probes, each utilising a different physical mechanism by which dark energy affects the Universe.

The complete survey represents hundreds of thousands of images and several tens of Petabytes of data. *Euclid*'s combination of very wide area and very high spatial resolution is unique: it will yield a single-band image of the sky with the greatest number of pixels ever observed. About 10 billion sources will be observed by *Euclid* out of which more than 1 billion will be used for weak lensing and several tens of million galaxy redshifts will be also measured and used for galaxy clustering. The scientific analysis and interpretation of these data are led by the scientists of the Euclid Consortium. Although low-redshift cosmology is the primary driver of the mission, a wide range of science will be possible with the *Euclid* data: undertaken both by members of the Euclid Consortium and by other scientists using the data when they are made public.

In order to meet the primary science goals of the mission, the dark-matter distribution will be probed via weak gravitational-lensing effects on galaxies. Gravitational lensing by foreground objects slightly modifies the shape of distant background galaxies, producing a distortion that directly reveals the distribution of dark matter. The way such lensing changes as a function of look-back time, due to the continuing growth of cosmic structure from dark matter, strongly depends on the accelerating expansion of the Universe and turns out to be a clear signature of the amount and nature of dark energy. Spectroscopic measurements, meanwhile, will enable us to measure features in the clustering pattern of galaxies called baryon acoustic oscillations (BAOs), caused by acoustic waves in the early Universe, which act as a standard ruler of fixed length, whose apparent size when observed can be used to constrain the distance-redshift relationship and the geometry of the Universe. Information about the growth rate of large-scale structure is obtained through redshift-space distortions (RSDs). RSDs arise because we do not observe true galaxy positions, but instead infer distances from measured redshifts, which include coherent flows due to the growth of structure.

3 The Euclid Legacy Data

Euclid will provide a data set of incredible legacy value. For example, the near infra-red imaging surveys that *Euclid* will perform would take many hundreds of years of dedicated operation using ground-based telescopes to reach the same depth. The complete processing pipeline from *Euclid*'s raw data to the final data products is a large information-technology project involving a few hundred software engineers and scientists, and has been broken down into functions handled by almost a dozen separate expert groups. A highly varied collection of data sets must be homogenised for subsequent combination: data from different ground and space-based telescopes, visible and near-infrared data, and slit-less spectroscopy. Very precise and accurate shapes of galaxies are measured, giving two orders of magnitude improvement with respect to current analyses.

Scientifically validated data will be released to the world-wide astronomical community via the Euclid Legacy Archive on an annual basis. The scientific products are categorised into three data levels. The first data level consists of the raw decompressed telemetry frames, the second level consists of calibrated data with instrument signatures removed, and the third level consists of extracted scientific information such as catalogues. In addition, *Euclid* provides quick-release data, Level Q, representing transient products suitable for most purposes in astronomy, except for the core cosmology objectives. The earliest public data release takes place 14 months after the start of the routine operations, and contains Level Q products of the first year of routine operations. The other associated data levels are released 12 months later, together with the Level Q products of the second year, and so on.

These data will have tremendous legacy value that will directly enable a wide range of science. Additionally, the *Euclid* archive will stimulate follow-up programs that will let Canadians capitalize on our community's other investments. For example, *Euclid* will map a large number of cluster gravitational lenses that will feed *JWST* and GIRMOS programs (the latter AO-fed multi-IFU instrument is being designed, in part, for efficient cluster lensed-source surveys). Another example is the leveraging of ongoing CFHT imaging of *Euclid* fields described in more detail in §5.

4 The Euclid Consortium

The definition of *Euclid*'s science cases, the development of the scientific instruments, and the processing and exploitation of the data are under the responsibility of the Euclid Consortium (EC) and carried out in collaboration with ESA. The EC brings together about 1500 scientists and engineers in astrophysics, space astronomy, theoretical physics, and particle physics, from around 200 laboratories in 14 European countries, Canada, and the US.

Scientists who are members of the Euclid Consortium have access to scientific opportunities that the broader astronomical community do not. Firstly, they can participate in the Euclid Science Working Groups. In addition to Weak Lensing and Galaxy Clustering, there are a dozen other Working Groups covering a wide spectrum of topics ranging from CMB-cross-correlations to the Solar System. The Working Groups are open to all EC members who wish to help by performing simulations and developing pipelines for future analyses. The most important of these analyses are defined as Key Projects. Members who have contributed to *Euclid* will be able to co-author or lead the Key Project publications. Secondly, EC astronomers have access to proprietary *Euclid* data for 1–2 years for individual projects that are not Key Projects.

5 Canada's place within Euclid

Participation in a dark-energy space mission such as *Euclid* was the top space-based recommendation in the 2010 LRP. Subsequently, in 2012, attempts were made to secure Canadian participation in *Euclid* through hardware, software, data management, and programmatic contributions, but these were unsuccessful.

In 2016, the CFHT Large Program proposal entitled "The Canada-France Imaging Survey (CFIS)" was accepted and allocated at least 271 nights in equal share from the Canadian and French agencies. This decision follows the recommendations of the Scientific Advisory Council (SAC), based on the ranking proposed by the Large Program Evaluation Committee, and approval from the CFHT Board.

The acceptance of the CFIS proposal allowed Canada to join the EC in 2016 by agreeing to provide the data to the Euclid Consortium to be used to measure photometric redshifts for *Euclid* galaxies. In response to an open call, 23 members of the Canadian astronomical community indicated a desire to join the EC, and membership for 24 Canadians (including one "future draft pick") was secured by an agreement to make data from the Canada-France Imaging Survey (CFIS) available to the EC. The CFIS data will be used by the EC to determine accurate photometric redshifts for the galaxies observed by *Euclid*, which are suitable for weak-lensing shape measurements. This is a critical component for *Euclid*, and provides a route for access to the heart of the project. A number of changes have been made in the interim period to the Canadian members of *Euclid*, and there are now 27 Canadian faculty members of the EC as listed in the cover page to this document. In addition, young researchers (i.e., postdocs and students) working with these senior scientists are also able to become members of the EC and hence to contribute to *Euclid*.

CFIS also has standalone scientific goals - primarily in weak gravitational lensing and Galactic archaeology – in addition to its contribution to Euclid ground-based photometry. At present, the CFIS observations are approximately 40% complete. The CFIS team has joined forces with colleagues at the University of Hawai'i as part of the Ultraviolet Near-Infrared Optical Northern Survey (UNIONS) which aims to cover the sky north of 30° declination and outside the Galactic plane in the $ugriz$ bands. We note that by continuing to support CFHT and augment its capabilities, the Canadian astronomical community was able to leverage it to participate in a much more ambitious project. This demonstrates the value of well-supported national facilities when used strategically. As international projects grow in scale, it is expected that this trend will continue. Finally, technical expertise gained from CFIS/UNIONS also helps prepare Canadian faculty and trainee HQP for exploitation of *Euclid* in a wide range of astronomical topics, especially weak gravitational lensing and photometric redshifts.

6 Request

In this white paper, we present a status update for *Euclid*, highlighting the incredible value of Canadian participation in the EC. We request that this opportunity be exploited and argue that this requires funding beyond that available through standard routes (e.g., NSERC Discovery grants). Bringing Canada into the Euclid Consortium was an amazing opportunity, but to compete within the EC we need to match the levels of support available to members in other countries. Funding for half a dozen postdocs on an ongoing basis (i.e., from 2020 through the life of the mission), plus travel for a significant fraction of the Canadian EC members, would allow Canadian astronomers to compete with our well-resourced European counterparts. This type of funding was at one time available through NSERC Collaborative Research Opportunity (CRO) and Special Research Opportunity (SRO) grants. For example, the CFHT Legacy Survey received substantial funding though a CRO. These grants, however, are no longer offered by NSERC. CSA has supported 2-year grants for a couple of *Euclid* members, but this does not allow us to effectively exploit our full allocation of 27 *Euclid* seats. A new funding source is urgently needed for this (and other long-term observational projects). This will also facilitate the training of HQP, who will be ready for the next generation of survey and space experiments (see White paper by McConnachie et al.)

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

Together, weak-lensing and spectroscopy data will reveal signatures of the physical processes responsible for the expansion and the hierarchical formation of structures and galaxies in the presence of dark energy. A cosmological constant, a new dark-energy component, or deviations to general relativity will produce different signatures. Since these differences are expected to be very small; however, the Euclid Mission is extremely demanding scientifically and also represents considerable technical, observational, and data-processing challenges. The combination of geometrical and structure-growth measurements has incredible power to constrain theories of acceleration based on modifications to GR: such theories cannot be easily tuned to match both the expansion rate and structure growth rate simultaneously. Galaxy surveys also allow measurements of the summed neutrino particle masses, and insight into the physics of the very young inflationary Universe, when the seeds that grow to form galaxies were produced.

By further analysing the *Euclid* data in terms of power spectra of galaxies and dark matter and a description of massive nonlinear structures like clusters of galaxies, *Euclid* can address cosmological questions beyond the accelerating expansion. Indeed, we will be able to address any topic related to power spectra or non-Gaussian properties of galaxies and dark-matter distributions. The relationship between the light- and dark-matter distributions of galaxies, for instance, can be derived by comparing the galaxy power spectrum (as derived from spectroscopy) with the dark-matter power spectrum (as derived from gravitational lensing). The physics of inflation can then be explored by combining the non-Gaussian features observed in the dark-matter distribution in *Euclid* data with existing from the *Planck* data. Likewise, since *Euclid* will map the dark-matter distribution with unprecedented accuracy; it will be sensitive to subtle features produced by neutrinos and thereby help to constrain the sum of the neutrino masses. On these and other topics, *Euclid* will provide important information to constrain cosmological models.

The original predictions for *Euclid*, made at the time of mission selection are presented in Laureijs et al. (2011). A recent exercise within the EC has updated these predictions using a better instrument model, and improvements in our understanding of the Universe and the two main probes. The primary goal of *Euclid* is defined in terms of the Dark Energy Task Force (DETF; Albrecht et al. 2006) "figure-of-merit" (FoM) for dark-energy experiments. In this framework, the dark-energy equation of state is parameterised as $w(a) = w_0 + w_a(1 - a)$, and the FoM is defined as the reciprocal ratio of the area of the 1σ errors on w_0 and w_a. A larger FoM implies a more precise measurement of the dark-energy properties. The revised analysis shows that the primary goal of *Euclid* – to recover an FoM of 400 is still expected to be met (Euclid Consortium et al. 2019; currently undergoing internal refereeing), showing that *Euclid* will be a transformational project within cosmology.

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

The weak-lensing, BAO, and RSD techniques are mature, and thus there is little risk inherent in the techniques themselves. However, *Euclid* will perform a survey that is approximately 25 times larger than previous projects, for both weak-lensing from imaging data and for the spectroscopic sample. Thus the statistical precision achievable is over 5 times that of previous experiments. Furthermore the combination of weak-lensing and galaxy-clustering results, thanks to the benefits of them measuring different cosmological quantities, offers a significantly larger improvement in precision. Making sure that all sources of systematic error are below the level of statistical precision is therefore going to be challenging.

The space-base for the instruments clearly helps here, and due to the maturity of the mission planning, most of the scientific risks specific to *Euclid* have been mitigated. Indeed, Euclid successfully passed the Mission Critical Design Review in November 2018, demonstrating the mission is considered as feasible by ESA and, based on our current knowledge of the mission performance, will meet its Level 0 and Level 1 scientific requirements. For weak lensing, there are still two areas of concern. The first is the quality and reproducibility of the point-spread-function (PSF). There is significant effort currently within the EC characterising all of the optical surfaces in order to build up a model for the PSF – a model that will be finalised and verified during the commissioning phase of operations. The second areas of concern is the characterisation of the photometric redshifts, and this is a problem that Canadians can specifically help with, particularly in light of the importance of CFIS data.

For the spectroscopic data, used to obtain redshifts and to make 3D clustering measurements, the primary concerns arise because of the slitless method adopted. A grism is used to disperse all of the incident near-infrared light, meaning that spectra often overlap, causing confusion. This is mitigated by a 4-pass strategy, where the dispersion direction is varied. Other concerns include line misidentification, and detector persistence, which will be mitigated within the data pipeline.

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

While Canada has not participated in the hardware development for *Euclid*, it has a significant role in the reduction and delivery of the data, particularly through CFIS. As full members of the EC, the Canadian members can apply for leadership positions within the scientific management structure. Any open positions – many are short-term with regular rotation, while there are open calls for others when people step down – are advertised within the EC and/or relevant scientific working groups. The following are examples where the Canadian members have already engaged with the EC.

Michael Balogh is a member of Steering Group for UNIONS, and of the *Euclid* Galaxy Clusters Science Working Group. He is interested in galaxy evolution and large scale structure, and looks forward to using the *Euclid* galaxy clusters and slitless spectroscopy to study the Hα distribution in galaxies within those clusters.

Stephen Gwyn is science lead at the Canadian Data Centre. He specializes in processing the data from the MegaCam camera on CFHT. He is reducing data from Canada-France Imaging Survey and will deliver that data to Euclid Consortium, will ensure that the calibration meets the Consortium requirements.

Mike Hudson is the Canadian member on the Euclid Consortium Board (ECB). The ECB works with the EC Lead (Mellier) to set rules for the collaboration, meeting face-to-face quarterly and monthly by telecon. He is a member of the UNIONS Steering Group, is the UNIONS r-band Scientist and coordinates the UNIONS Weak Lensing Team. He is also a member of the *Euclid* Weak Lensing Science Working Group, and is working on many of the same topics with Euclid as he is with UNIONS. His particular interest is galaxy-galaxy lensing and lensing by large-scale structures such as filaments and voids.

Will Percival is a *Founder* of the project, and his contributions to the mission have already been acknowledged, such that he has authorship rights on all future publications. He currently serves as a co-lead of the Galaxy Clustering Science Working Group, and together with the equivalent scientists work in weak lensing, is one of four Science Coordinators for the consortium. He also serves as a member of the Coordination Group, the Editorial Board, and the Science Publication Group, and contributes regularly to the Calibration and Survey Working Groups. His primary responsibility is to make sure that the Galaxy Clustering component of *Euclid* (effectively half of the mission) is a success.

Marcin Sawicki works in galaxy evolution research and is especially interested in the *Euclid* deep fields. He will combine *Euclid* spectroscopic and photometric data with deep CFHT u imaging as part of a multi-λ campaign.

Douglas Scott expects to contribute to the CMB cross-correlation science, through his experience with the Planck Consortium. Additionally has been an organiser of workshops for Early Career Scientists.

Chris Willott is a member of the Primeval Universe working group. He is part of a group determining how to optimally discover high-redshift ($z > 7$) quasars from the combination of *Euclid* near-infrared and ground-based optical imaging. The first part of this work was published in Euclid Collaboration et al. (2019).

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

The Canadian Euclid Consortium (CEC) is led by Mike Hudson, who recently took over from Ray Carlberg as the representative of Canada on the EC Board. The CEC recently met at the 2019 CASCA meeting to discuss its role within *Euclid*. The CEC Steering Group with members Mike Hudson (ECB rep, CFIS rep), JJ Kavelaars (CADC rep), Jo Bovy (community rep), Laura Parker (community rep), and Nick Cowan (community rep) advises on the operations of the CEC, its membership and the agreement with the wider EC. It promotes Canadian involvement in *Euclid*, and acts as a conduit for information and communication with the broader Canadian astronomy community. The primary interest of astronomers outside of the *Euclid* community for *Euclid* will be access to the public data.

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

The exploitation of *Euclid* data provides an opportunity to create a core group of Canadian scientists who are world-experts on survey data analysis, and on mining these data to make astronomical measurements. These skills will support Canadian ambition in the new era of astronomical survey science with the generation of surveys to come after *Euclid*, including: optical projects, such as the Large Synoptic Survey Telescope (LSST), the Maunakea Spectroscopic Explorer (MSE), and The Cosmological Advanced Survey Telescope for Optical and UV Research (CASTOR); as well as surveys in other wavebands, such as the Square Kilometer Array (SKA), the Cerro Chajnantor Atacama Telescope (CCAT), and CMB-Stage 4.

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

Having access to *Euclid* in exchange for CFIS access was an incredibly good deal for Canada. In comparison, the U.S. community, through NASA, provided detector hardware and obtained 40 EC seats. The FY19 NASA Budget Estimate suggests that the total cost of Euclid participation for NASA will be more than $77M USD. In contrast, the cost of EC membership to Canada is essentially zero because CFIS is an excellent stand-alone survey project with clear science goals even without *Euclid* data, and Canada was fortunate that the EC has a strong need for these data. Because of this, there is no requirement for Canada to provide operating costs; however, there is a strong need to provide science support to allow Canadians to compete within the EC.

While there are no major hardware costs to consider, the cost for scientists to actively participate in the EC is high. The core work, including making the cosmological measurements for which *Euclid* was designed will be undertaken by collaborative teams working on Key Projects defined within the EC. In order to fully engage, scientists have to travel to many meetings – not just the main annual EC meeting, but additional meetings organised to deal specifically with science, simulations, calibration, organisation, management, etc. These are usually in Europe, and travel is therefore expensive. Furthermore, in order to fully exploit the potential of these data, graduate student and postdoctoral support is required. Canadians have to compete with European and American colleagues who are often awarded million dollar grants (e.g., European Research Council grants) for scientific exploitation. In the past, it was possible for Canadian groups to compete for this level of funding, but with the demise of the NSERC CRO and SRO programs, this has become very difficult. Having scientific exploitation funding beyond the level of NSERC Discovery grants is required.

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

The *Euclid* project is now sufficiently mature that many of the risks have been retired. The structural and thermal model of the satellite recently completed its thermal qualification tests at Thales Alenia Space's premises in Cannes, France. Integrated in near-flight configuration, including the payload and service modules, the satellite model is ready to undergo mechanical vibration tests in the coming weeks. Delivery of the flight-model instruments will happen late in 2019, followed by Spacecraft Integration & Testing over the following two years. A few programmatic risks remain, but back-up capabilities have been identified. The biggest current risk is that if the schedule slips and launch does not happen in 2022, then access to the Soyuz launcher is uncertain. However, ESA has identified an Ariane 6 back-up option.

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?

Observational cosmology is one of the most exciting and active areas of research in Physics and Astronomy, and it therefore attracts excellent HQP and provides many stimulating and exciting topics for study. It also provides projects that allow HQP to pick up a range of skills during their training by undertaking different types of research. Working on *Euclid*, all HQP will receive training to understand methods in observational and theoretical cosmology, gain experience with sophisticated statistical data analysis tools, understand big data sets and their manipulation, develop advanced numerical and computational skills (including high-performance computing), as well as learning academic publication, presentation, and dissemination skills.

Given the data volume provided by *Euclid*, the skills developed will be exactly those required to fulfil the industry demand for Data Scientists in this era of big data. Specific projects will teach coding skills, and provide experience using a number of software packages for data analysis.

In addition to HQP training, the Euclid Consortium is committed to Education and Public Outreach, with significant activity planned during the mission.

References

Albrecht, A., Bernstein, G., Cahn, R., et al. 2006, arXiv e-prints, astroph/0609591

Euclid Collaboration, Barnett, R., Warren, S. J., et al. 2019, arXiv e-prints, arXiv:1908.04310

Laureijs, R., Amiaux, J., Arduini, S., et al. 2011, arXiv e-prints, arXiv:1110.3193

Racca, G. D., Laureijs, R., Stagnaro, L., et al. 2016, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 9904, Proc. SPIE, 99040O