Evaluation of the NRC's Herzberg Astronomy and Astrophysics Research Centre

Office of Audit and Evaluation

November 29, 2021

Final Report

National Research Council Canada | Conseil national de recherches Canada

Canada

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Abbreviations and acronyms

- **ALMA:** Atacama Large Millimeter/submillimeter Array
- **ACURA:** Association of Canadian Universities for Research in Astronomy
- **ATD:** Astronomy Technology Directorate
- **BMS**: Business Management Support
- **BC:** British Columbia
- **CAD:** Canadian
- **CADC:** Canadian Astronomy Data Centre
- **CASCA:** Canadian Astronomical Society / Societé canadienne d'astronomie
- **CASTOR**: Cosmological Advanced Survey Telescope for Optical and UV Research
- **CFHT:** Canada-France-Hawaii Telescope
- **CFI:** Canada Foundation for Innovation
- **CHIME**: Canadian Hydrogen Intensity Mapping Experiment
- **CHORD:** Canadian Hydrogen Observatory and Radio-transient Detector
- **CNC:** Canadian National Committee
- **CS:** Computer Systems Administrator
- **CSA:** Canadian Space Agency
- **DAO:** Dominion Astrophysical Observatory
- **DRAO:** Dominion Radio Astrophysical Observatory
- **EDI:** Equality, Diversity and Inclusion
- **EVLA:** Expanded Very Large Array
- **FY:** Fiscal Year
- **FTE:** Full-time equivalent
- **FRB:** Fast Radio Burst
- **GBA Plus:** Gender-based Analysis Plus
- **GIRMPS:** Gemini InfraRed Multi-Object Spectrograph
- **GMOS:** Gemini Multi-Object Spectrographs
- **GPI:** Gemini Planet Imager
- **Gs&Cs:** Grants and Contributions
- **HSE:** Health, Safety and Environment
- **IP:** Intellectual Property
- **JVLA:** Jansky Very Large Array
- **JWST:** James Webb Space Telescope
- **KITS:** Knowledge, Information and Technology Services
- **LoI:** Letter of Intent
- **LNA:** low noise amplifiers
- **LRP:** The Canadian Astronomy Long Range Plan
- **MoU:** Memorandum of Understanding
- **NFIRAOS:** Narrow Field InfraRed Adaptive Optics System
- **ngVLA:** Next Generation Very Large Array
- **NRAO:** National Radio Astronomy Observatory
- **NRC:** National Research Council of Canada
- **NRCan:** Natural Resources Canada
- **NSERC:** Natural Sciences and Engineering Research Council
- **OAD:** Optical Astronomy Directorate
- **OAE:** Office of Audit and Evaluation
- **OGD:** Other governmental departments (Canadian federal)
- **PDF:** Postdoctoral Fellows
- **PRC:** Peer Review Committee
- **RAD:** Radio Astronomy Directorate
- **RASC:** Royal Astronomical Society of Canada
- **RCO:** Research Council Officer
- **RO:** Research Officer
- **RPPM:** Real Property Planning and Management Branch
- **SPIRou:** Spectropolarimetre Infrarouge
- **SKA:** Square Kilometre Array
- **SSC:** Shared Services Canada
- **STEM:** Science, technology, engineering and mathematics
- **TO:** Technical Officer
- **TMT:** Thirty Meter Telescope
- **UVIT:** Ultra violet imaging Telescope

Introduction • Herzberg Astronomy and Astrophysics Research Centre

An evaluation of the Herzberg Astronomy and Astrophysics Research Centre was conducted in 2021. It assessed the research centre's relevance and performance. This report provides an overview of the main findings and conclusions as well as recommendations.

Introduction

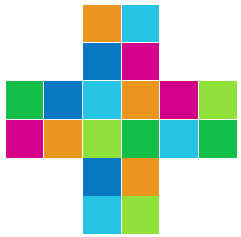
The evaluation of the National Research Council's (NRC) Herzberg Astronomy and Astrophysics Research Centre covered the period of 2016-17 to 2020-21. The research centre was last evaluated in 2015-2016. The evaluation was carried out in accordance with the NRC's approved evaluation plan, Treasury Board's Policy on Results (2016) and the requirements of the *Financial Administration Act*.

This report begins by providing a profile of the research centre. It then presents evaluation findings on the research centre's scientific excellence, relevance, engagement, capabilities, and a summary of expected results. Following the evaluation findings are 5 recommendations for improvements to the Herzberg Astronomy and Astrophysics Research Centre.

In this report, you will see the following symbols:

This symbol indicates information that is useful to know to help understand the findings.

This symbol indicates a quote that helps illustrate or support the main findings.



This symbol indicates information that supports equity, diversity, inclusion and Gender-Based Analysis Plus (i.e., factors that illustrate how diverse groups may experience policies, programs and initiatives).

Sources: These are the methods from which the findings are drawn. The sources are listed at the bottom of each page.

Evaluation approach

Approach

This evaluation used a mixed-methods approach, incorporating both qualitative and quantitative data from several lines of evidence. This allowed for triangulation (i.e., convergence of results across lines of evidence) and complementarity (i.e., developing better understanding by exploring different facets of a complex issue) of the evaluation findings. In addition, a Gender-Based Analysis Plus lens was applied throughout the evaluation.

Methods

The evaluation included:

- document review
- data review (administrative and performance data)
- survey of Canadian astronomers and astrophysicists (n=133, 17% response rate)
- internal focus groups and interviews (n=28)
- external interviews (n=16)
- peer review with national and international experts (n=6)

Evaluation questions

Scientific Excellence

1. To what extent is the Herzberg Astronomy and Astrophysics Research Centre a leader in scientific excellence?

Relevance

2. Is the Herzberg Astronomy and Astrophysics Research Centre focussed on the right areas?

Engagement

3. Has the Herzberg Astronomy and Astrophysics Research Centre engaged with the most appropriate partners and collaborators in the most effective ways?

Capabilities

4. To what extent does the Herzberg Astronomy and Astrophysics Research Centre have the capacities, competencies and facilities to achieve its objectives?

Summary of Expected Results

5. To what extent has the Herzberg Astronomy and Astrophysics Research Centre achieved or contributed to its expected results?

For more detailed information on the methods, including limitations, refer to appendix A. Short biographies of each peer review member are located in appendix B.

Profile • Herzberg Astronomy and Astrophysics Research Centre

The Herzberg Astronomy and Astrophysics Research Centre operates Canada’s national observatories, manages Canada’s participation in international ground-based facilities and provides merit-based access to these observatories for Canada's astronomy research community. The research centre identifies and addresses next generation astronomical technologies and works with academic partners on cutting-edge science to serve the Canadian astronomy community. The Herzberg Astronomy and Astrophysics Research Centre designs and deploys new astronomical instruments as well as providing large-scale scientific computing infrastructure and specialized astronomy data management expertise.

Research centre structure

The Herzberg Astronomy and Astrophysics Research Centre is under the NRC's Emerging Technologies Division. It obtains strategic guidance from the Herzberg Astronomy and Astrophysics Research Centre Advisory Board, which comprises 10 members from government, academia, research and industry. The members of the Advisory Board are expected to provide independent and neutral expert advice to the research centre's Director General.

Figure 1. The Herzberg Astronomy and Astrophysics Research Centre organizational structure

Sources: Document review

Herzberg Astronomy and Astrophysics Research Centre

The Herzberg Astronomy and Astrophysics Research Centre is mandated by the ***National Research Council Act*** to "operate and administer any astronomical observatories established or maintained by the Government of Canada."

The research centre's **vision** is to be a leader among the world's national astronomy programs by enabling Canadians to perform research at the highest level of international science.

The Herzberg Astronomy and Astrophysics Research Centre's **mission** is to drive research excellence through international partnerships in world-class observatories and collaborate across the global innovation system to provide facilities and instruments that push technological boundaries forward through cutting-edge science and creative engineering.

Guiding principles

- **The *National Research Council Act***
- **International Contributions Program:** the international agreements carry obligations to ensure that observatory use is merit-based and commit the partners to maintain the facilities at competitive levels
- **Long Range Plan (LRP):** the plan provides the context for operational decisions, prioritization of projects, deployment of resources, development of new competencies and capital investments
- **University community engagement:** engagement with various university and research networks, such as the Association of Canadian Universities for Research in Astronomy (ACURA), to provide continuous external validation of the Herzberg Astronomy and Astrophysics Research Centre's internal work ensuring its relevance in supporting the astronomy community in achieving its goals

Approach

- **Observatory support:** engages in governance, manages observatory access, provides expert assistance, operates Canadian Astronomy Data Centre (CADC)
- **Research community support:** provides on-site observatory staff and distributed operations for observatories (including maintaining a unique site for community radio telescopes)
- **National and international scientific and engineering leadership:** enables large-scale science and instrumentation development projects as well as adjunct positions within the Herzberg Astronomy and Astrophysics Research Centre
- **The Herzberg Astronomy and Astrophysics Advisory Board:** provides independent strategic advice to the Herzberg Astronomy and Astrophysics Research Centre from diverse perspectives, representing the range of the astronomy community (government, academia, research and industry)

See appendix C for the Herzberg Astronomy and Astrophysics Research Centre's logic model

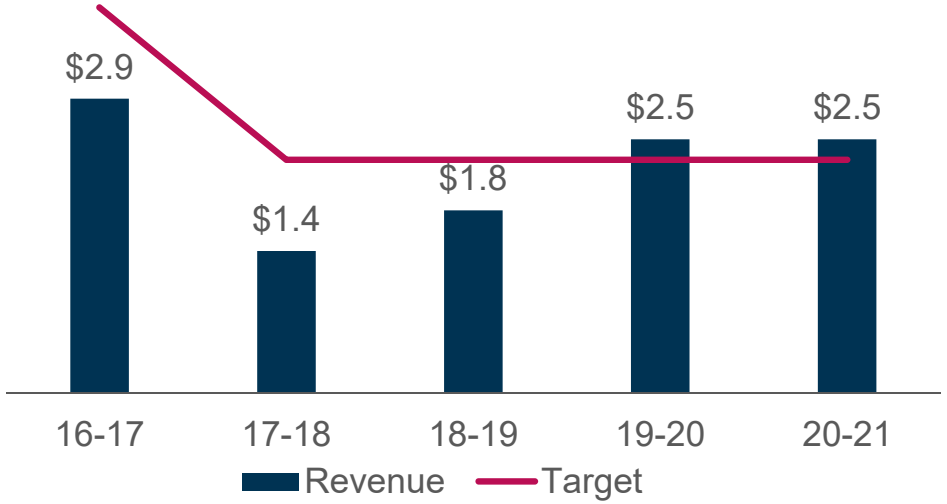
Sources: Document review

Financial resources

Most revenues generated by strategic research

- Over the evaluation period, the Herzberg Astronomy and Astrophysics Research Centre generated $11.1M in revenues and $242M in expenses.
- The nature of the NRC is to make investments into science. Revenues are not intended to exceed expenses.
- Strategic research revenue accounted for 86% ($9.5M) of the research centre's total revenue over the evaluation period, while technical service revenues accounted for 12% ($1.3M). Other revenue sources (2% of total over the evaluation period, $274K) came from royalties and licenses, lease and use of property, sales of goods and information and products, and grants and contributions.
- It is important to note that the research centre's revenues are not linear and are based on a few large-scale international projects with partner organizations. The research centre does not have the ability to adjust revenue targets on a year-by-year basis.

Figure 2. Total revenue (in millions) was below the revenue target from 2016-2019



Total expenses yearly average **$48.4 million**

Lowest Year	$44.3M (2017-18)
Highest Year	$52.8M (2019-20)

Technical services versus strategic research? Technical services are services that assist clients in solving immediate technical problems through the delivery of specialized fee-for-service support, whereas strategic research consists of research projects often conducted in collaboration with partners.

In order to reallocate resources to real property and major capital, the NRC has introduced a **10% reduction over 3 years** for all NRC research centres and corporate branch budgets beginning in 2021-22. Like other research centres, managing increasing costs will be a challenge for the Herzberg Astronomy and Astrophysics Research Centre, as it reduces its spending in the short-term to meet this requirement.

Sources: Document and data review, internal focus groups and interviews

Human resources

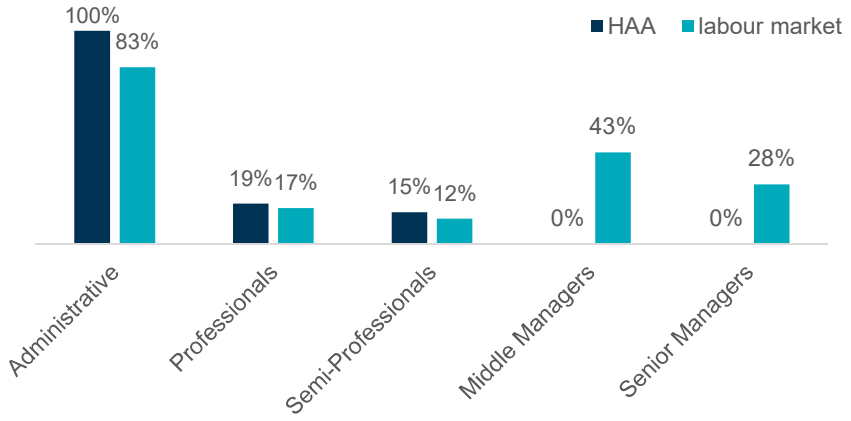
Workforce

- As of March 31, 2021, the Herzberg Astronomy and Astrophysics Research Centre had a total of 149 staff including 89 technical and scientific researchers, 11 technical officers, 25 students (both graduate and co-op), 21 administrative/corporate staff and 5 management staff (includes Directors and the Director General).
- In addition, there are 14 Common Services FTEs that directly support the Herzberg Astronomy and Astrophysics Research Centre (report centrally, but managed by the Herzberg Astronomy and Astrophysics Research Centre Operations Director).

Gender, diversity, and inclusion

- When compared to labour market availability, the Herzberg Astronomy and Astrophysics Research Centre has good representation of women in administrative, professional as well as semi-professional and technical positions. There were no women, however, in the 5 middle (Directors and Managers) or 1 senior management (Director General) positions.
- As is the case across the NRC's research centres, visible minorities, Aboriginal people and persons with disabilities are all underrepresented in the Herzberg Astronomy and Astrophysics Research Centre's occupational groups. As there are fewer than 5 Aboriginal people and persons with disabilities at the Herzberg Astronomy and Astrophysics Research Centre's the workforce availability data were unavailable for these groups.

Figure 3. Workforce representation of women at the Herzberg Astronomy and Astrophysics Research Centre compared to labour market availability



Sources: Document and data review, internal focus groups and interviews

Clients and collaborators

The Herzberg Astronomy and Astrophysics Research Centre's clients and collaborators consist almost exclusively of the users of the observatories they support, including international partnerships that operate and administer offshore observatories. Over the evaluation period, the Herzberg Astronomy and Astrophysics Research Centre had a total of 45 signed agreements (16 Canadian and 29 international) with a total revenue of $8.3M*. It should be noted that 85% of the total revenue, over the evaluation period, was from 15 signed agreements.

Other Government Departments

- 5 agreements with Canadian Federal Government entities
- Total revenue of agreements is $0.8M
- Responsible for 10% of total revenue

Academia & Others**

- 25 agreements
- 20% Canadian and 80% international
- Total revenue of agreements is $4.4M
- Responsible for 52% of total revenue

***Includes associations, organizations and observatories*

Industry

- 15 agreements
- 40% Canadian and 60% international
- Total revenue of agreements is $3.1M
- Responsible for 38% of total revenue

**Total revenue over the evaluation period ($11.1M) includes both revenue from agreements signed during the evaluation period (valued at $8.3M) as detailed above and revenues remaining from agreements signed prior to the evaluation period.*

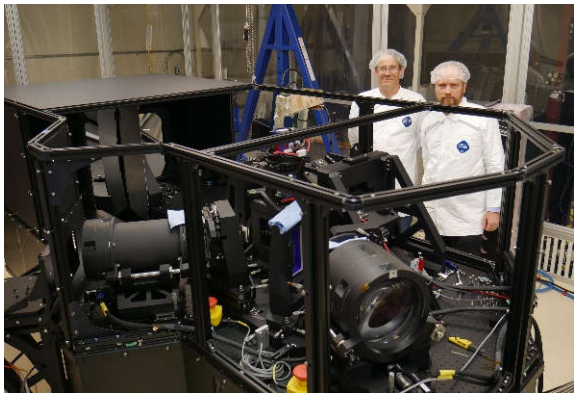
Sources: Data and document review

Directorates

To fulfill its mandate and to advance the LRP, the Herzberg Astronomy and Astrophysics Research Centre operates 3 directorates: the Optical Astronomy Directorate, the Radio Astronomy Directorate and the Astronomy Technology Directorate.

The Dominion Astrophysical Observatory

The John A. Galt Telescope



GHOST optical bench

Optical Astronomy Directorate (OAD)

- Operates at the Dominion Astrophysical Observatory (DAO) site and includes the Canadian Astronomy Data Centre
- Supports and facilitates access to optical, ultraviolet and infrared telescopes for Canadian astronomers
- Provides in-kind and contracted support for the operation of Canada's UV/optical/IR observatories, and acts as the interface between these observatories and the Canadian astronomy community
- Operates and manages the onsite 1.8-m Plaskett and 1.2-m telescopes

Sources: Document review

Radio Astronomy Directorate (RAD)

- Operates at both the DAO and the Dominion Radio Astrophysical Observatory (DRAO) sites
- Supports and facilitates access to millimeter/submillimeter and centimeter observatories
- Acts as the interface between the Canadian astronomy community and the Atacama Large Millimetre/submilimeter Array (ALMA), and provides scientific and technical services to support Canada's national and international radio telescopes
- Supports the hosting of University owned telescope experiments at the DRAO

Astronomy Technology Directorate (ATD)

- Operates at both DAO and DRAO sites
- Designs and develops instruments and observatory infrastructure for the national and international telescope facilities supported by Canada
- Provides scientific, technical and advisory services

For a list of areas of expertise, refer to appendix D.

Facilities

- The Herzberg Astronomy and Astrophysics Research Centre maintains 2 Canadian facilities and participates in 3 international facilities and is also involved in 2 future international facilities.
- The Herzberg Astronomy and Astrophysics Research Centre operates out of the Dominion Astrophysical Observatory (DAO; Victoria, British Columbia (BC)) and the Dominion Radio Astrophysical Observatory (DRAO; Penticton, BC). The CADC operates out of the DAO facility.

Canadian facilities

- Dominion Astrophysical Observatory (DAO)
- Dominion Radio Astrophysical Observatory (DRAO)

International facilities

- Atacama Large Millimeter / submillimeter Array (ALMA)
- Canada-France-Hawaii Telescope (CFHT)
- Gemini Observatory

Future facilities

- Square Kilometre Array (SKA)
- Thirty Meter Telescope (TMT)

Figure 4. DAO (Victoria) and DRAO (Penticton) are located in British Columbia

For more information on these facilities, refer to appendix E.

Sources: The Herzberg Astronomy and Astrophysics Research Centre website

Scientific excellence • Herzberg Astronomy and Astrophysics Research Centre

The Herzberg Astronomy and Astrophysics Research Centre is a leader in scientific excellence. It has contributed to a variety of scientific achievements and technological developments which continue to have positive impacts on the field of astronomy and have been recognized by national and international science communities. The Herzberg Astronomy and Astrophysics Research Centre has developed instrumentation that is used by domestic and international astronomers. The research centre is very involved in international committees, working groups and advisory boards, which maintains Canada's presence on the international stage. Scientists and Postdoctoral Fellows at the research centre produce significant levels of publications, exceeding annual NRC targets. CADC data have contributed towards many refereed scientific publications.

Scientific achievements and technology development

The Herzberg Astronomy and Astrophysics Research Centre has contributed to a variety of scientific achievements and technological developments which have continuing positive impacts on the field of astronomy. The research centre has developed instrumentation that is used by domestic and international astronomers.

Key examples of the Herzberg Astronomy and Astrophysics Research Centre scientific achievements

Over the evaluation period, the research centre's contributions have led to:

- **development of new instrumentation**, including: the Square Kilometre Array (SKA) Correlator and Beam Former, the Thirty Meter Telescope (TMT), Narrow Field InfraRed Adaptive Optic System (NFIRAOS), Gemini Infrared Multi-Object Spectrograph (GIRMOS) and Gemini Planet Imager (GPI)
- **new scientific discoveries relating to priority research questions in astronomy** (e.g., astrometric reference frame for the NASA New Horizons mission)
- **industry applications** (e.g., Calian Advanced Technologies built a dedicated facility in Saskatoon, Canada to produce a new line of 6-m and 10-m composite dish antennas for satellite communications at higher frequencies based on Herzberg Astronomy and Astrophysics SKA-related technology)

- The Herzberg Astronomy and Astrophysics Peer Review Committee (PRC) found that for a small organization, **the Herzberg Astronomy and Astrophysics Research Centre manages an impressive number of research and technical projects** and is providing high value to Canadian astronomers.

Use of Herzberg Astronomy and Astrophysics developed instrumentation is an indication of scientific excellence

- Between 2012-2017, the research centre contributed to the design and construction of 2 advanced high-resolution spectrographs (SPIRou at CFHT and NIRPS at ESO/La Silla) that conduct large, dedicated surveys for rocky planets around hundreds of M-type stars.
- **Major Herzberg Astronomy and Astrophysics instruments operating at large observatories are heavily used** to deliver high-impact science. These include the WIDAR correlator for the Jansky Very Large Array (JVLA), the ALMA Band 3 receivers and the Gemini Multi-Object Spectrographs (GMOS).
- **50% of the observing time at Gemini uses GMOS** even though these twin spectrographs were commissioned nearly 20 years ago.
- The research center's support for Canadian Hydrogen Intensity Mapping Experiment (CHIME) in terms of site location, postdoctoral fellows (PDFs) and staff will contribute to the detection and localization of nearly all CHIME-detected Fast Radio Bursts (FRBs).

"The Herzberg Astronomy and Astrophysics Research Centre has the ability to punch above its weight continually on the international stage and to support the universities in their pursuits of new missions such as CHIME." **—Herzberg Astronomy and Astrophysics Peer Review Committee**

Sources: Document and data review, online survey, internal focus groups, internal and external interviews, and peer review

Presence and recognition on the international stage

The Herzberg Astronomy and Astrophysics Research Centre is very involved in international committees, working groups, and advisory boards, which maintains Canada's presence on the international stage. The research centre is recognized by the national and international science communities for its contributions to astronomy research.

The Herzberg Astronomy and Astrophysics Research Centre's involvement at astronomy gatherings

- From 2016 to present, Herzberg Astronomy and Astrophysics staff participated in **66 committees** (49 international), **12 international working groups and 11 advisory boards**.
- Over the same time period, staff attended **54 national and international astronomy conferences** and made presentations at 39 national and international institutes, conferences and workshops.
- Research centre staff are recognized, by stakeholders, for their ability to bring parties together and to help address sensitive issues, such as those around Indigenous engagement or equity, diversity and inclusion (EDI) goals.

CHIME, Penticton B.C

The Herzberg Astronomy and Astrophysics Research Centre awarded nationally and internationally

Over the evaluation period, research centre staff were recognized for their contributions to research through national and international awards, including:

- Governor General's Innovation Award (2020)
- Guggenheim Award (2020)
- Fellow into Royal Society of Canada (2020)
- Breakthrough Initiative's New Horizons in Physics Prize (2020)
- American Astronomical Society's Warner and Rubin Prizes (2019)
- Gruber Prize for cosmology (2018)
- Natural Sciences and Engineering Research Council Herzberg Gold Medal (2016)

Sources: Document and data review, online survey, internal focus groups, internal and external interviews, and peer review

Publications

Over the evaluation period, the Herzberg Astronomy and Astrophysics Research Centre produced significant levels of publications, exceeding annual targets. In addition, CADC data contributed towards many refereed scientific publications.

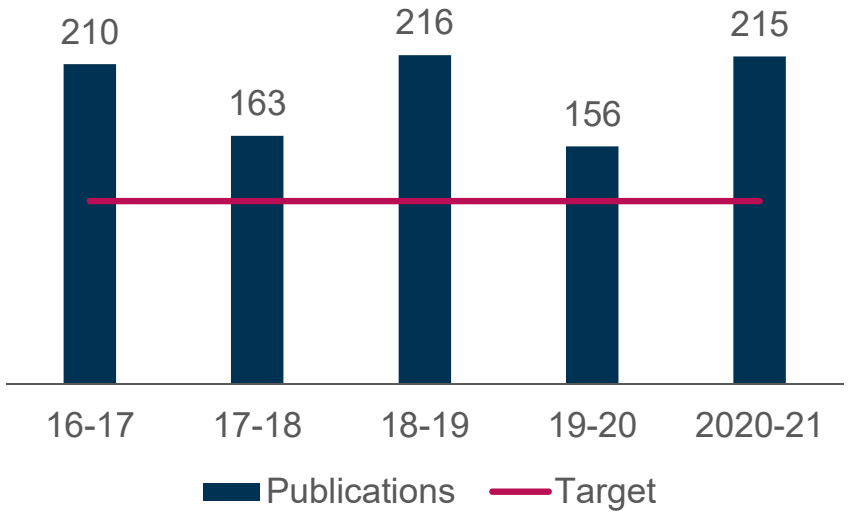
The Herzberg Astronomy and Astrophysics Research Centre successfully publishes its research

- Over the evaluation period, the research centre published 960 unique peer-reviewed publications, **exceeding their 5-year target** of 600.
- Citation scores varied between 1.72 and 2.36, also **exceeding the annual NRC average citation** score of 1.5.
- The **research centre employs highly regarded scientists** who are actively advancing astronomical science and publishing their findings on a wide variety of topics.
- The PRC noted that the research centre is publishing in **high-impact scientific journals,** such as **nature** and has produced highly regarded engineering papers.
- Since the 2016 evaluation, the research centre's access to domestic telescopes resulted in 49 refereed publications and access to international telescopes led to 796 refereed publications.

Key numbers coming out of the CADC

- The **data from the CADC are seen as highly relevant for the astronomy community**; 723 refereed publications have acknowledged the use of CADC data over the evaluation period.
- In addition, over the past 5 years, **membership registration for the CADC has increased** from 4,498 to 8,000.

Figure 5. From 2016-17 to 2021-22 publication numbers were above targets



Sources: Document and data review, online survey, internal focus groups, internal and external interviews, and peer review

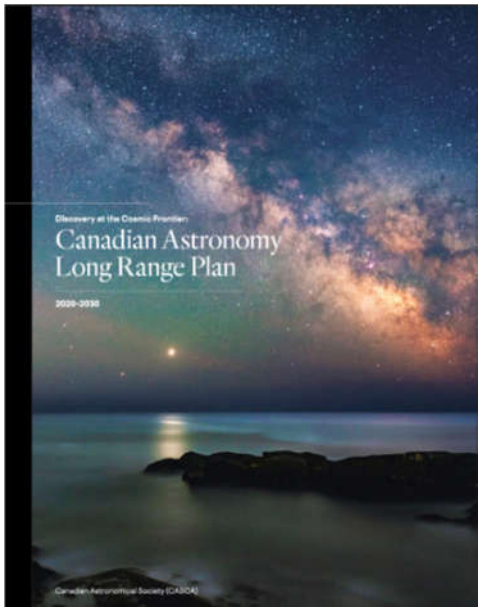
Relevance • Herzberg Astronomy and Astrophysics Research Centre

The Herzberg Astronomy and Astrophysics Research Centre's activities and strategic priorities are closely aligned with the needs of the Canadian astronomy community, which indicates the research centre's relevance. New domestic facilities such as CHIME and the Canadian Hydrogen Observatory and Radio-transient Detector (CHORD) show strong focus and relevance. In addition, the research centre supports the strategic objectives of the federal government and the NRC.

Alignment with the needs of the Canadian astronomy community

The Herzberg Astronomy and Astrophysics Research Centre relies on the direction of the Canadian Astronomical Society's Long Range Plan for Canadian Astronomy. This ensures that the research centre's activities and strategic priorities are closely aligned with the needs of the Canadian astronomy community.

- To ensure that the Herzberg Astronomy and Astrophysics Research Centre's activities and strategic plans are aligned with the research needs and demands of the Canadian astronomy community, the research centre takes direction from the **Long Range Plan for Canadian Astronomy** (LRP).
- For example, LRP 2010 identified the search for life beyond our Solar System ("Are we alone?") as a major scientific priority for the coming decades. This led the research centre to establish the **NEW EARTH Laboratory in 2019**, the only laboratory of its kind in Canada, to develop technologies and algorithms for very high-contrast imaging.
- As per the LRP 2020, the Herzberg Astronomy and Astrophysics Research Centre continues to participate in the development of future telescopes, contributes to the improvement of mid-scale facilities, lays the groundwork for space facilities and engages in Canada's digital research infrastructure with the CADC.
- The PRC reported that there is **an opportunity for the Herzberg Astronomy and Astrophysics Research Centre to update its current strategic plan** to reflect the LRP 2020 as well as recent developments in the future facilities (i.e., TMT and SKA).
- The committee also reported that the research centre may find value in broadening its expertise in operations and management of facilities, to complement its other core areas of expertise, such as the CADC.



Cover of the Long Range Plan 2020
Source: © Canadian Astronomical Society / Société canadienne d'astronomie

Long Range Plan

- The LRP was established by the Canadian Astronomical Society/ La Société Canadienne d'Astronomie (CASCA) in collaboration with the NRC and the Natural Sciences and Engineering Research Council of Canada (NSERC) and is supported by the Royal Astronomical Society of Canada (RASC).
- The LRP reports **the consensus of the Canadian astronomical community** regarding future directions and research.

Sources: Document review, facility reviews, online survey, internal focus groups, internal and external interviews and peer review

Alignment with the needs of the Canadian astronomy community

The Herzberg Astronomy and Astrophysics Research Centre provides access to relevant domestic and international telescopes, which are oversubscribed by astronomers. There is limited awareness among external stakeholders of the existence and purpose of the Herzberg Astronomy and Astrophysics Advisory Board.

The Research Centre's engagement in international and domestic facilities indicates relevance

- The PRC found that the Herzberg Astronomy and Astrophysics Research Centre's **activities and engagement in international research facilities,** such as ALMA, Jansky Very Large Array (JVLA), SKA, Next Generation Very Large Array (ngVLA), TMT, Gemini and CFHT, as well as **new domestic facilities** such as CHIME and CHORD are **indicators of its strong focus and relevance.**
- Survey respondents who engage in ground-based observational research use **a wide range of ground-based telescopes**, including but not limited to those supported by Canada.

of survey respondents that engage in ground-based observational research requiring access to telescopes, reported that the **international telescopes supported by Canada are critical to their research needs**

of the same respondents reported that the domestic ground based telescopes (located at the DAO and the DRAO) were critical to their research

- Both international and domestic **telescopes supported by Canada are oversubscribed by astronomers**, demonstrating their relevance.

The Herzberg Astronomy and Astrophysics Advisory Board

- The Herzberg Astronomy and Astrophysics Advisory Board was implemented in response to the **2016 evaluation recommendation** to establish a formal consultation process to allow the Canadian astronomy community to provide strategic advice on the research centre's scientific activities and priorities.
- The Advisory Board **provides diverse perspectives** representing the range of the astronomy community (10 members from: government, academia, research and industry).
- The Advisory Board provides **strategic recommendations** to the research centre (e.g., the development of a formal internal process to prioritize the Herzberg Astronomy and Astrophysics Research Centre's participation in projects).
- Among external stakeholders from the Canadian astronomy community, there is **limited awareness of the existence of the board and its purpose.** As a result, there may be a risk that the research centre has not included the broader perspective of Canadian astronomy community in their activities and priorities.

Sources: Document review, facility reviews, online survey, internal focus groups, interviews and external interviews and peer review

Alignment with the federal and the NRC priorities

The Herzberg Astronomy and Astrophysics Research Centre is aligned with strategic objectives of the federal government including advancing fundamental science, fostering the next generation of scientists, and making science collaborative. The research centre is also aligned with the NRC's mandate and strategic goals.

Aligns with the strategic objectives of the federal government

- The Herzberg Astronomy and Astrophysics Research Centre's current and future objectives are aligned with federal government objectives of **pursuing fundamental research** (Budgets 2019 & 2021) and ensuring **pure science** is available to researchers and the public through the CADC (2019 NRC President's Mandate Letter).
- Canada's Science Vision identifies the goals of **fostering the next generation of scientists** and making **Canadian science more collaborative**. The research centre meets these goals by training students and Postdoctoral Fellows (PDFs), and through its partnerships with universities, institutes and industry on research projects.

Aligns with the NRC's mandate and strategic areas of focus

- The research centre fulfills the NRC's mandate **"to operate and administer any astronomical observatories established or maintained by the Government of Canada."**
- The Herzberg Astronomy and Astrophysics Research Centre supports the NRC's strategic area of focus of **understanding our world through fundamental scientific research** by contributing to large astronomical projects and the advancement of astronomy.
- The Herzberg Astronomy and Astrophysics Research Centre also supports the NRC's strategic area of focus of **creating Canadian wealth through innovation** by employing Canadian small and mid-size enterprises (SMEs) to supply technical solutions for observatories and by engaging with SMEs to apply the Herzberg Astronomy and Astrophysics Research Centre developed astronomical technologies to industry, such as the prototype dishes developed for SKA now used by industry in Saskatchewan, Canada.

Sources: Document review, facility reviews and internal interviews and focus groups

Engagement • Herzberg Astronomy and Astrophysics Research Centre

The Herzberg Astronomy and Astrophysics Research Centre has been effective in establishing and maintaining strong partnerships and collaborations with key national and international partners. By participating in major international and domestic astronomy projects, the research centre demonstrates effective engagement with appropriate partners and collaborators. The range of services and support offered by the research centre is well known within the Canadian astronomical community, but awareness could be enhanced internationally, within industry, among students and the public. The Herzberg Astronomy and Astrophysics Research Centre has increased its work with other NRC research centres. As the research centre's facilities (DAO, DRAO) are situated on traditional Indigenous lands, the research centre maintains ongoing consultations and engagement with local Indigenous communities.

Collaborations and partnerships

The Herzberg Astronomy and Astrophysics Research Centre has strong collaborations and partnerships with Canadian and international universities and institutes. To a lesser degree, the research centre has also established national and international industry partnerships, which have led to commercial spin-offs and technological applications within industry.

Canadian and international collaborations and partnerships

- Most of the Herzberg Astronomy and Astrophysics Research Centre's activities include partners and collaborators which allow for knowledge transfer, access to specialized skill sets and assistance in managing complex projects. **The research centre relies on these collaborations to increase efficiency**.
- Over the evaluation period, the Herzberg Astronomy and Astrophysics Research Centre engaged with **Canadian** (e.g., Calian Advanced Technologies in Saskatoon, Canada) **and international** (e.g., EMSS in South Africa) **industry partners, government departments** (e.g., Canadian Space Agency - CSA), and **university and research networks** (e.g., the International Association of Universities for Research Astronomy).
- Some of these relationships are contracting-out agreements, with elements of collaboration, knowledge transfer and capacity building.
- The PRC found the research centre has **a good track record in terms of commercial engagement**, including commercial spin-off of Intellectual Property (IP) and other technical developments to industry.
- In addition, the PRC reported that the research centre has energetic engagements that led to the development of new ideas such as the astrophotonics project (briefly described in the Collaboration with other NRC research centres section).

Calian Advanced Technologies (Saskatoon, Canada)

- The Herzberg Astronomy and Astrophysics Research Centre partnered with Calian Advanced Technologies to provide knowledge and expertise to build radio dish antennas from composite materials.
- This new type of antenna delivers a high beam quality for an efficient use of receiving and transmitting power due to its surface smoothness, stiffness and thermal stability.
- Based on knowledge acquired from the research centre, Calian Advanced Technologies has a dedicated division producing these dish antennas.

EMSS (South Africa)

- The Herzberg Astronomy and Astrophysics Research Centre has worked with EMSS to provide low noise amplifiers (LNAs) for cryogenic radio astronomy receiver systems.
- EMSS supplies the MeerKAT observatory (a precursor to the much larger SKA) with these receiver systems and will contribute to the development of the SKA.

Sources: Document review, internal focus groups, internal and external interviews and peer review

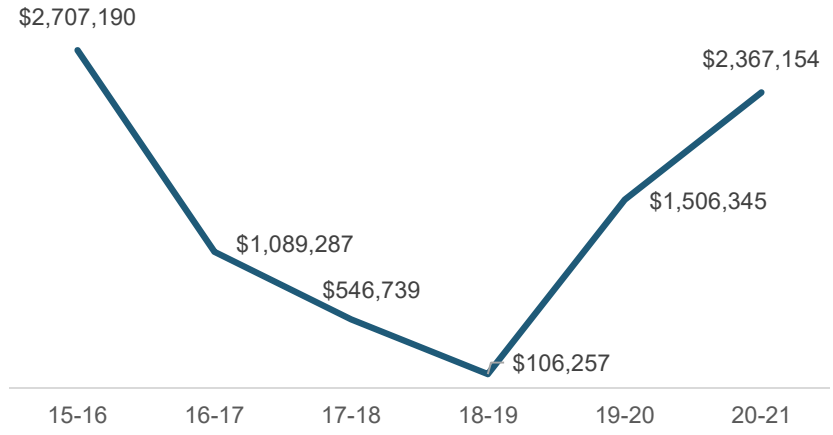
Collaborations and partnerships

Over the evaluation period, the Herzberg Astronomy and Astrophysics Research Centre signed 45 agreements with Canadian and international partners. The research centre partners with specific organizations in order to gain expertise and build internal capacity. The Herzberg Astronomy and Astrophysics Research Centre's strong reputation within the astronomy community has supported its ability to attract national and international partners.

Strategic partnerships

- Over the evaluation period, the Herzberg Astronomy and Astrophysics Research Centre signed **45 agreements** with Canadian and international partners with a **total revenue of $8.3M**.
- The research centre has engaged with major telescope organizations (e.g., ALMA, Gemini, SKA, TMT) to allow the Canadian astronomy community access to leading facilities.
- The PRC indicated that through participation in major international and domestic astronomy projects, the Herzberg Astronomy and Astrophysics Research Centre demonstrates **effective engagement with appropriate partners and collaborators**, including some strategic partnership arrangements with industry.
- The PRC remarked that the research centre tend to partner early with external organizations to gain specific expertise (e.g., staff became engaged in TMT management to increase complex project management skills) which **increases internal capacity and reduces project risks.**
- The Herzberg Astronomy and Astrophysics Research Centre's expertise and strong project management have led to a **solid reputation within the astronomy community** and have strengthened its ability to attract national and international partners.

Figure 6. Total revenue for partnership agreements by fiscal year*



**2015-2016 data were included as some revenues associated with that fiscal year's agreements were received during the evaluation period.*

"The Herzberg Astronomy and Astrophysics Research Centre brings in external assistance early to gain specific expertise to augment their technical talent and to mitigate risk." **—Herzberg Astronomy and Astrophysics Peer Review Committee**

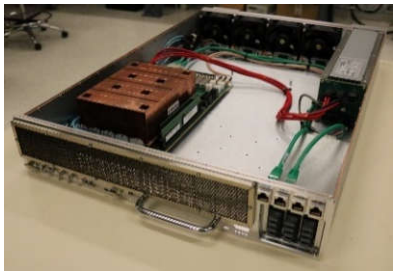
Sources: Document review, internal focus groups, internal and external interviews and peer review

Working with other research centres and awareness of the Herzberg Astronomy and Astrophysics Research Centre

Since 2016, The Herzberg Astronomy and Astrophysics Research Centre has increased its collaborations with other NRC research centres. There may be opportunities for the research centre to seek further collaborations with other NRC research centres. While the Herzberg Astronomy and Astrophysics Research Centre is well known within the Canadian astronomy community, within industry, internationally and among the public, there are opportunities to increase awareness.

Collaborations with other NRC research centres

- Within the NRC, the Herzberg Astronomy and Astrophysics Research Centre has evolved from working in isolation, as observed in the 2016 evaluation, to **developing collaborations with other NRC research centres**, including the Nanotechnology Research Centre (e.g., lower-voltage deformable mirrors for image quality for Finding Earth 2.0) and the Advanced Electronics and Photonics Research Centre (e.g., astrophotonic chip development for instrumentation to discover life outside our solar system).
- There may be opportunities for the Herzberg Astronomy and Astrophysics Research Centre to seek further collaborations with other NRC research centres.



TALON board

Opportunities to increase awareness

- While the Herzberg Astronomy and Astrophysics Research Centre is well known in the Canadian astronomy community, there is less awareness within some segments of the international astronomy community, industry and among the public.
- The PRC suggested that the research centre **improve communication** of its outcomes and successes to both external stakeholders and the public.
- In addition, the PRC felt that the research centre could improve its strategies for connecting to industry by taking **a more targeted approach** such as exploring opportunities for industry training and internships to enhance staff capacity and skills in-line with the Herzberg Astronomy and Astrophysics Research Centre's expected results.
- Among students, beyond the universities that the Herzberg Astronomy and Astrophysics Research Centre engages with (e.g., University of Victoria, University of Montreal, McGill University and University of Toronto), there is **limited awareness of research opportunities** at the research centre or options for PDFs.
- According to survey respondents, the CADC provides significant support to the astronomy community. However, there is a perception among external stakeholders and the PRC that **others within the community are not fully aware of all services that the research centre offers**, such as research collaboration opportunities and data support provided by CADC.

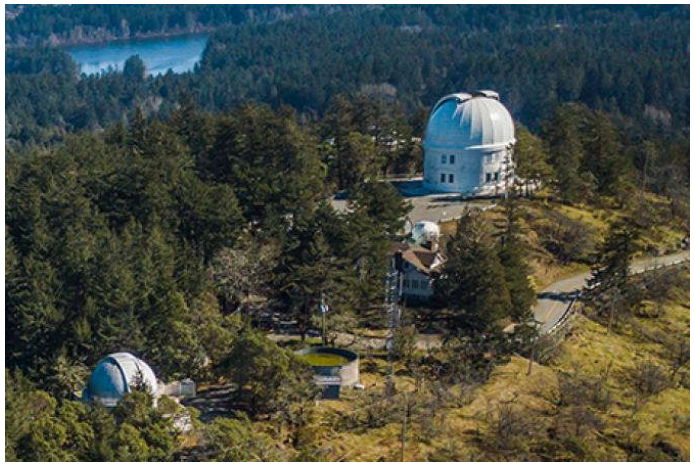
Sources: Document review, internal focus groups, internal and external interviews and peer review

Indigenous engagement and environmental sustainability

The Herzberg Astronomy and Astrophysics Research Centre has established connections with local Indigenous communities. The research centre also plays a leadership role in Indigenous dialogue internationally and ensures environmental sustainability of the DAO and DRAO sites.

The DAO in Victoria is part of the Douglas Treaties and the DRAO in Penticton is located on unceded territory of the Sylix peoples. The Herzberg Astronomy and Astrophysics Research Centre recognizes its moral and legal obligation to consult and engage with local First Nations when there is potential for impact from any planned project.

- The Herzberg Astronomy and Astrophysics Research Centre staff reported a **positive relationship with the local Indigenous communities** where transparent, on-site consultations and engagement are ongoing, on an as-needed basis.
- The Herzberg Astronomy and Astrophysics Research Centre staff also reported that the DRAO has a long-standing relationship with the Okanagan Nation Alliance based on **personal ties, aligned interests, trust and respect** and that the DAO has recently begun to meet with the W̱SÁNEĆ Leadership Council to discuss opportunities such as sharing Indigenous knowledge at public observing nights and research/training opportunities.
- External stakeholders and the PRC recognized that **the research centre is actively engaging with local Indigenous communities** and is sensitive to ensuring that Indigenous groups determine the extent and type of engagement in consultation with the research centre.
- External stakeholders reported that the Herzberg Astronomy and Astrophysics Research Centre **is known to play a leadership role in Indigenous dialogues in international settings**.
- The research centre also works to ensure **environmental sustainability** of the DAO and DRAO sites, e.g., by engaging with the NRC's Health, Safety and Environment Office for any environmental issues such as the preservation of species-at risk.



The Dominion Astrophysical Observatory (DAO) and surrounding lands
Source: Research Facilities Navigator

No Indigenous individuals from the local communities were interviewed as part of this evaluation. These findings represent the views of the research centre, external stakeholders and peer review committee members.

Sources: Document review, internal focus groups, internal and external interviews and peer review

Capabilities • Herzberg Astronomy and Astrophysics Research Centre

The Herzberg Astronomy and Astrophysics Research Centre has had the capacities, competencies and facilities needed to achieve its objectives, but many of the operational challenges highlighted in the 2016 evaluation persist, including resource constraints, challenges with IT infrastructure/support and lengthy procurement processes. With the increasing complexity and size of projects, the research centre has implemented a project prioritization/selection process to manage project demands with current resources. The workforce of the Herzberg Astronomy and Astrophysics Research Centre lacks diversity compared to the Canadian labour market availability. In addition, approximately 1/3 of the staff are eligible to retire over the next 5 years. The Herzberg Astronomy and Astrophysics Research Centre facilities are unique in Canada, however some are in need of maintenance or upgrading. The annual grants and contributions for Canadian access to international observatories have remained static since 2011, which could reduce the amount of time designated to Canadian astronomers in the future.

Centralization of services

The 2012 centralization of IT services under Shared Services Canada (SSC) continues to challenge efficiency and has had a negative impact on the operation of the research centre. Within the NRC, network security features, increased administrative tasks and lengthy procurement of basic workplace devices create challenges for the research centre.

CONTEXT

- In 2012, Shared Services Canada (SSC) was created. As per the federal *Shared Services Canada Act*, this department became the mandatory provider of IM/IT infrastructure services to the federal government. Part of all federal departments/organizations' IM/IT resources were transferred to SSC. A consolidated service delivery model was introduced and efforts to standardize the services were initiated.
- Prior to 2012, the Herzberg Astronomy and Astrophysics Research Centre IM/IT requirements were serviced by internal IM/IT specialists with subject matter expertise to respond to their unique IM/IT needs. As part of the implementation of the NRC's Strategy (2013-2018), IT supports and many administrative functions (e.g., human resources, finance, communications, facility management, business management, procurement) that were previously internal to the research centres were centralized within the NRC.

A reduction in services and efficiency

- IT improvements since the 2016 evaluation include a 10 gigabyte (GB) internet upgrade at the DAO, a 1GB internet upgrade at the DRAO and increased storage capacity for the CADC. **Despite improvements, challenges persist**.
- According to research centre staff, centralization of IT services under SSC has led to a **reduction in services and efficiency** for the research centre.
- There are few on-site staff that are equipped to deal with the research centre's specialized dynamic requirements and SSC staff lack scientific expertise to respond to the research centre's specialized technical needs.
- Because SSC's data storage is insufficient for the quantity of data held at the CADC, the research centre has partnered with Compute Canada to **use a cloud processing system** to support data storage needs.

Sources: Document review, internal focus groups and interviews

Some NRC services create challenges for the research centre

- The NRC's network is slow due to **NRC IT security features**, which has led to inconsistent connections and video quality during virtual meetings, creating communication challenges when working with external partners.
- The research centre has experienced long delays in the procurement of basic workplace technology devices, such as laptops for researchers.
- With the centralization of NRC services, **the research centre lost dedicated support specialists.** Hiring, onboarding, travel arrangements and ergonomic assessments have been delegated to researchers and supervisors, increasing workload and shifting priorities away from research and management to administrative tasks.
- The NRC must follow the Government of Canada's **standardized formatting** for all research centres' webpages. As content is the responsibility of the Communications Branch, the research centre must seek their approval, which can affect their ability to provide rapid updates and specific content.
- The PRC found that the research centre should improve its communication of both outcomes and successes (through its website) to external stakeholders.

Project size and selection

The number, scope and complexity of astronomy projects are increasing. In response, the Herzberg Astronomy and Astrophysics Research Centre is working to leverage external funding opportunities from collaborative projects and has recently implemented a project prioritization/selection process to balance project demands with current resources. In some cases, the research centre is reducing the number and scope of projects it can support.

- With the current level of resources, the Herzberg Astronomy and Astrophysics Research Centre **effectively managed its operations over the evaluation period** (e.g., consistently exceeded publication goals and met revenue targets for the last two years).
- In addition to NRC funding, the research centre is working to **leverage external funding opportunities** with other NRC research centres, industry and academia.
- In some cases, balancing project demand with available resources has reduced the number and scope of projects the research centre can support and in some cases has led to the **cancellation of projects** (e.g., engineering designs for the ngVLA 6m compact array).

Project Selection Process

- Based on advice from the Herzberg Astronomy and Astrophysics Research Centre Advisory Board, the research centre developed a **project selection process** and began implementing it in December 2020.
- The goal of this project selection process is to enable an **informed decision regarding engagement** in new opportunities by:
    - establishing a clear understanding of what the proposed opportunity is
    - reviewing how well matched it is to the research centre and NRC strategic objectives
    - assessing the extent to which it satisfies needs in the Canadian astrophysics research community
    - considering what the resource and management implications would be for the Herzberg Astronomy and Astrophysics Research Centre
- According to the PRC, this selection process is important and occurs in **a fair, consistent and open manner**.
- As this project selection process was only implemented in December 2020, the evaluation was not yet able to assess its impacts.

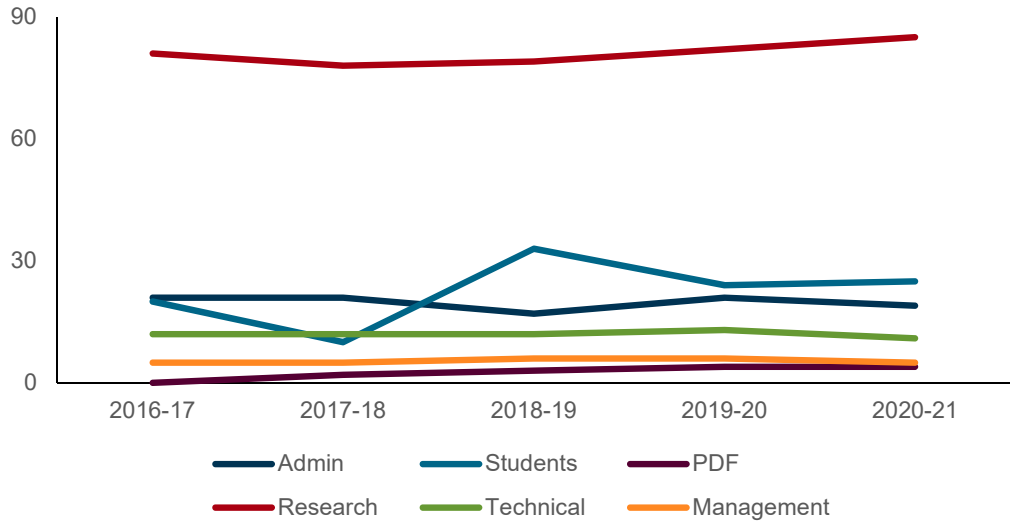
Sources: Document and data review, internal focus groups and interviews and peer review

Staffing and succession planning

With approximately 1/3 of the research centre's workforce eligible to retire within 5 years, the research centre has created a succession plan that includes EDI considerations.

- About 26% of the research centre's staff are over 56 years of age and approximately **1/3 will be eligible to retire over the next 5 years**.
- The research centre has created a succession plan that identifies critical positions, highlights current employees qualified to act should there be an immediate requirement and emphasizes **increasing diversity** when filling positions vacated by retirements.
- The research centre's workforce, including management positions, **is under-represented in most employment equity designations**, compared to the Canadian labour market availability. In response, the research centre:
    - established an EDI Committee (2020)
    - participates in an environmental sustainability committee
    - provided NRC diversity and gender-bias training to staff
- The research centre has adapted its hiring posters to emphasize the flexibility of job requirements and accommodations available and ensures hiring panels are diverse, using external panel members as required.

Figure 7. Over the evaluation period staffing remained relatively stable



Sources: Document and data review, internal focus groups and interviews and peer review

Facilities

The Herzberg Astronomy and Astrophysics Research Centre facilities are unique in Canada, however some are in need of maintenance or upgrading. Canadian astronomers are satisfied with the process to access both domestic and international observatories. The CADC is critical for research and the centre is working to improve its services.

The research centre provides researchers access to both domestic and international observatories

- The Herzberg Astronomy and Astrophysics research centre has a **strong track record** in managing national astronomy facilities and in participating in international facilities.
- According to the NRC facility reviews, **the research centre's facilities are unique in Canada**, providing researchers with core capabilities and expertise in the development of observatory instrumentation, however **some facilities are in need of maintenance or upgrading** (e.g., DAO 1.8-m Plaskett and DRAO Synthesis Telescope).
- The PRC reported that the research centre has **invested in the infrastructure necessary for future projects** such as the new integration facility in Victoria, BC.
- Located on the DRAO site and completed in 2017, CHIME, a university owned and Herzberg Astronomy and Astrophysics Research Centre supported telescope experiment, was designed to learn more about dark energy. There are no other comparable radio telescopes to the CHIME in the northern hemisphere.

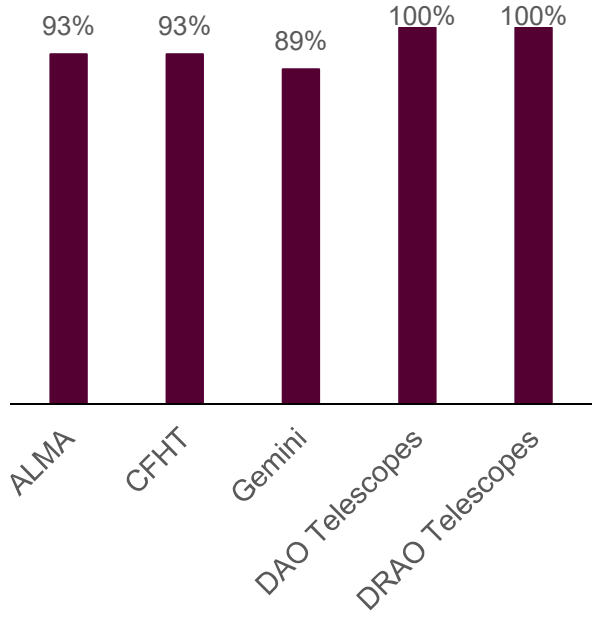
CADC is critical to research needs, some improvements underway

- 82% of survey respondents reported that access to the CADC is **critical to their research needs**. A small number (n=10 or 13%) commented that the user interface and search engine of the CADC could be improved.
- Suggestions include improving the ability to select data based on more specific criteria, a multi-use hub that analyzes and processes data with Python and a more responsive search engine to access and extract data. The research centre's staff report that many of these improvements are underway.

Sources: Document review, online survey and internal interviews

Facility reviews were conducted for all NRC major facilities by the **NRC Finitiatives team** and an external committee of experts.

Figure 8. Survey respondents were satisfied with the efficiency of the application process for accessing the research centre's domestic and international telescopes



Grants and contributions

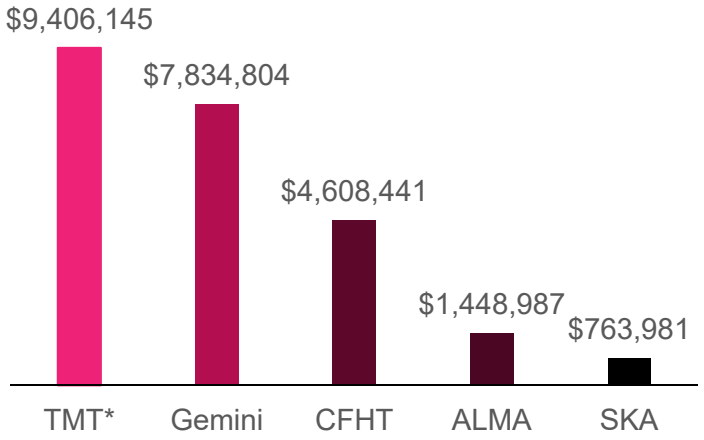
The annual grants and contributions (Gs&Cs) for Canadian access to international observatories have remained static since 2011 and do not account for rising inflation or fluctuating international exchange rates. In the absence of increased Gs&Cs, there may be a reduction in the amount of telescope time designated to Canadian astronomers in the future.

Canada's participation in international telescopes relies on 2 Gs&Cs programs

The Herzberg Astronomy and Astrophysics Research Centre receives funding for Canada's participation in international telescopes. The 2 programs are:

- **Annual International Telescope Grants & Contributions (Gs&Cs) Program:** provides an annual allocation to fund Canada's participation in international telescopes: ALMA, Gemini, CFHT and supports Canada's participation in SKA
- **TMT (Gs&Cs) Program:** funds Canada's participation in the development of the TMT. The Herzberg Astronomy and Astrophysics Research Centre leads Canada's participation in TMT and the research centre's Director General is a standing Board Member on the TMT International Observatory.

Figure 9. Grant and contribution values for 2020-21



**TMT contributions began in 2018-19*

The research centre manages the annual Gs&Cs which do not account for inflation or exchange rates

- The Herzberg Astronomy and Astrophysics Research Centre effectively manages the annual Gs&Cs for the international telescopes. Flexibility in the terms and conditions of the Gs&Cs allows observatories to allocate the funding to the areas of highest need.
- The dollar value of the Gs&Cs, established in 2011, does not account for rising inflation or fluctuating international exchange rates. Historically, gaps in funding have been covered by the NRC. In the absence of increased Gs&Cs, there may be a reduction in the amount of telescope time designated to Canadian astronomers in the future. ($1 CAD in 2011 is equivalent to $1.18 CAD in 2021).

Gs&Cs values over the evaluation period were **similar**, but varied year-to-year due to exchange rates.

Sources: Document and data review, internal focus groups, and internal and external interviews

Summary of expected results • Herzberg Astronomy and Astrophysics Research Centre

Based primarily on findings from previous sections, this section provides a summary of how the Herzberg Astronomy and Astrophysics Research Centre is achieving or contributing to its 5 expected results.

The research centre is highly capable in managing both national facilities and Canada's participation in international facilities. While significant challenges exist in relation to the Thirty Meter Telescope (TMT) and the Square Kilometer Array (SKA), the factors affecting these projects are beyond the control, but not the influence, of the research centre. The research centre offers significant training and research opportunities for students and Postdoctoral Fellows. The Herzberg Astronomy and Astrophysics Research Centre demonstrates a strong ability to provide research support that aligns with the needs of the Canadian astronomy community and plays a critical role in contributing to Canada’s position as a world leader in astronomy.

The Herzberg Astronomy and Astrophysics Research Centre's expected results (as identified in the research centre's strategic plan (2017-18 to 2021-22):

a. manage Canada's current suite of national and international facilities
b. provide Canadian astronomers with access to national and international observatories
c. contribute to the training of students and PDFs
d. provide research support services as requested by the Canadian astronomy community and required by observatories
e. contribute to Canada's position among world's leaders in astronomy

Access to Canada's national and international facilities *(expected results a and b)*

The Herzberg Astronomy and Astrophysics Research Centre manages Canada's current suite of national and international facilities and provides Canadian astronomers with access to national and international observatories.

- The Herzberg Astronomy and Astrophysics Research Centre is **effectively managing** Canada's current suite of national and international facilities and has **been efficient in facilitating access to both national and international observatories**. (See section Capabilities: Facilities)
- Canadian astronomers report that the **application process for accessing the national and international observatories is efficient** and that staff provide high-quality support to applicants. (See section Capabilities: Facilities)
- There is a **high demand for both domestic and international facilities** managed by the research centre. Both international and domestic telescopes supported by the Herzberg Astronomy and Astrophysics Research Centre are **oversubscribed by astronomers.** (See section Relevance: Alignment with the Canadian astronomy community)
- There is the potential for future challenges in terms of Canadian access to the international telescopes as the value of the Herzberg Astronomy and Astrophysics Research Centre Gs&Cs **has been static since 2011** and does not account for inflation or fluctuating international exchange rates. (See section Capabilities: Grants and contributions)

Canada-France-Hawaii-Telescope (CFHT)

Sources: Document and data review, internal focus groups, and internal and external interviews

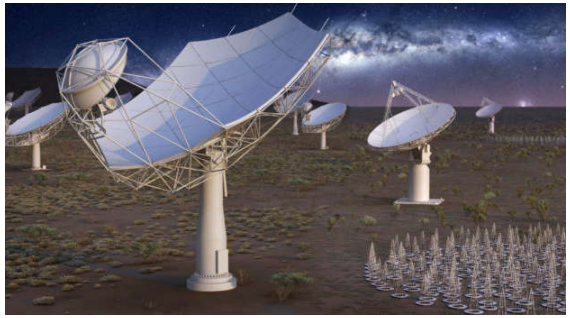
Access to Canada's national and international facilities

Significant challenges exist in relation to the Thirty Meter Telescope (TMT) and the Square Kilometer Array (SKA). The factors affecting these projects are beyond the control of the Herzberg Astronomy and Astrophysics Research Centre, but not beyond the research centre's influence.

Challenges surrounding TMT and SKA

- There have been significant challenges with the construction of TMT (e.g., delayed Mauna Kea access negotiations, rising project costs and partners shifting funding to health related fields) and with the SKA (e.g., construction delays and funding uncertainty).
- Although the factors affecting these projects are beyond the control of the research centre, **it seeks to mitigate risks by contributing to constructive dialogue with international partners**.
    - In the case of TMT, the research centre continues design work and supports project-wide efforts to secure funding
    - For SKA, the Herzberg Astronomy and Astrophysics Research Centre is exploring other applications for already developed technology to preserve the value of the investments in instruments designed for SKA

Rendering of TMT Complex, Source: TMT Organization



Artist's impression of SKA, Source: The SKAO Public Website

PRC recommends the Herzberg Astronomy and Astrophysics Research Centre use influence with regards to TMT and SKA

- The PRC recommended that the research centre continue to exert its influence on these major international projects through its roles on international committees and by working in collaboration with the Canadian community and other related organizations (e.g., CASCA, ACURA) **to ensure Canada's future participation and to preserve Canada's significant investment in these projects.**
- In addition, the research centre should **clearly communicate the risks associated with these larger projects to the Canadian astronomy community** to ensure that the community's expectations for the research centre's resources are managed.

Sources: Document and data review, internal focus groups, and internal and external interviews

Training of students and postdoctoral fellows *(expected result c)*

The research centre offers significant training and research opportunities for students and PDFs, however more could be done to increase awareness among students. Increased awareness could also help the research centre attract more women and minority-group students.

Between 2016-17 and 2020-21, the Herzberg Astronomy and Astrophysics Research Centre supervised 92 co-op and 20 graduate students, and employed 13 PDFs.

Overall satisfaction with PDF program, but some challenges

- Students were generally satisfied with the co-op and graduate selection process. The research centre offers **very attractive PDF positions with competitive funding**.
- Students and PDFs reported that the Herzberg Astronomy and Astrophysics Research Centre has had **a positive impact on their early careers** by providing:
    - **flexibility** to choose their research interests
    - access to opportunities in a **large variety of research areas**
    - ability to **network and participate in research collaborations**
    - **sufficient funding** for travel and conference fees
- The selection process for PDFs, however, has some challenges:
    - the NRC posts PDF job opportunities according to its internal schedule, which is not aligned with the general astronomy PDF hiring season which occurs in the fall and winter
    - this **misalignment reduces the candidate pool** as many of the PDFs have already been hired elsewhere, by the time the research centre posts their available positions

Increasing awareness and opportunities

- The Herzberg Astronomy and Astrophysics Research Centre could increase awareness of opportunities among students, both nationally and internationally, which **could attract more women and minority-group students** to the field of astronomy and astrophysics.
- There may be opportunities to provide students with **greater industry exposure** and technical career development.
- The PRC found that the research centre could establish a stronger **mentoring system for early career researchers**, including skill development tools.

Preparation Work for CHORD Prototype

Sources: Data review, internal focus groups, internal and external interviews, and peer review

Research support services
(expected result d)

The Herzberg Astronomy and Astrophysics Research Centre demonstrates a strong ability to provide research support that aligns with the needs of the Canadian astronomy community, however there may be opportunities to increase awareness of the research centre's services. On the other hand, astronomy projects are increasing in size and cost, which limits the number of projects the research centre can undertake, thus strengthening the need for the recently developed project selection process.

Opportunities to increase awareness of services

- The research centre offers strong research, technology and data support services and aligns these service with the needs of the Canadian astronomy community. (See section Relevance: Alignment with the Canadian astronomy community)
- While the research centre is **well known within the Canadian astronomy community**, external stakeholders expressed that not all researchers are aware of the full range of services, such as the potential for research collaborations. (See section Relevance: Alignment with the Canadian astronomy community)
- The data and technical support provided by the CADC are also seen by many survey respondents (82%) as critical to their research needs, however there is a perception among external stakeholders and the PRC that others within **the community are not fully aware of all services that the research centre offers,** including the data support provided by CADC.

Astronomy projects are becoming more complex

- The research centre's ability to provide greater research support is **limited by available resources** (i.e., budget and staff). The availability of resources determines which projects are supported and the scope of the research centre's involvement. (See section Capabilities: Project size and selection).
- In general, astronomy projects are becoming larger, more complex and more expensive. As a result, **the research centre developed a project selection process** whereby project participation is assessed against the research centre's strategic plan and available resources. (See section Capabilities: Project size and selection).

Sources: Document and data review, internal focus groups and internal and external interviews

Contribution to Canada's position in astronomy *(expected result e)*

The Herzberg Astronomy and Astrophysics Research Centre plays a critical role in contributing to Canada's position as a world leader in astronomy. However, the future of Canada's performance in astronomy is uncertain.

The research centre plays a significant role in Canada's position

- Canada has maintained its **overall high ranking position in astronomical science** over the evaluation period. External stakeholders rank Canada highly, as do independent web rankings, **ranging from 3rd – 6th**, from The World University Rankings, Scimago Journal and Country Ranking, and Kenznow.

of survey respondents indicated that the **research centre has been an important factor in Canada's performance in astronomy**

- According to the PRC, **the research centre delivers high impact** for the Canadian astronomy community and **its expertise is world-leading and highly regarded** (e.g., expertise in high contrast imaging for exoplanet research, its support of high performance computing and legacy data resources, and its active role in both science and technical support and development for CHIME).

Factors affecting Canada's future in astronomy

- Although **the research centre consistently participates in high-impact projects**, it is challenging for the research centre to commit to these large, long-term projects, as Canada does not have a clear process to fund them.
- While Canada continues to move forward in astronomical science, there is concern among external stakeholders that **other countries are moving faster** and that due to the present funding structure, Canada is struggling to keep pace.
- The fate of the **TMT and Canada's funding decisions around SKA are critical in determining Canada's position in the field**, which by extension could impact the research centre.
- Stakeholders recognize that should TMT remain stalled and Canada not engage financially in SKA, it would be a significant setback in light of all the **time and resources the Herzberg Astronomy and Astrophysics Research Centre has invested** into these longstanding complex projects.

"The Herzberg Astronomy and Astrophysics Research Centre should preserve and expand its core forward-looking technology and scientific research that will bolster the long-term success of the research centre and Canadian astronomy overall." **—Herzberg Astronomy and Astrophysics Peer Review Committee**

Sources: Document review, internal focus groups, internal and external interviews, and peer review

COVID-19 impacts

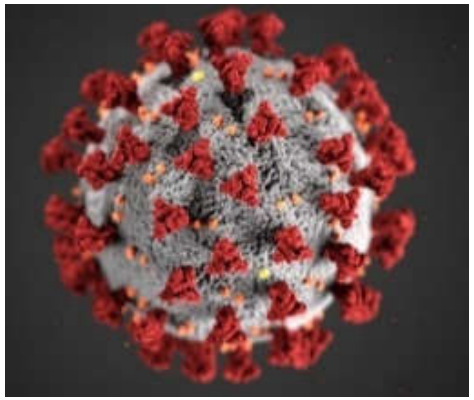
COVID-19 has affected the Herzberg Astronomy and Astrophysics Research Centre in a number of ways, providing both challenges and opportunities.

Challenges

- COVID-19 has affected the research centre in a number of ways, including allowing **fewer opportunities for students and PDFs to network** or to form critical relationships with project partners.
- **Travel restrictions** have affected international projects such as the installation of new technology developed for GEMINI South.
- In addition, the ability **to attract international PDFs has been curtailed**.

Opportunities

- Despite these challenges, the research centre **met and in some instances exceeded its targets during COVID-19** (e.g., publications, number of collaborators working with the research centre).
- COVID-19 also provided new opportunities for staff, including the development of **targeted virtual groups** such as the Optical Spectroscopy group, as well as **greater interactions between DAO and DRAO staff** (e.g., DVA2, 26-m upgrade, ARTTA-4 and the SKA digitizer).



Coronavirus
Source: Centers for Disease Control and Prevention (CDC)

Sources: Document and data review, internal focus groups, and internal and external interviews

Recommendations • Herzberg Astronomy and Astrophysics Research Centre

Recommendations and supporting rationale

Strategic Plan

The PRC recommended that both the LRP 2020 and the latest developments on the TMT and SKA be included in the research centre's strategic plan.

Recommendation 1

The Herzberg Astronomy Astrophysics Research Centre management team should update its strategic plan to reflect the 2020 LRP and the recent developments with the TMT and SKA.

Increase awareness

Both internal and external stakeholders reported limited awareness of the research centre within the international astronomy community, industry and the public.

The PRC suggested that the research centre improve communication of its outcomes and successes to external stakeholders and the public. The committee also recommended the research centre develop a targeted strategy for connecting with industry to enhance staff capacity and skills.

There are examples of collaboration between the Herzberg Astronomy and Astrophysics Research Centre and other NRC research centres. There may be opportunities for further collaboration among NRC research centres where areas of research overlap.

Recommendation 2

The Herzberg Astronomy Astrophysics Research Centre should develop a targeted strategy to increase engagement and awareness of its services, (e.g., CADC), its outcomes and its successes among:

a. Canadian astronomy community
b. International stakeholders
c. Industry
d. The public
e. NRC Research Centres

Improve IT solutions

Both staff and OGDs indicated that there are ongoing challenges with IT support for the Herzberg Astronomy and Astrophysics Research Centre. Although there have been some IT improvements since the 2016 evaluation, there continues to be a reduction in services and efficiency, which has had a negative impact on the operations of the research centre.

Recommendation 3

The NRC's Knowledge, Information and Technology Services (KITS) should develop concrete options to provide the research centre with responsive, flexible and appropriate services and IT solutions, taking into consideration available resources and government-wide centralization of IT services.

Recommendations and supporting rationale

Increase diversity

The Herzberg Astronomy and Astrophysics Research Centre workforce is currently under-represented in most employment equity targets groups including women in middle and senior management. The PRC also recommended that workforce diversity should be improved when filling positions vacated by retirement and that the research centre aim to attract high-profile diverse talent for high-level positions.

Recommendation 4

The Herzberg Astronomy Astrophysics Research Centre should develop and implement a strategic EDI plan that focusses on research excellence, student engagement, reducing barriers for women to become future leaders, as well as those for minority-group populations, and moving from consultation to empowerment for local Indigenous communities.

Early career mentoring and development

The PRC found that the research centre could be more proactive and impactful for its staff and the Canadian astronomy community in mentoring and career development. This could include working with universities to ensure appropriate mentoring and career development is occurring for Herzberg Astronomy and Astrophysics students. The research centre has the opportunity to become a leader in the professional development of early career researchers in Canada.

Recommendation 5

The Herzberg Astronomy Astrophysics Research Centre management team should develop a mentoring and career development strategy for its early career researchers, students and women in professional and semi-professional positions.

Management response action plan (MRAP)

Recommendation 1			
The Herzberg Astronomy Astrophysics Research Centre management team should update its strategic plan to reflect the 2020 LRP and the recent developments with the TMT and SKA. **Risk-level associated with not addressing recommendation:** low			
Management Response	**Proposed Person(s) Responsible**	**Measure of Achievements**	**Expected Date of Completion**
Response: Accepted **Action:** The research centre will update its 2019-2024 strategic plan based on the findings and recommendations from the 2020 Canadian Long Range Plan for Canadian Astronomy and the 2020 US Decadal Survey report to re-align its activities and priorities where required to ensure continuing relevance to its stakeholders and maintain its commitment to research excellence.	Director-General, Herzberg Astronomy Astrophysics Research Centre	**1.** Analysis of LRP2020 and Astro2020 reports complete **2.** Consultations with key stakeholders complete **3.** Strategic plan update complete	August 2022

Management response action plan (MRAP)

Recommendation 2
The Herzberg Astronomy Astrophysics Research Centre should develop a targeted strategy for increasing awareness/engaging, including the services provided (e.g., CADC), outcomes and successes among: a. Canadian astronomy community b. International stakeholders c. Industry d. The public e. NRC Research Centres **Risk-level associated with not addressing recommendation:** medium

Management Response	Proposed Person(s) Responsible	Measure of Achievements	Expected Date of Completion
Response: Accepted **Action:** The research centre and NRC Communications will jointly develop a communication plan on an annual basis. We will refocus this plan to fully integrate this recommendation, and we will seek additional resources to deliver on this plan given that the research centre has far fewer resources devoted to communications than other astronomy organizations of similar size or smaller.	R&D Director, Herzberg Astronomy Astrophysics Research Centre	**1.** In consultation with NRC Communications, identify key messages and approaches for reaching identified key target audiences **2.** Discussions with NRC Communications on allocation of additional resources completed **3.** New plan ready for implementation based on priorities and available resources	April 2022

Management response action plan (MRAP)

Recommendation 3			
The NRC's Knowledge, Information and Technology Services (KITS) should develop concrete options to provide the research centre with responsive, flexible and appropriate services and IT solutions, taking into consideration available resources and government-wide centralization of IT services. **Risk-level associated with not addressing recommendation:** medium			
Management Response	**Proposed Person(s) Responsible**	**Measure of Achievements**	**Expected Date of Completion**
Response: Accepted **Action:** This recommendation addresses an NRC-wide challenge with IT services and solutions. Through Program Mercury, KITS is working to address these NRC-wide IT challenges, including those specifically related to HAA. KITS has already been involved in conversations with HAA to identify IT related barriers and gaps for its research. Several solutions are currently being explored with HAA.	Chief Information Officer, Knowledge, Information and Technology Services	**1.** KITS has worked with HAA to better understand its IT requirements and issues. **2.** KITS has developed a plan in consultation with HAA, to address its research IT needs. The options in the plan will take into account the availability of resources for KITS and the Mercury Program to support research IT going forward at the NRC.	March 2022

Management response action plan (MRAP)

Recommendation 4			
The Herzberg Astronomy Astrophysics Research Centre should develop and implement a strategic EDI plan that focusses on research excellence, student engagement, reducing barriers for women to become future leaders and minority-group populations and moving from consultation to empowerment for local Indigenous communities. **Risk-level associated with not addressing recommendation:** medium			
Management Response	**Proposed Person(s) Responsible**	**Measure of Achievements**	**Expected Date of Completion**
Response: Accepted **Action:** The research centre will develop and implement a strategic EDI plan with at its core the recognition that diversity is a source of research excellence	R&D Director, Herzberg Astronomy Astrophysics Research Centre	**1.** Inclusion survey at Herzberg Astronomy Astrophysics Research Centre done **2.** Initial round of consultations with stakeholders and local communities completed **3.** Plan developed and implemented **4.** Local Indigenous teachings are included in joint outreach activities, and community members especially students have access to training opportunities **5.** Gap in visible minority representation within staff is significantly reduced and diversity in hiring committees and applicant pools is increased	**Actions 1, 2 and 3:** Apr 2022 **Actions 4 and 5:** Dec 2023

Management response action plan (MRAP)

Recommendation 5			
The Herzberg Astronomy Astrophysics Research Centre management team should develop a mentoring and career development strategy for its early career researchers, students and women in professional and semi-professional positions. **Risk-level associated with not addressing recommendation:** medium			
Management Response	**Proposed Person(s) Responsible**	**Measure of Achievements**	**Expected Date of Completion**
Response: Accepted **Action:** The NRC mentoring program is open to NRC employees at all levels, across all functions and from all locations across the country. The program enables connections between mentors and mentees on a range of topics including career development, managing work-life balance and acquiring new leadership skills. The research centre will raise awareness of this program among its staff and encourage participation as mentors and/or mentees at all levels. The research centre will consult with its early career researchers, students and women in professional and semi-professional positions and also use advice from NRC's Early Career Researcher Network (ECRN) to develop local opportunities as required.	R&D Director, Herzberg Astronomy Astrophysics Research Centre	**1.** Herzberg Astronomy Astrophysics Research Centre senior staff strongly encouraged to join NRC Mentoring program as mentors **2.** Training identified and mentors complete training **3.** All women in professional and semi-professional positions, early Career Researchers and students strongly encouraged to join NRC Mentoring program **4.** NRC mentoring program augmented with local opportunities as required	December 2022

Appendices • Herzberg Astronomy and Astrophysics Research Centre

Appendix A – Methodology

Document Review

Internal and external documents were reviewed to provide context and to complement other lines of evidence in assessing relevance and performance. Internal documents included the research centre logic model, operational and strategic plans, departmental reports, advisory board terms of reference and presentations, facility reviews and project prioritization documents. External documents included website information, telescope contribution agreements and documents related to government priorities.

Data Review

The research centre's administrative and performance data for 2016-17 to 2020-21 were reviewed to provide information on program inputs (i.e., resources), outputs and client engagement. This included key performance indicators, financial data, human resource data, project data and client data.

Survey of Canadian Astronomers and Astrophysicists

An online survey of Canadian astronomers and astrophysicists was conducted to assess the extent to which the Herzberg Astronomy and Astrophysics Research Centre's activities and objectives met the needs of the Canada astronomy community; the research centre's ability to provide access to national and international telescopes as well as research supports; and the scientific impacts from the telescope access and research supports.

The survey targeted members of ACURA universities or the Centre de recherche en astrophysique du Québec (CRAQ); Canadians researchers that have applied for time on domestic (DRAO, DAO) and/or international telescopes (CFHT, Gemini, ALMA); and researchers who have used CADC data from 2016 to present.

Survey invitations were sent to 767 individuals. A total of 133 respondents completed the survey, representing a 17% response rate.

Appendix A – Methodology

Internal Focus Groups & Interviews

Internal focus groups and interviews were conducted with a total of 28 individuals to collect information such as personal experiences, opinions and expert knowledge related to the research centre's relevance, engagement, resources, scientific excellence and achievement of expected results.

Focus groups included the research centre's Directors and the Head of the CADC (n=6), the Herzberg Astronomy and Astrophysics Advisory Board (n=6), Researchers and Technicians (n=5), students and PDFs (n=5). Interviews included the Director General of the Herzberg Astronomy and Astrophysics Research Centre, the Vice-President of Emerging Technologies and other key internal individuals (n=6).

Information was used to complement other lines of evidence and to contextualize quantitative information.

External Interviews

External interviews were conducted with stakeholders to collect qualitative evidence with regards to the research centre's relevance, engagement, facilities, scientific excellence and achievement of expected results.

A total of 16 external interviews were completed, including academics (n=9), industry partners (n=2), other federal government departments or agencies (n=2) and telescope directors (n=3).

Information gathered through the interviews provided contextual information and was used in conjunction with the other lines of evidence.

Peer Review Committee

A peer review committee was convened to assess the research centre's relevance, engagement and scientific excellence. The committee was composed of 6 members with expertise in astronomy and astrophysics (see appendix C for PRC members' biographies).

Members included national and international representatives from academia, research organizations and industry. To ensure objectivity and avoid conflicts of interest, peer review committee members signed a confidentiality and conflict of interest agreement.

Peer review members examined key research centre documents, the preliminary evaluation findings and facility reviews prior to participating in 4 virtual review sessions. Virtual sessions included presentations and poster sessions delivered by the research centre, a student session and discussions with the Herzberg Astronomy and Astrophysics Research Centre's Director General and senior management.

Based on the documents reviewed and the virtual sessions, the peer review committee produced a report that responded to each of the areas under assessment. This report was used as a line of evidence in the overall evaluation findings.

Appendix A – Methodology

Limitations and mitigation strategies

Although the evaluation encountered some challenges, methodological limitations were mitigated, where possible, through the use of multiple lines of evidence and the triangulation of data. This approach was taken to establish the reliability and validity of the findings and to ensure that conclusions and recommendations were based on objective and documented evidence. Details on limitations and their associated mitigation strategies are described below.

Low response rate to online survey

Higher response rates are generally associated with a lower non-response bias (i.e., bias in statistics when respondents differ from non-respondents), greater generalizability (i.e., how well the respondents compare with the population of interest) and greater statistical confidence in drawing conclusions. The response rate for the online survey was 17%, which is considered low but statistically valid. With a 95% confidence level there was a margin of error of 7%. An acceptable margin of error used by most survey researchers falls between 4-8% at the 95% confidence level*. Therefore the results are valid, but not generalizable to the entire Canadian astronomy and astrophysics population.

Mitigation

To mitigate the low survey response rate, no evaluation findings were based solely on survey results. Survey findings were examined in conjunction with findings from other lines of evidence to enhance the validity of the overall evaluation findings.

Availability of focus group participants

Some internal focus group participants were unable to attend the virtual focus group session due to competing priorities.

Mitigation

Focus group participants who were unable to attend the virtual focus groups were invited to submit their responses to the focus group questions in writing. Three focus group participants submitted written responses.

Lack of Indigenous perspective

The evaluation examined the research centre's engagement with local Indigenous communities, however no Indigenous individuals were interviewed. Therefore the findings related to the research centre's relationships with local Indigenous communities reflect only the perspective of the research centre, external stakeholders and peer review committee members.

Mitigation

The evaluation team conducted interviews with internal staff, NRC staff who act as the liaisons between the research centre and surrounding Indigenous communities as well as other external stakeholders.

***Source:** Margin of Error and sample Size Calculator. https://www.pollfish.com/margin-of-error-calculator/

Appendix B – Peer Review Committee members

Dr. Carole Jackson (Committee Chair)

Dr. Carole Jackson is the British/Australian past Director General of ASTRON, the Netherlands Institute for Radio Astronomy based at Dwingeloo in the Netherlands. She is an expert in extragalactic radio astronomy and technology research management, gained from working in commerce, industry and the research sectors through her long career. Whilst working for CSIRO Astronomy and Space Science (2003-2013), Dr. Jackson led the design and delivery of the 36 antennas forming the core part of the Australian SKA pathfinder telescope (ASKAP). She has a long association with the International Square Kilometre Array (SKA) project where she has worked closely with the Australian, and more recently, Dutch, governments to guide their business cases towards investing in the SKA.

Dr. Stefi Baum

Dr. Stefi Baum is currently on sabbatical from the University of Manitoba after serving as Dean of the Faculty of Science and Professor of Physics and Astronomy since October 1, 2014. She came to the University of Manitoba following ten years at the Rochester Institute of Technology (RIT) where she served as Professor and Director of the Chester F. Carlson Center for Imaging Science. Prior to RIT, Dr. Baum served just under 2 years as an American Institute of Physics Science Diplomacy Fellow at the U.S. Department of State where she worked to promote agricultural science and food security in developed and developing countries.

Dr. Mark Bentum

Dr. Mark Bentum received the PhD degree from the University of Twente, Enschede, The Netherlands in 1995. In 1996 he joined the Netherlands Foundation for Research in Astronomy (ASTRON). From 2005 to 2008 Dr. Bentum was responsible for the construction of the first software radio telescope in the world, LOFAR (Low Frequency Array). In 2008 he became an Associate Professor in the Telecommunication Engineering Group at the University of Twente. From December 2013 to September 2017 he was also the program director of Electrical Engineering at the University of Twente. In 2017 Dr. Bentum became a Full Professor in Radio Science at Eindhoven University of Technology. He is now involved with research and education in radio science. His current research interests are radio astronomy, short-range radio communications, novel receiver technologies (for instance in the field of radio astronomy), channel modeling, interference mitigation, sensor networks and aerospace. Since 2020 he is the head of the Astronomy & Operations department at ASTRON.

Appendix B – Peer Review Committee members

Dr. Makenzie Lystrup

As Vice President and General Manager of Civil Space, Dr. Mackenzie Lystrup is responsible for Ball Aerospace's portfolio of civil space systems that include science, operational weather and Earth observation, and advanced technologies development objectives. Dr. Lystrup joined Ball Aerospace in January 2013 in the company's Strategic Operations organization, based in Washington, D.C. She most recently served as Senior Director, Civil Space Advanced Systems and Business Development. Previously, Dr. Lystrup worked in the U.S. House of Representatives as a Congressional Science & Technology Policy Fellow. During her time, she managed an issue portfolio ranging from technology and privacy to national defense to nuclear energy and nonproliferation. In 2019, Dr. Lystrup was elected to the rank of Fellow of the American Association for the Advancement of Science for her distinguished record in the fields of planetary science and infrared astronomy, science policy and advocacy and aerospace leadership.

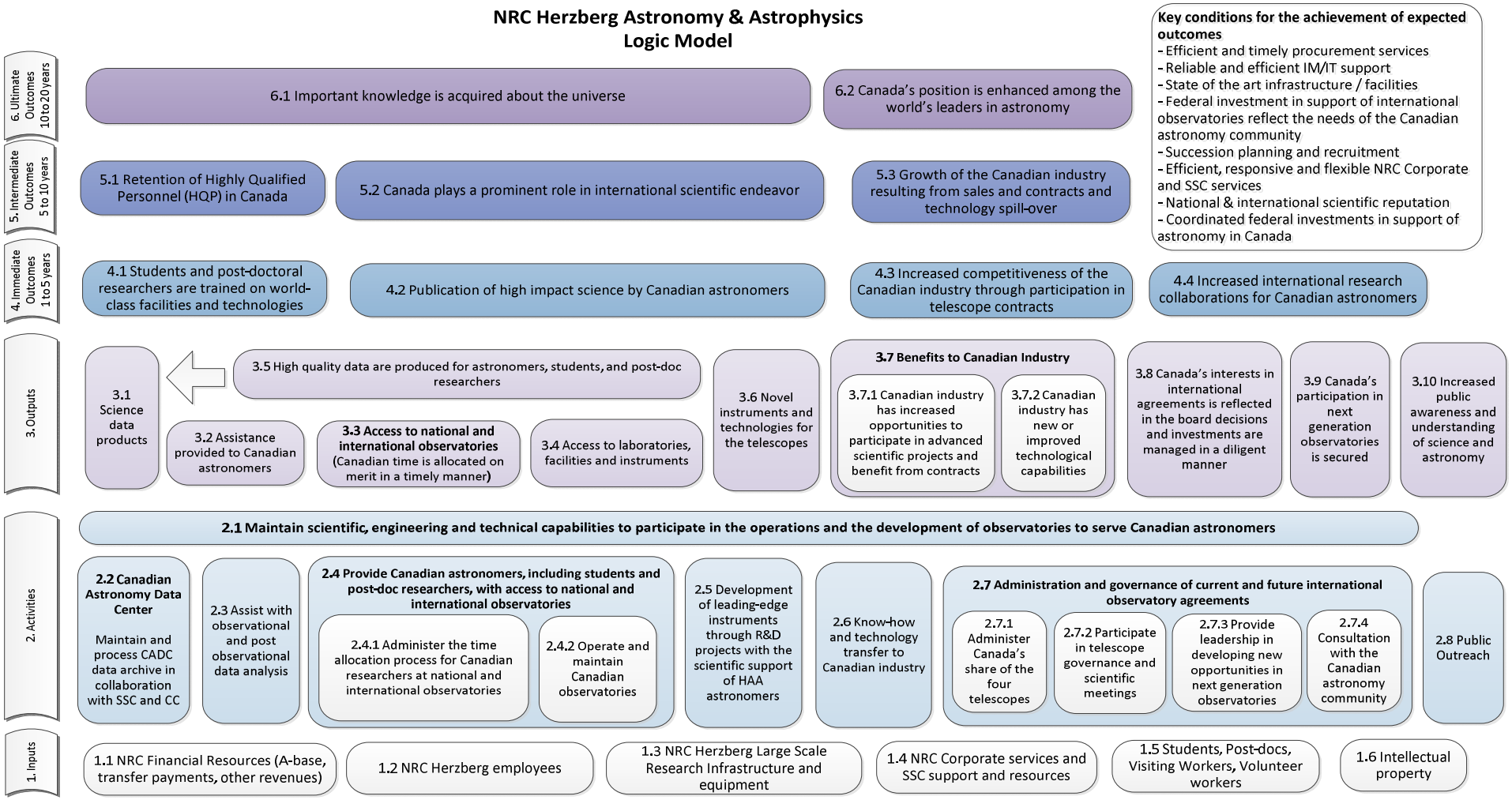
Dr. Mark McKinnon

Dr. Mark McKinnon is the Assistant Director for New Mexico Operations with the National Radio Astronomy Observatory in Socorro, New Mexico, USA. His department operates and maintains the Very Large Array and Very Long Baseline Array radio telescopes. He has over 25 years of experience in the design, construction, operation, and maintenance of large, ground-based radio astronomy facilities. Dr. McKinnon has held project management roles in the construction of the Green Bank Telescope, the Expanded Very Large Array, and the Atacama Large Millimeter Array. He has also led the Dish Consortium for the Square Kilometer Array. His research interests include pulsar astrophysics, polarimetry and statistics.

Dr Suzanne Ramsay

Dr Suzanne Ramsay is an astronomer working at the European Southern Observatory headquarters outside Munich, Germany. Dr. Ramsay is a specialist in infrared and optical ground based instrumentation and has delivered instruments and systems to the UKIRT, Gemini and VLT telescopes. She is the Instrumentation Manager for ESO's Extremely Large Telescope that is currently in development. In this role, Dr. Ramsay is responsible for the delivery of the first suite of instruments to the 39-m ground-based telescope, coordinating with consortia of instrument builders in the ESO member states. Dr. Ramsay also maintains an interest in astrophysical research, specifically in the formation of young stars and their impact on their surroundings.

Appendix C – The Herzberg Astronomy and Astrophysics Research Centre logic model



Appendix D – Areas of expertise

Astronomy Technology R&D and Services

- Adaptive optics
- Digital and analog electronics, signal processing
- Scientific leadership to observatories
- Manufacturing and machining
- Mechanical engineering
- Millimetre technology
- Optical engineering
- Project management and systems engineering
- Radio signal chain, receivers, correlators and digitizers
- Software and controls
- Canadian Time Allocation Committee (CanTAC)
- Solar radio monitoring
- Large-scale scientific computing infrastructure
- Specialized astronomy data management: data mining, processing, distribution and transfer of astronomical datasets

Scientific R&D

- Solar system origins
- Planetary systems
- Galactic structure
- Evolution of galaxies
- Evolution of structure
- Time domain
- Magnetic fields
- High-redshift universe

Operations and Support of Ground-Based Telescopes

- DAO – 1.8-m and 1.2-m Optical Telescopes
- DRAO – 26-m, Synthesis, Solar, CHIME
- Atacama Large Millimeter / submillimeter Array (ALMA)
- Gemini Observatory
- Canada-France-Hawaii Telescope (CFHT)
- Canadian Time Allocation Committee (CanTAC)

Scientific Support to Space-Based Telescopes

- James Webb Space Telescope (JWST)
- Cosmological Advanced Survey Telescope for Optical and UV Research (CASTOR)
- Ultra Violet Imaging Telescope (UVIT)

Sources: Document review and peer review

Appendix E – Canadian facilities

The Herzberg Astronomy and Astrophysics Research Centre office building at DAO
Source: Centre of the Universe

Dominion Astrophysical Observatory

- Located in Victoria, British Columbia
- Conducts technology research and development associated with instrumentation, facility design and construction projects of the domestic, international and future telescopes they support
- Offers capabilities in optical imaging, spectroscopy and spectropolarimetry
- Includes the 1.8-m Plaskett Telescope, 1.2-m Telescope and the CADC

Canadian Astronomy Data Centre

- Established in 1986, this web-accessible virtual observatory and archive for data has grown to house some of the world's most important astronomical data collections, including those from CFHT, the twin Gemini telescopes and the James Clerk Maxwell Telescope
- Capabilities include large-scale scientific computing infrastructure and specialized astronomy data management expertise

The Herzberg Astronomy and Astrophysics Research Centre's facility at DRAO

Dominion Radio Astrophysical Observatory

- Located in Penticton, British Columbia
- Provides scientific and technical services to support Canada's national and international radio telescopes
- Operates several telescopes on its extensive radio-quiet site
- Features laboratories and specialized equipment for design and construction of radio-frequency instrumentation, from highly sensitive antennas and receiver systems to high-speed digital signal-processing hardware and software
- Provides science and service support to Canadian university led and owned telescope projects e.g., Canadian Hydrogen Intensity Mapping Experiment (CHIME)

Sources: Document review

Appendix E – International facilities

ALMA Radio Telescope
Source: ALMA (ES/NAOJ/NRAO), Adhemar Duro

Gemini Observatories
Source: NoirLab

CFHT Telescope
Source: Canada-France-Hawaii-Telescope

Atacama Large Millimeter / submillimeter Array

- Located on the Llano de Chajnantor, Chile
- The world's most powerful millimetre/submillimetre telescope and the largest ground-based astronomy endeavour ever undertaken
- The NRC has contributed to several technical components of the ALMA telescope

Canada-France-Hawaii Telescope

- Located on Mauna Kea, Hawaii
- The telescope is jointly owned and operated by the NRC, the Centre National de la Recherche Scientifique of France and the University of Hawai'i
- While CFHT's main users are from Canada, France and Hawaii, collaborative agreements also offer telescope access to astronomers in Europe, Taiwan, Brazil, South Korea and China

Gemini Observatory

- Canada is 1 of 6 member countries in an international partnership that built and operates the Gemini Observatory, twin 8.1-m optical/near infrared telescopes
- 1 telescope is located on Mauna Kea in Hawaii (North) and the other on Cerro Pachon in Chile (South)
- The NRC facilitates telescope access for Canadian astronomers, and engages in collaborative research projects with university and other partners

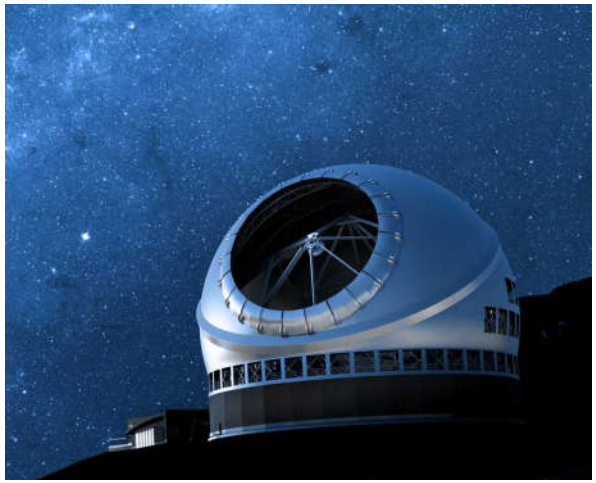
Sources: Document review

Appendix E – Future facilities

Rendering of SKA Dishes
Source: SKA Organization

Square Kilometre Array (SKA)

- SKA is an international collaboration to build the world's largest radio telescope. The SKA will monitor the sky in great detail and map it hundreds of times faster than any current facility
- Canadian scientists, engineers and industry have been engaged in SKA design since its earliest stages over 20 years ago, and the SKA is the second highest priority for ground-based astronomy in the 2020 LRP for astronomy and astrophysics
- Canada led the design of the digital signal processors at the heart of the telescope arrays



Rendering of TMT
Source: TMT International Observatory

Thirty-Meter Telescope (TMT)

- TMT is an extremely large telescope with a 30-m primary mirror diameter. TMT will be 3-times as wide, with nine times more area, than the current largest visible-light telescopes in the world
- TMT will provide images more than 12 times sharper than those from the Hubble Space Telescope
- Observing in wavelengths ranging from the ultraviolet to the mid-infrared, this instrument will allow astronomers to address fundamental questions in astronomy ranging from understanding star and planet formation to unraveling the history of galaxies and the development of large-scale structure in the universe

Sources: Document review