Canadian Participation in the LSST

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Abstract

The Large Synoptic Survey Telescope will revolutionize optical wide-field astronomy while opening the window to short time-domain astronomy. Many astronomy communities, like the Canadian community, largely do not have membership in the LSST, but could benefit from its data products. We have conducted a survey of the Canadian community to gauge their interests with the LSST, and what data products are most desirable. We have found that the astronomy research of Canadians would greatly benefit from having access to the LSST. Canadian astronomers fall broadly into two categories: those interested in time domain, and the LSST's alerts; and those interested in more classical wide-field astronomy of the stationary sky. We have identified 4 data products in particular which the majority of responders desired. These data products represent a relatively low data volume compared to the full LSST pixel-to-catalog products, and present the opportunity to host a so-called LSST-light data centre. This centre would act as a national facility, which would largely satisfy the LSST-related data needs of the vast majority of Canadian astronomers.

Introduction

The Large Synoptic Survey Telescope (LSST) is an astronomical project designed to generate significant advances in four science areas: cosmology (dark matter and dark energy); the Solar System (with a focus on potentially hazardous asteroids); the Milky Way Galaxy; and transient phenomena. To do this, the LSST will deliver a deep survey that covers $\sim 1.8 \times 10^4$ square degrees in the southern sky and will detect ~ 40 billion stars and galaxies (Ivezić et al., 2008). A total of ~ 825 visits to each part of the sky within this area will be made in six filters, *ugrizy*, over 10 years. About 10% of the observing time will be devoted to community-proposed special programs that extend the areal coverage, depth, and/or sampling cadence (e.g., mini-surveys, deep drilling fields). The LSST currently estimates that full operations will begin in late 2022.

The LSST will acquire ∼20 terabytes of raw data each night and process it in real time, distributing alerts on objects that vary in brightness or position within 60 seconds, delivering processed images and updated object catalogs within 24 hours, and releasing a yearly reprocessed data set including deep image stacks (details below; Jurić et al. 2018). With the exception of the alerts, LSST data products are subject to a two-year proprietary period. Only scientists in the US or Chile, or who are individuals named in membership agreements (referred to collectively as LSST Members in this document), may access, analyse, and publish proprietary LSST data[1]. To enable science with this massive data set, the LSST Data Management System includes the Science Platform: a web-based service for data access, analysis, and processing that includes software tools and computational resources, and which will be accessible by LSST Members (Jurić et al., 2017). This is distinct from the NOAO's Community Science and Data Center (CSDC) which currently supports access to data from telescopes operated by NOAO. Additional advantages of LSST membership includes participation in the Science Collaborations, which are currently developing software for processing and analyzing the LSST data. The LSST data rights and access policies are currently under review by Project leadership and the funding agencies. If the proprietary period and/or terms of membership changes in the future, it is likely the changes would be in the direction of increased openness and relaxed restrictions. Such changes would impact both the scientific potential available to the Canadian community and the costs of realizing it, and we would update this white paper accordingly.

Prompt Data Products – Every standard visit image (~ 30 s integration) acquired by the LSST will be immediately reduced, calibrated, and processed with Difference Image Analysis (DIA), wherein a template image (a deep stack of previously obtained images) is subtracted to generate a difference image. All sources detected in the difference image represent the time-variable components of transient phenomena (e.g., supernovae), variable stars (e.g., RR Lyrae), and moving objects (e.g., asteroids). For all difference-image sources detected with a signal-to-noise ratio (SNR) of at least 5, an alert packet containing information about the source (location, fluxes, derived parameters, and $\sim 6'' \times 6''$ cutouts) will be generated and released within 60 seconds of the end of image readout. Alerts are world public and can be shared with anyone, anywhere. It is expected that alerts on moving objects will be integrated into the Minor Planet Center. Due to the very high bandwidth of the LSST Alert Stream it will only be delivered in full, in real-time, to 4-7 Alert Brokers (Bellm and co authors, 2018), who will serve them to their communities (some brokers plan to provide public access, e.g., Narayan et al. 2018). All other prompt data products (e.g., visit, template, and difference images, catalogs of difference-image objects) will be made available to LSST members via the Science Platform within 24 hours, but are subject to a two-year proprietary period, after which time they can be shared with anyone, anywhere, worldwide. LSST members will also have access to the LSST Alert Filtering Service where they may define filters and recieve alerts on their targets of interest in real-time, and access to a queryable database of alerts.

Data Release Data Products – After the first half-year of operations, and on an annual basis thereafter, LSST will reprocess and release all of its data via the Science Platform. This will include all of the data products associated with DIA, the raw and calibration images, deeply coadded all-sky image mosaics in each filter, and object catalogs with measurements and parameters derived from both the visit and coadded images (incuding catalogs of moving-object orbits based on LSST data alone). Release data products are subject to a two-year proprietary period, after which time they can be shared with anyone, anywhere.

Memberships

There are two routes for non-US astronomers to gain LSST membership. The first option is a national level buy-in, such as the UK has recently committed to. The funds for UK buy-in, which were granted through the Science and Technologies Facilities Council (STFC), was sufficient for 100 senior memberships (faculty) and 400 junior associates (PhDs and post-docs). The funds are being awarded in four phases. In the now complete Phase A, £15 million ($20 million USD in 2015) was awarded as a contribution to LSST operations. An additional £3.4 million (£2.7 million award plus matching funds from the STFC) was awarded for software development and development of a national data centre (the DAC) which will host a copy of the LSST data products, and the LASAIR alert broker (Smith et al., 2019). While exact values are still to be determined, an additional £4 million is expected for Phase B, which is intended to cover additional software

[1]If the proprietary period and/or terms of membership changes in the future, it is possible that the changes would be in the direction of increased openness and relaxed restrictions. Any such change would positively impact both the scientific potential available to the Canadian community and the costs of realizing it, and we would update this white paper accordingly.

and data product development up to the start of LSST operations. An additional ~£11.5 million will be requested during Phases C and D, which will cover DAC operations, and Education and Public outreach activities. The expected total of the STFC contributions for the national UK LSST buy-in is roughly £34 million, or roughly £340,000 per faculty membership (<£300,000 when excluding the UK DAC expenses).

For those astronomers not in countries with national membership, individual or institutional-level memberships can be purchased. A full list of member institutional member facilities can be found on the LSST webpages (hql; con).

As a country, Canada is not buying into LSST. Rather than national membership, Canadian astronomers have the option to buy individual team memberships. At time of writing, each membership costs $240,000 USD, which provides data rights for the astronomy, and three junior teammates such as post-docs and PhD students. To have access to NOAO's compute centres where the LSST data will be hosted and manipulated by users costs another $1,700 per user per year, of $6,800 per team. Including typical institutional overheads and exchange rates, the estimated cost per membership is $517,000 CAD. As such, to Canadians, individual team memberships with full data rights and access are roughly 85% of the equivalent price paid by the UK. Despite the lower cost to entry, funds for membership are very difficult to come by in the Canadian funding climate. There are a few exceptions, however.

Canadian interest in the LSST has manifest itself in a couple of different ways. The University of Waterloo has recently committed to institutional membership, purchasing full membership for 5 faculty members, supported by contributions by the National Science and Engineering Research Council, the Waterloo Faculty of Science, the university provost, and a half membership fund provided by the Dunlap Institute (see below). Though additional memberships for other Waterloo faculty may be purchased.

As part of the preparations for the LSST, a Canadian consortium has been formed, led by Dunlap Institute, that is providing funding to a limited number of Canadian investigators. While the exact breakdown of the funding is still to be determined, the nominal plan is 50% funding for 10 Canadian participants. Those participants will need to fund the other 50%, plus additional data access fees. Development activities from this consortium include a CFI proposal (PI: Renée Hlozek) to develop software infrastructure aimed at utilize the LSST alert stream. Additional development activities inside the Canadian Astronomy Data Centre (CADC) are likely, will depend on the scope of Canadian LSST user's plans.

Anecdotally, while national support for Canadian participation in the LSST has been low, the desire for membership by some has been high indeed. To that end, we sent out a survey to the Canadian astronomy community seeking responses to various question aimed at gauging specific interest Canadians had with the varied aspects of LSST science, and to gauge funding availability accordingly. In this white paper, we discuss this survey and the responses we received. From this survey, it is made clear that there is significant interest in the products associated with transient, variable, and moving objects.

The results of that survey have made apparent one possible low-cost route to providing data access to the most desirable data products. This so-called *LSST-light* database, would consist mainly of annual release images and source catalogs (including time domain information) made available after the proprietary period, and would take advantage of the hosting and compute facilities provided by the CADC. The *LSST-light* data centre would provide the necessary LSST data products requested by the vast majority of survey respondees, but at a cost of roughly half of the full buy-in costs for the respondees. The *LSST-light* data centre represents an opportunity to create a national level facility that is useful to the majority of Canadian astronomers, at a relatively low overall cost.

The Canadian Survey

To gauge the Canadian astronomy community's scientific interest in usage of the LSST observations and data products in a non-anecdotal fashion, a survey was sent out to the community. The survey was designed to broadly assess community scientific interests, LSST data requirements to meet those interests, and plans for access to those data. In the following section we discuss in detail the responses to the questions posed in the survey. Below, we discuss a potential route forward to LSST data access that makes use of the facilities and expertise inside the CADC that would address the majority of needs of the survey respondees.

The scientific interests of respondees

Thirty six scientists responded to the survey, representing roughly ˜30% of the total active Canadian astronomy community (125 members of the Canadian astronomy Society Société Canadienne D'Astronomie attended the 2018 AGM). Responses arrived from 16 unique Canadian institutions, including both federal research centres and universities. While the response rate might seem low, we emphasize here that the responses to this survey are likely biased towards those Canadians who are directly interested in science fields related to the LSST. It is unlikely that those with disinterest in transient or wide-field astronomy will have taken the time to respond to this survey.

To gauge scientific interest, two simple questions were asked: "What are your general science interests?"; and "What are your LSST-specific science interests?" Multiple responses were possible. We present the summary of responses in Figure 1.

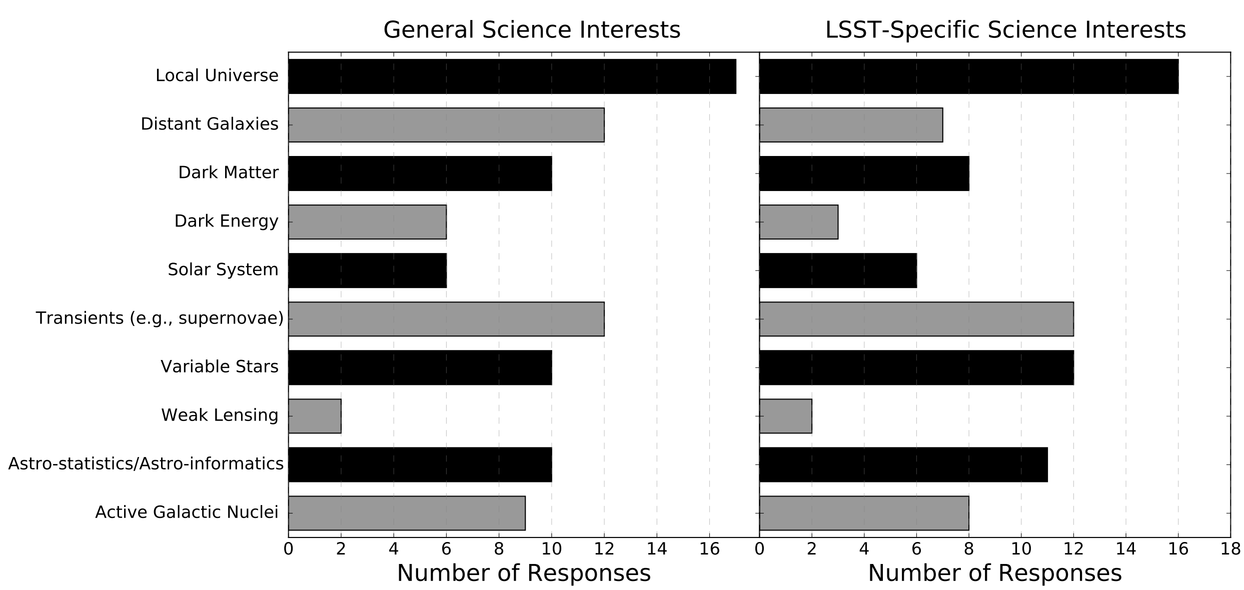

Figure 1: The general and LSST-specific science interests of the survey respondees.

While the interests of Canadians span the breadth of observational astrophysics, the majority interest rests in studies of the local universe and transient sources - both single event transients like supernovae, and repeating transients like variable stars.

Desired Data products

The data products that will be produced by the LSST fall in two flavours, or types: prompt products, and release products. To assess interest in both types of products, we presented respondees with a list of prompt and release data products, and asked them to state which data products they anticipated using in their LSST-related research. The responses to both are presented in Figures 2 and 3.

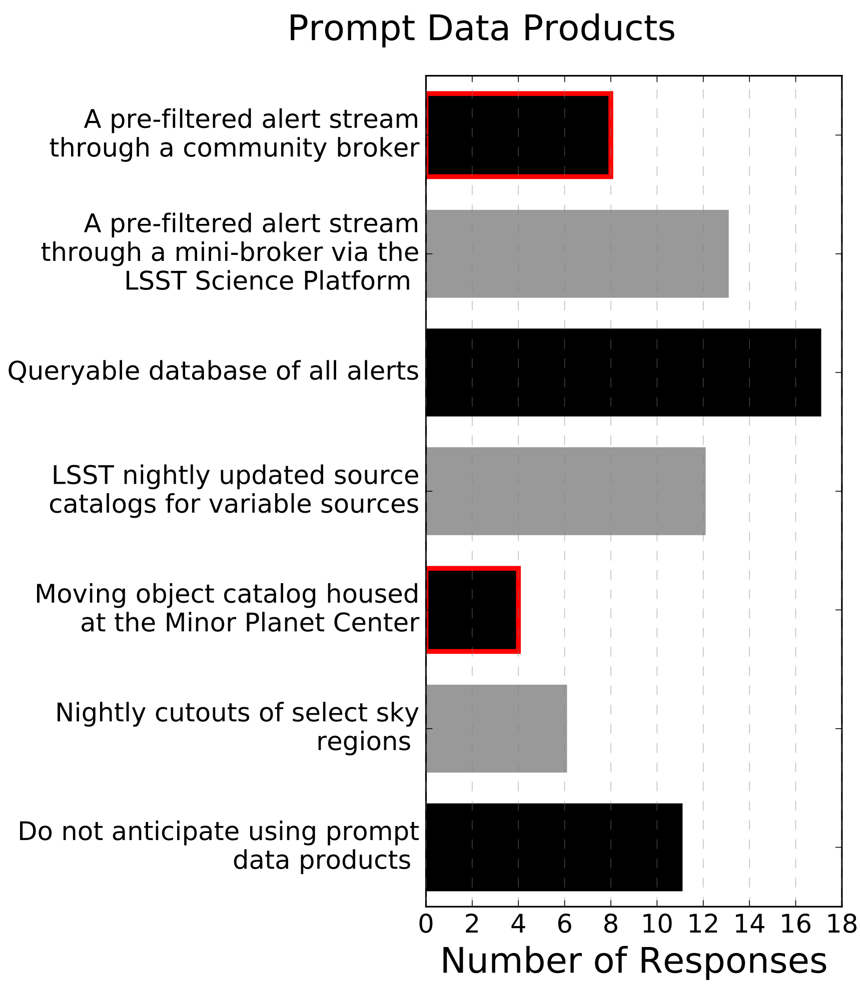

Figure 2: Summary of responses to the question "Which prompt data products do you anticipate using in your LSST-related research?" Publicly available products have been highlighted with a red outline.

Two interesting results are implied by the data presented in Figures 2 and 3. The first and most notable result is that more than half of the respondees are interested in making use of the prompt data products. Most of the respondees with interest in the prompt products have interest in making use of a queryable catalog of transient alerts, with 1/3rd having interest in utilizing the alert stream itself, either from a community broker, or from the LSST Science Platform.

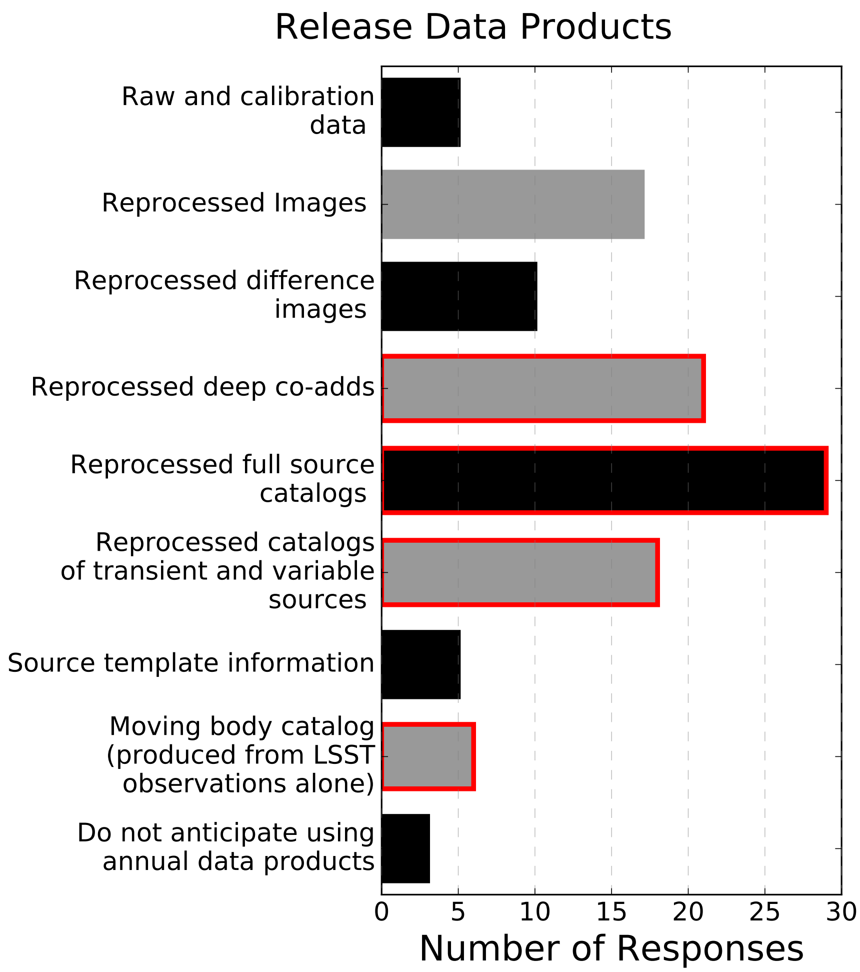

Figure 3: Summary of Responses to the question "Which release data products do you anticipate using in your LSST-related research?" Those products that will be publicly available after a 2 year proprietary period are highlighted with a red outline.

The second interesting result is the demonstration of great interest by Canadians in the "all-sky" data products. The annual products most Canadians are interested in are the reprocessed full source catalogs, and the reprocessed deep co-adds. The third most sought after annual product, reprocessed catalogs of transient and variable source, matches interest in the most sought after prompt data product, a queryable database of alerts.

Taken together, both of the above results would imply that Canadians fall into two types of users: those interested in fast time-domain astronomy, and more oriented towards classic wide field astronomy. The first group makes up 1/3rd of respondees, which is fractionally higher than those with LSST membership (based on membership of the various LSST science working groups). Clearly, live access to alerts in one form or another is important for Canadian astronomy.

From the responses, it is also clear that the majority of Canadians interested in use of LSST observations remain highly interested in classical wide field astronomy of the stationary sky. It seems the majority of that interest can be served with only the four most sought after of the aforementioned data products. This presents the possibility of serving a light version of the LSST data products to Canadian astronomers without the need for many of the expensive products, or the compute facilities required for their use. We discuss this scenario below.

Respondees were also asked "Regardless of your membership status and data rights access, how beneficial might access to LSST data, either before or after the 2 year proprietary period, be for your personal science goals? Please rank between 1 (least beneficial) and 5 (most beneficial)." The summary of responses is shown in Figure 4. The response is clear; the respondees overwhelmingly agree that LSST data would be greatly beneficial to their science research. The mean response was 3.86, with only three responses of 2 or lower. 70% responded with 4 or higher, demonstrating a clear desire for access to LSST data products.

In addition, respondees were asked if they had access to funding for LSST membership, and if so, from what source (see Figure 4). The large majority, >80%, have no membership funds of any kind. Only three responded with full funding, and an additional four with partial funding. The respondees with funding are funded either through the Dunlap fund appropriated by Director Brian Gaensler, or as faculty at the University of Waterloo.

Finally, respondees were asked if membership were available, would they purchase into the NOAO compute pool ($1700 USD per year per member). While the majority (22) responded N/A, of those that did not, 10 responded negatively, and only 4 responded positively.

The response to these questions demonstrate a clear desire by the Canadian astronomy community to at least have access to LSST data, if not to participate directly. With the exception of the lucky few that have secured funds through unique means, within the current Canadian research funding structure, no funds are available for LSST membership through *any* of the major funding bodies (eg., NSERC or NRC), let alone compute resources. With the current arrangements, without an influx of funds, the majority of Canadians will not have access to LSST data for any purpose.

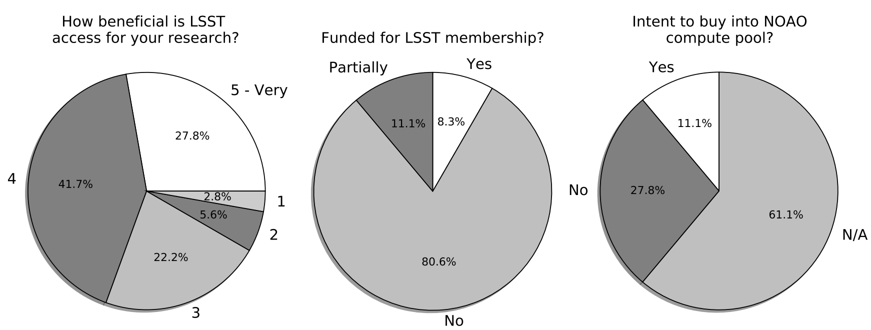

Figure 4: Membership status, compute pool, and benefits to science.

The Canadian "LSST-light" data centre: A possible low cost route for LSST Data products

From the survey, the most desired data products, in decreasing order, are:

1. Reprocessed full source catalogs
2. Reprocessed multi-band stacks
3. Full queryable alerts database
4. Reprocessed transient catalog

Of these four data products, only the queryable alerts database is a prompt product. The other three are annual release products. These 4 products cover the majority of Canadian user's LSST science interests, with 33 of 37 respondees desiring at least one of those products, with 30 of the respondees desiring two or more.

The summary of responses present an opportunity to host a so-called *LSST-light* database. That is, a hosting of only the above 4 most desirable data products. Such a database would require only a small fraction of the overall data storage, and provide useful data to the vast majority of Canadians interested in using LSST observations for their science goals. By hosting data only after the 2 year grace period after release, Canadians will avoid the proprietary restrictions placed on them by not being members of the LSST itself, and the costs of being members!

The full source and transient catalogs will be roughly 2 petabytes (PB) at first release, and grow to a full 15 PB at survey completion. [https://www.lsst.org/scientists/keynumbers]. A single copy of the all sky co-adds will occupy a relatively small 0.6 PB. More precise data volume estimates are not yet available. It is unlikely that more than the most recent release needs to be hosted in the LSST-light database. The most complex data product is the queryable transient catalog. Each alert packet will be 82 kb or less, with roughly 10,000 alerts produced per visit, on average. As the survey executes, the alerts database will grow roughly linear in size, growing to roughly 2.2 PB after the full 10 year duration of the survey [https://dmtn-102.lsst.io/]. The total storage requirement of this LSST-light database is 18 PB, or only ~25% of the full LSST data product volume.

Given the unprecedented data volume, it is unlikely that any users will have sufficient personal compute resources with which to process more than minute quantities of the LSST data products. Rather, LSST will operate with large-scale, user accessible compute resources hosted on site at the NOAO, that are directly to the dataset itself. Access to the data and compute facilities will be provided through a Jupyter python compute environment currently in development by the LSST. This environment will provide LSST users the necessary compute facilities and environment for both small scale and large scale compute tasks that interact with the databases, and of the images themselves. For Canadians, a similar setup will be required to be able to utilize the LSST-light dataset through three points of access.

Building off of the infrastructure that already exists at the CADC, the LSST-light dataset should be queryable in the same way as current CADC-hosted data. These data should also be processable through the CADC VOSpace virtual machine system, which would act as the primary method through which computationally expensive scientific processing will be performed. Furthermore, to provide direct personal access to the LSST-light products, the CADC should run the NOAO Jupyter notebook system being developed by for the LSST. These three points of access will provide the necessary and sufficient data access and processing capabilities for Canadian users.

	Work Type (FTE)				
	Operations	Science	Development	Management	Total
HTML Data Query	0.25	0.5	0.5	0.5	1.25
Jupyter Notebook	0.25	1.0	1.0	-	2.25
VM Compute	0.5	1.0	1.0	-	2.5
Longterm Operations	0.75	0.5	0.5	0.5	2.25

Table 1:
Estimates of person labour requirements for development and long term operations of an LSST-light data centre hosted at the CADC. These estimates are based on a 2 year initial development period, and a 0.5-0.5 duty-science labour split. All units are in Full Time Equivalent values. Long term operations include 0.5 FTE required to maintain the data centre hardware.

The Canadian LSST science centre we describe above will require some advanced development. We provide summary estimates of the overall Full Time Equivalent (FTE) person power required in Table 1 below. Roughly, an LSST-light data centre hosted at the CADC will require a commitment of 28.5 FTE including 2 years of initial development, and 10 years of operations over the duration of the LSST survey.

Long term management and operations of the CADC LSST data centre will require roughly 1.75 FTE, including management, science, and on-going development. An additional 0.5 FTE will be required to maintain the hardware on which the data centre will be stored. Overall, 6 FTE will be required during an initial 2 year development period, with 2.25 FTE required for long term operations.

If funds were successfully found for such a CADC LSST data centre (likely a combination of CFI and NRC funds), a bid for compute resources will be submitted to Compute Canada.

There is likely to be additional costs associated with the simple action of transferring the data products from NOAO servers to those located at the CADC. While these costs are still to be determined by NOAO, we can get a rough estimate of the magnitude of those costs from the current pricing structure of the Amazon Web Services (AWS). AWS charges $0.021 per GB download. The sky stacks and source catalogs will be of a nearly constant size after the first year of operations, requiring roughly a 10 PB transfer per year at annual estimated cost of $220,000 USD, with an additional ˜$50,000 USD in total transfer costs associated with the alerts database.

The annual release products are likely to be batch transferred 2 years after their release. How the alerts database is transferred largely depends on the results of a CFI proposal (PI: Renée Hlozek) to provide an alert broker for the few Canadians who will hold membership with the LSST. If successful, this alert broker will already receive a fraction of the live alert stream, if not the entire stream itself, in which case the queryable database will be constructed from that stream.

Cost comparison with national buy in

The proposed CADC LSST-light data centre will require roughly 28.5 FTE. At current NRC rates, each FTE costs roughly $150,000. We estimate the total person power costs to be $4.3 million CAD. A further ˜$2.9 CAD (2.2 million USD) in data transfer costs estimated at the current business cloud rate are anticipated, totalling $7.2 million CAD, excluding hardware costs.

The current cost for direct membership purchase for the LSST is $200,000 USD per senior scientist. This includes data access for 3 junior team members (post-docs and PhD students). While this buys data rights, it does not provide data access or compute facilities, which are currently rated at $1700 USD per person per year of access. Admittedly data rights without data access is pointless, and the overall faculty member buy-in is $268,000 USD, or roughly $350,000 CAD. The majority of survey respondees are either already faculty, or will be at an equivalent level by the LSST commences operations. If we assume the response represents the majority of Canadian interest in the LSST, then a national buy-in, with 40 membership positions, will cost roughly $14 million CAD. Or nearly double the labour and data transfer costs associated with a national CADC LSST-light data centre.

The benefits to full by-in are obvious. Members have complete data access to all LSST data products, including pixel products, source catalogs, and alerts, with no proprietary period to access those products. Moreover, members will have access to the NOAO compute resources tied directly to the full LSST database, at an equivalent level to US and other national members. Without a special influx of funds however, full membership of Canadian scientists is virtually impossible, as no appropriate funding source exists within the current Canadian funding climate from which a membership can be funded.

Beyond the lower cost, the clear benefit of the CADC LSST data centre is the creation of a national data centre for the benefit of all Canadian scientists. The centre would provide data access and compute facilities that would satisfy the majority of *current* Canadian interests in wide-field optical astronomy, albeit after a 2 year proprietary period, and with no direct access to *live* alerts produced by the LSST. There are synergies between the proposed CADC LSST-light data centre and current and future planned telescope projects that Canada is a participant in. We discuss those synergies below.

For comparison, the United Kingdom has bought in as a national partner at a cost of $9 million pounds ($15.5 million CAD). This cost includes full membership and operations funds to the LSST to provide data rights and full data access for 100 faculty, as well as 4 junior team members per faculty member. In addition, it includes the hardware and FTE costs of a full national UK science centre which is being built at the Royal Observatory in Edinburgh, to provide the necessary national compute facilities, and the facilities to operate the LASAIR full stream alert broker [https://lasair.roe.ac.uk/]. Clearly, a national buy in provides a much lower - roughly 45% less - cost to LSST access than individual memberships.

Considerations for current and future Canadian astronomy facilities

There are many current or upcoming Canadian national astronomical facilities that have large synergies with the CADC-hosted LSST-light data centre we outline above. In particular, the ManuaKea Spectroscopic Explorer, and the Gemini-North and South Telescopes both will need to utilize LSST data products in their daily operations to be able to fulfill the basic science requirements of each facility. We discuss both of these facilities, and their LSST data requirements below.

MaunaKea Spectroscopic Explorer

The MaunaKea Spectroscopic Explorer (MSE; https://mse.cfht.hawaii.edu/) is a highly developed vision for the future of the Canada-France-Hawaii Telescope. If that vision comes to fruition, we will see the CFHT transformed into an 11-m, highly multiplexed, fibre-fed, optical spectroscopic survey telescope, and provide a national astronomical facility for use of all Canadians. MSE will have acquire up to 4,332 spectra over a 1.5 square degree field in every exposure it acquires. MSE's fast fibre placement would make it an excellent tool for LSST follow-up of moderately bright (<23 mag.) sources. Most of the planned science activities however, centre around gathering spectra of the non-transient local universe (boo).

A critical outstanding item required for the success of MSE is a deep, all-sky source catalog, without which accurate fibre placement will be impossible. The northern portion of this finder chart will likely come from some combination of the Euclid survey, and the Pan-STAARS 1 and 2 surveys. The LSST all-sky catalogs and image stacks are ideal for MSE's purposes, providing accurate photometry and astrometry of all sources more than a magnitude fainter than realistically observable by MSE. The LSST will provide coverage for the entire sky South of 0 degrees declination, or roughly 1/3rd of the observable sky over MSE.

The minimum data products that would be useful for producing MSE finder charters are a single release of the all-sky source catalogs and multi-band deep co-adds, above -30 degrees declination (half the coverage of the wide-fast-deep survey). At the very minimum, that dataset will total at least 1.3 PB (the first annual release). While a relatively small data volume compared to the full LSST-light dataset outlined above, even just the repeated handling and manipulation of a PB-scale dataset still comes at substantial effort and expense.

With the fully integrated compute and storage facilities a CADC-hosted LSST-light data centre would provide an essential service to the MSE. In particular, such an integrated facility would afford the straight-forward creation of the catalog manipulation and target selection tools required of the MSE observing planning, and enable the creation of the combined photometric and spectroscopic imaging dataset that would be afforded by combination of the hosted LSST data products.

It should be noted that the current LSST data rights policy prevents usage of proprietary data by non-members. This excludes use of the LSST by the MSE collaboration, until after the proprietary period lapses. It may be possible that an arrangement between MSE and the LSST could be reached to provide early access to certain parts of the LSST products at some cost to MSE.

Gemini South as an LSST Follow-up Tool

Canada has been a long term partner in the the pair of 8-m Gemini telescopes, holding a share of the partnership of at least 10% since the inception of the facilities. The Gemini telescopes act as one of Canada's primary large, optical and NIR ground based telescopic facilities.

In 2016, Gemini underwent a review of its strategic vision, with input from the partner country members.

As a main recommendation of the resultant science vision report (`http://www.gemini.edu/files/general-announcements/2021beyond_strategic_vision.pdf`),

> *"Beyond 2021, Gemini should exploit its geographical location and agile operational model in order to be the premiere facility for the follow-up investigation of targets identified by the Large Synoptic Survey Telescope."*

This is strategy is favoured over developing synergies with upcoming 30 m class telescopes like the TMT, as it is seen as a more useful specialization, taking better advantage of the special capabilities of the Gemini telescopes. At the time of the last strategic vision survey, a large fraction of Gemini users think that a substantial fraction of Gemini time should be spent following up LSST transients. For example, ˜30% of users think that at least 30% of Gemini's time should be spent on LSST follow-up. The reasoning for this is obvious. With exposure times of less than a minute, the majority of LSST transients will be brighter than 23rd magnitude, relatively easy targets for detailed follow-up from a facility such as Gemini.

It is the desire to enable fast transient follow-up of LSST transients and to maximize science output from observations of non-transient LSST targets that has largely guided the on-going upgrades and enhancements to both Gemini telescopes. Example enhancements include an upgrade to the Gemini-North laser for improved adaptive optics imaging, and improvements to the software and hardware backend to dramatically enhance response times and enable dynamic scheduling response to transient alerts. In particular, Gemini has become a partner of the Astronomical Event Observation Network, and will respond to brokered LSST alerts. Full details of the upgrade program will be provided in a forthcoming strategic plan document.

In addition to strong support for LSST follow-up, equally strong support was given to preserve PI-lead science capabilities of normal, non-transient science. That is, member proposed standard queue observations, but will encompass triggered programs in response to LSST alerts, and observations of non-trigger targets, so best serve both the LSST, and the non-LSST Gemini users. Although many Canadian astronomers have interest in transient science, about twice as many fall into the latter category. While many of the upgrades to the Gemini telescopes are driven by transient follow-up, most of those upgrades are generic, and will improve most aspects of observing at Gemini.

Canadian astronomers could consider the LSST-light data centre as a necessary upgrade in their observing capabilities. Like for the MSE, the CADC LSST-light data products will first and foremost provide interesting targets for detailed follow-up with the Gemini telescope. With the CADC compute infrastructure, it will be a relatively straight forward process to mine the transient and stationary source catalogs for targets of a given type or class, eg. cepheid variables, or high-redshift active galactic nuclei, or even targets that haven't been reliably classed from LSST observations alone.

In addition to straight forward target selection, Gemini provides observing capabilities not afforded by the LSST data alone, including medium to high resolution spectroscopy, and high spatial resolution observations in both the optical and NIR. The combination of observation from both telescopes will provide opportunity for extremely rich scientific dataset that wouldn't be afforded by either telescope alone. Clearly, access to the LSST-light dataset (at the very least!) is necessary for the Canadians to remain at the forefront of optical-NIR observational astronomy.

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