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Executive Summary of White Paper (5000 character limit)

Over the last 40 years enormous advances have been made in infrared astronomy. Virtually all of these can be traced to the use of space-based telescopes, which avoid the deleterious effects of the earth's atmosphere, and continued improvements in detector sensitivity and instrument design. Since its initial and modest contributions to previous infrared space astronomy missions, starting with ISO through to Herschel, Canada has grown in stature and is now recognized as a partner of choice by leading space agencies and scientific consortia embarking on the next generation of IR space astronomy missions. This white paper reviews the history of Canada's contributions to IR space astronomy missions and presents the case for Canadian participation in the ESA-JAXA SPICA mission, which has been selected as one of three finalists for ESA's fifth medium class mission, M5.

Observations at far-infrared (FIR) wavelengths are optimal, not only for exploring galaxy formation in the farthest reaches of the Universe, but also star formation in our own Galaxy. Indeed, the study of cold and/or enshrouded systems can only be observed in the FIR. In essence, this provides the rationale for all space astronomy missions from IRAS through to Herschel. By any measure, Herschel was an outstanding success. It has caused astronomers to re-examine their theories of star formation and provided our first large scale view of distant star forming galaxies. With the SPICA telescope actively cooled to ~8 K, the lower thermal background will enable sensitivities two to three orders of magnitude better than Herschel's! This sensitivity increase will allow SPICA not only to label photons by their wavelength over a volume of the Universe somewhere between one and ten thousand times greater than observed with Herschel, but also, and for the first time, allow it to label photons by their polarization in our Galaxy. Together these improvements augur major advances in the field. The SPICA instrument suite consists of three independent instruments: SAFARI – a FIR spectrometer; SMI – a mid-Infrared camera and spectrometer; and B-BOP - a FIR imaging polarimeter. The key features of each instrument are presented.

Canadian scientific, technical and strategic leadership in the SPICA mission is well established. As a founding member of the SPICA/SAFARI consortium, Canada not only has much greater visibility and influence on the project, but also has the opportunity to contribute high-profile flight hardware to the mission. One of the primary tasks of the initial CSA-funded SPICA SAFARI Study was to identify and leverage Canadian signature technologies to establish a potential role for Canada in SPICA. As a result of the work undertaken over the last decade, Canada has the opportunity to deliver the high-resolution spectrometer component of the SAFARI instrument; one of three critical components of SAFARI which lies at its very heart. It is key to two of the main science drivers of the mission: i) galaxy evolution through spectral measurements of galaxies at high-redshift, and; ii) disk evolution by disentangling the line and continuum components of emission from spectral measurements of disks. Both of these fields of study are areas of excellence in Canadian astronomy. Several members of the team have a wealth of experience from science exploitation of Herschel data, some playing leading roles in Herschel key projects and many have been involved in developing the science cases for SPICA. All stand ready to assume leadership roles once the mission is selected by ESA and receives mission funding from the CSA. The impact on Canadian science, in terms of return on investment by the involvement of Canadian astronomers in science exploitation with SPICA through access to the guaranteed time will be over twice that of Herschel, which was one of, if not the, highest ROI of any

CSA-funded space astronomy missions.

Over the last decade Canada will have invested over $5M to establish a leading role in SPICA and as a result is now positioned to build the mission critical, high-resolution spectrometer for what will be the leading infrared observatory of the next decade if it is selected by ESA in 2021. At that time, Canada will have to make a decision on whether it will sign up for the mission. This point will be the last off-ramp for any nation in the SPICA consortium. Perhaps the greatest risk at an agency level is to diminish the trust that ESA has in the CSA as a dependable partner after staying the course for over a decade. ESA will hold the Mission Selection Review, to pick the winner of the three M5 finalists in April 2021. Programmatically, a letter will be required before this date (early 2021) from the CSA to ESA effectively stating that if ESA chooses SPICA, Canada is committed to the project. Securing mission funding requires approval from the Treasury Board of Canada. A strong statement of endorsement for SPICA in the LRP is a necessary prerequisite.

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E001 – SPICA: the next observatory class infrared space astronomy mission

Introduction

This white paper reviews the history of Canada's contributions to leading infrared space astronomy missions and presents the case for Canadian participation in the ESA-JAXA SPICA mission, which has been selected as one of three finalists for ESA's fifth medium class mission, M5 [1]. https://www.esa.int/Our_Activities/Space_Science/ESA_selects_three_new_mission_concepts_for_study A companion white paper, E026, led by Doug Johnstone, reviews the science cases for SPICA and other infrared missions within the road maps of leading space agencies, as well as the Canadian context

Background

The earth's atmosphere is opaque to most of the mid- to far-infrared spectral region. Observations from the highest observatories are only possible in restricted spectral windows. Even observations from aircraft and balloon borne platforms are limited by emission from the residual atmosphere and warm telescope optics. For this reason, as we probe the limits of infrared astronomy, cryogenic space borne telescopes are essential. Moreover, because of the stable thermal conditions that exist there, the second Lagrangian point of the sun-earth system (L2) is now regarded as the choice location for all advanced space astronomy missions (e.g., Herschel, Planck, Eddington, Gaia, JWST, Darwin).

The roots of infrared space astronomy are widely held to have started with the Infrared Astronomical Satellite (IRAS) launched in 1983 [2], less than 40 years ago. This joint venture between the Netherlands, United Kingdom and USA produced the first maps of the entire sky at four infrared wavebands (12, 25, 60 and 100 µm). IRAS also contained a slitless low resolution spectrometer (LRS) that provided modest resolving power, R ~ 20, over the range from 7.5 µm to 23 µm. The impressive IRAS images immediately revealed the power of infrared astronomy from the first observations of star-forming regions detected through their infrared excess, to the detection of high redshift galaxies. The success of IRAS provided the impetus for spectroscopic observations and paved the way for the European Space Agency's (ESA) Infrared Space Observatory (ISO) launched in 1995 [3].

Operating over the wavelength range from 2.5 µm to 240 µm, ISO became the world's first general-purpose infrared space observatory. The 60 cm diameter primary mirror of the ISO telescope was housed in a large cryostat of superfluid liquid helium together with its instrument suite, which consisted of an imaging photo-polarimeter (ISOPHOT), a camera (ISOCAM), a short wavelength spectrometer (SWS) and a long wavelength spectrometer (LWS) [3]. Together, the SWS [4] and LWS [5] spectrometers covered the wavelength range from 2.4 µm to 200 µm at both low and high spectral resolving powers. The low resolving power mode (R ~ 200) of the LWS was implemented with a grating spectrometer, while two Fabry-Perot interferometers provided the high-resolution mode (R ~10000). What is less widely known is that during the initial instrument concept studies ESA considered a Fourier transform spectrometer (FTS) for LWS. While the FTS solution was not selected, due to the low technical maturity of cryogenic FTSs at that time, because of their contributions to the development of the LWS, Canadian scientists, with funding from the Canadian Space Agency (CSA), received access to the guaranteed time (GT), leading a topical science team [6-9].

Recognizing the spatial resolution limitations of small aperture telescopes mounted in large cryostats, ESA subsequently proposed a bold solution in which a large aperture, passively-cooled, telescope would be placed outside of the cryostat that housed the cryogenically cooled instrument suite. Launched in 2009, ESA's 3.5 m diameter Herschel Space Observatory (Herschel) carried a suite of three instruments, HIFI, PACS and SPIRE, designed to provide imaging photometry and spectroscopy over the wavelength range from 57 µm to 670 µm [10]. With funding from the CSA, Canada made significant contributions to both the HIFI [11] and SPIRE [12] instruments. In the case of SPIRE, both the low- and high-resolution spectroscopic modes were provided by an imaging FTS, now recognized as a field of academic excellence in Canada. SPIRE, however, was not to be the first cryogenic astronomical imaging infrared FTS to be placed in orbit; that honour fell to the FIS instrument [13] on JAXA's AKARI mission [14]. Despite having no formal connections with the AKARI mission, Canadian expertise in Fourier spectroscopy was sought by the AKARI team. With funding from the CSA, Canada again played an important role in characterizing the performance of the FIS instrument [15].

By any measure, Herschel was an outstanding success. It has caused astronomers to re-examine their theories of star formation, provided our first large scale view of distant star forming galaxies, and garnered several national/international awards. Indeed, by the CSA's independent analysis presented at CASCA 2019 [16], Herschel holds the highest return in terms of publications by Canadian authors and co-authors of any CSA funded mission over the last 16 years.

With its high angular resolution and sensitivity, compared to previous infrared space missions (IRAS, ISO, AKARI), Herschel has shown what can be accomplished with a passively-cooled, large aperture, far-infrared space telescope. Since the Herschel telescope represents the largest monolithic structure that can be launched, however, improved angular resolution must await a far-infrared interferometer mission (e.g., FIRI, SPIRIT [17], [18]).

The case for SPICA: the SPace Infrared telescope for Cosmology and Astrophysics

Observations at far-infrared wavelengths are optimal, not only for exploring galaxy formation in the farthest reaches of the Universe, but also star formation in our own Galaxy. Indeed, the study of cold and/or enshrouded systems can only be observed in the far-infrared. Examples, discussed in more detail in white paper E026 led by Doug Johnstone, include: the earliest stages of star formation; evolution in nearby stellar systems, including the path from protoplanetary disks, to disks with planets in formation, all the way to debris disks; and high redshift star forming galaxies. In essence, this provides the same rationale as for all previous space astronomy missions from IRAS through to Herschel.

Although the final operating temperature and emissivity of the Herschel telescope could not be determined prior to launch, it was already recognized that the ultimate sensitivity of Herschel would be limited by emission from its passively-cooled telescope. It was also understood that if a telescope could be actively cooled to temperatures of less than 8 K, the background photon noise would be effectively eliminated, allowing for an enormous increase in sensitivity if suitable detectors and instrumentation could be developed. Thus, for several years before the launch of Herschel, teams of scientists supported by both ESA and JAXA had been discussing its successor: the SPace Infrared telescope for Cosmology and Astrophysics (SPICA) [19, 20]. Furthermore, Canadian scientists were at the forefront of this effort. The asterisked names of the authors of this WP are members of the original CSA-funded SPICA SAFARI Study. This study was awarded to the University of Lethbridge following a competition for Canadian contributions to mission concepts submitted to the ESA Cosmic Vision program. Under the terms of the initial CSA contract, the team was tasked to identify a meaningful role for Canada in the SPICA mission, which is discussed in detail below.

SPICA was conceived to have a similar-sized aperture to Herschel. With the telescope now actively cooled to ~8 K, however, the lower thermal background would enable sensitivities two to three orders of magnitude better than Herschel's (dependent on wavelength). This sensitivity increase would allow

SPICA not only to label photons by their wavelength over a volume of the Universe somewhere between one and ten thousand times greater than observed with Herschel, but also, and for the first time, allow it to label photons by their polarization in our Galaxy. Together these improvements augur major advances in the field.

More recently, NASA had been studying a number of mission concepts for its next Decadal Survey as part of its Astrophysics Roadmap for the next 30 years. Of the four final candidate missions identified, one is a Far-Infrared Surveyor mission [21] whose conceptual design was to be established by a community-based Science and Technology Definition Team (STDT). Douglas Scott (UBC) serves as the as the Canadian representative on the STDT, supported by the CSA. Over the last few years the STDT has worked with the astronomical community to develop science cases and derive science requirements for the Far-IR Surveyor mission. In 2016 the science cases were prioritized to determine the optimum architecture for the mission. The STDT concluded that the Far-IR Surveyor would be a single-aperture cooled telescope, subsequently renamed Origins [22]. Several Canadian astronomers are already actively involved in the science working groups of Origins. It is worth noting that while Origins is more ambitious (and costly) than SPICA, the fundamental goals and instrumentation are very similar. Thus, continued investment in the Canadian technology for SPICA positions Canada for a significant instrument development role in Origins.

The fact that ESA, JAXA and NASA have all identified a single-aperture cryogenic telescope as the next far-infrared space astronomy mission, with an almost identical instrumentation suite, is confirmation that the future direction of the field is well understood.

SPICA instrument complement

Spectroscopic observations at infrared wavelengths allow us to determine the physical state and energy balance of cool matter in space. Also they allow us to study the processes that govern the formation and early evolution of stars and planetary systems in the Milky Way, and of galaxies over cosmic time. Previous far-infrared missions, from IRAS to Herschel, revealed the obscured Universe, but their sensitivity was limited either by their cold, but small apertures or, in the case of Herschel, its large, but warm aperture; and the sensitivities of detectors available at the time. The SPICA mission concept addresses these issues by utilizing a 2.5 m diameter telescope that is cooled to < 8 K, which can be exploited by current state-of-the-art detectors. The detectors themselves have seen continual improvements over that last decade, and now boast factors of between 2 and 3 orders of magnitude more sensitivity than any flown on previous space missions. Furthermore, instead of liquid cryogens, a combination of passive and mechanical coolers will cool both the telescope and instrument suite. No longer dependent on a limited consumable, the mission lifetime may extend significantly beyond the nominal 3 years. This combination of low telescope background and instruments employing state-of-the-art detectors allows SPICA to bridge the gap in capabilities between JWST and ALMA, as shown in Figure 1, and represents a major advance in capability over previous far-infrared missions [23]. For a more detailed review of the science cases for SPICA the reader is referred to [24].

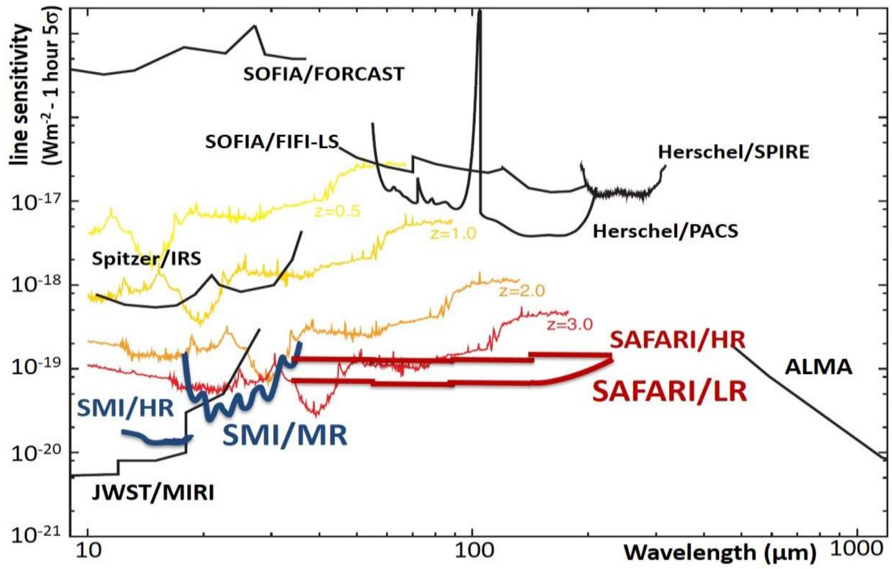

Figure 1 Projected sensitivity of the SPICA instruments compared to leading infrared facilities. The infrared spectrum of the Circinus galaxy, scaled to L=$10^{12}L_{\odot}$ for redshifts 0.5 to 3 is superimposed.

As an overview, the SPICA instrument suite provides spectral resolving powers, R, ranging from 50 to 11,000 between 17 μm and 230 μm, respectively, and R ~ 28,000 between 12 μm and 18 μm. Additionally, SPICA will be capable of efficient broad band mapping over the range 30-37 μm, and spectroscopic and polarimetric imaging in the 100 - 350 μm range.

The SPICA instrument suite consists of three independent instruments [23]: SAFARI – a far-infrared spectrometer; SMI – a mid-Infrared camera and spectrometer; and B-BOP - a far-infrared imaging polarimeter. The key features of each instrument are summarized below. Fact sheets that describe the capabilities of each instrument are included in the appendix.

SAFARI: the SpicA FAR-infrared Instrument. With galaxy evolution over cosmic time as one of the main science drivers, the SAFARI instrument is optimised to achieve the best possible sensitivity, within the bounds of the available resources (mass, thermal, power, number of detectors) at a moderate resolving power, R ~ 300, with instantaneous coverage over the full 34 to 230 μm spectral range. A secondary driver is the requirement to study line profiles at higher resolving power between 2000 and 11000, to study the infall and outflow of matter from active galactic nuclei and star-forming galaxies, and to study the gas, dust and ice content of protoplanetary disks, which requires observations at both high and low spectral resolution. The high-resolution mode will be implemented using a Martin-Puplett (MP) interferometer [25]. This design will enable far-infrared spectroscopy with an unprecedented sensitivity of ~5x10^{-20} W/m^2 (5σ/1hr) - at least two orders of magnitude better than achieved to date (Figure 1). As envisaged this high-resolution spectrometer will be designed, built and tested in Canada.

SMI: the Spica Mid-Infrared instrument. This mid-infrared spectrometer/camera combination is designed to cover the wavelength range from 12 μm to 36 μm with both imaging and spectroscopic capabilities. The instrument employs four separate channels: the low-resolution spectroscopy mode SMI/LR, R = 50 – 120; the broad-band imaging mode SMI/CAM, R = 5; the mid-resolution spectroscopy mode SMI/MR, , R = 1300 - 2300, and the high-resolution spectroscopy mode SMI/HR, R = 28000. The prime science drivers for these individual modes are: high-speed spectral mapping of galaxies for the polycyclic aromatic hydrocarbon (PAH) features at z > 0.5 with SMI/LR; wide-area surveys of obscured AGN and starburst galaxies at z > 3 with SMI/CAM; and velocity-resolved spectroscopy of gases in protoplanetary discs with SMI/HR. It is expected that the SMI instrument will also serve as a pathfinder for additional detections of debris disks and galaxies at large redshift. Complementary to these specific modes, SMI/MR provides more versatile spectroscopic modes, bridging the gap between the JWST/MIRI instrument and SAFARI.

B-BOP: Far-IR Polarimeter. This polarimeter will allow, for the first time, measurements of the far-infrared polarization that will trace the local magnetic fields associated with regions of star formation. Canada has a rich history in dust polarization studies both from ground (JCMT - SCUPOL, POL-2) and balloon borne (BLAST-POL) telescopes. While the Planck mission has produced all sky polarization maps, the spatial resolution of 10 arcmin is insufficient to probe the details of the roles of magnetic fields in star formation. Polarimetric mapping of Galactic filamentary structures, in particular, requires a high dynamic range in both spatial scales and flux density. As such the detectors must have high sensitivity at low flux levels, with an immunity to high flux levels. The wavelength bands centred on 100 µm, 200 µm and 350 µm, having spatial resolutions of 9, 18 and 32 arcsec, respectively, were chosen to observe filaments on both sides of their peak emission. For efficient polarimetry, polarizing detectors will be used and the required detector sensitivity of 3×10^{-18} W/√Hz has already been achieved. To put this improvement into perspective, the increased sensitivity provided by SPICA and B-BOP will enable polarimetric images of nearby molecular clouds with signal-to-noise ratios the same as or better than Herschel's continuum imaging maps!

In summary, the enormous increase in sensitivity provided by the SPICA instrument suite will open up a vast and unique discovery space, allowing astronomers to study galaxy evolution and metal production over cosmic time, to investigate dust formation and evolution, and trace the formation history of planetary systems. Furthermore, this discovery space will be one that can be efficiently targeted, as it will build on the legacies of Herschel, ALMA, JWST, and the next generation of large ground-based IR telescopes.

Proposed Canadian Role in SPICA SAFARI

As noted earlier, Canada made significant contributions to both the HIFI and SPIRE instruments on Herschel. In the case of the heterodyne HIFI instrument, its local oscillator units. When Canada joined the Herschel-SPIRE mission, the project was already well advanced, the instrument design was frozen and Canada had little choice between the few remaining tasks left to be assigned (none of which involved flight hardware). Nonetheless, as David Naylor became the Canadian PI on the SPIRE instrument, his team at the University of Lethbridge became heavily involved in the development and testing of SPIRE, being responsible for providing: test hardware; interactive data analysis software; and personnel to the SPIRE ground test facility at the Rutherford Appleton Laboratory, UK. The Canadian team played a lead role in evaluating the performance of SPIRE through an extensive series of pre-flight test campaigns. Also over 90% of the SPIRE FTS data-analysis software was developed in Canada. Given Canada's reputation in the field of Fourier transform spectroscopy, and well established collaborations with European colleagues developed through the Herschel mission, Canada was invited by the European consortium to join the SPICA project in 2007.

Compared with Herschel, the situation with SPICA/SAFARI is fundamentally different. Being a founding member of the SPICA/SAFARI consortium, Canada not only has a much greater visibility and influence on the project, but also has the opportunity to contribute high-profile flight hardware to the mission. Indeed one of the primary tasks of the initial CSA-funded SPICA SAFARI Study was to identify and leverage Canadian signature technologies to establish a potential role for Canada in SPICA. As a result of the work undertaken over the last decade, Canada has now been given the opportunity to design, build, test, validate and deliver the high-resolution spectrometer component of the SAFARI instrument. This spectrometer is one of the three critical components of SAFARI and lies at its very heart. It is key to two of the main science drivers of the mission: i) galaxy evolution through spectral measurements of galaxies at high-redshift, and; ii) disk evolution by disentangling the line and continuum components of emission from spectral measurements of disks. Both of these fields of study are recognized as areas of excellence in Canadian astronomy.

While an individual nation's contributions to SAFARI are not expressed in terms of monetary value, they are nonetheless acknowledged and weighted by the project. In this scheme, Canada is regarded as being a significant contributor to the mission. While the details of the Science Implementation Plan (SIP), which is the formal agreement describing the management of all aspects of the instruments (including on how guaranteed time (GT) is divided up) are still to be worked out, the SPICA consortium has adopted the Herschel-SPIRE SIP model. What can be stated at present, however, is that the impact on Canadian science, in terms of return on investment (ROI) by the involvement of Canadian scientists in science exploitation through access to the guaranteed time will be over twice that of Herschel, which was one of, if not the, highest ROI of any CSA-funded space astronomy mission.

Any Canadian astronomer interested in participating in discussions surrounding the SPICA mission is welcome to join the group by contacting the author.

LRP2020 assessment criteria

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

Mid- and far-infrared observations of the spectral energy distribution provide unique information on the physical properties of matter in both the local and high-redshift Universe. With sensitivities between two and three orders of magnitude better than Herschel over the spectral range between JWST and ALMA, and now at matching sensitivities, SPICA represents an enormous advance in the field. Moreover, the addition of a polarimetric imaging capability will open up a completely new window for observations of star formation in our galaxy. SPICA will provide unique observations covering many branches of astronomy including: the evolution of galaxies over cosmic time; the baryonic cycle within galaxies; the details of star formation within molecular clouds; and the evolution of protoplanetary disks.

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

Since its initial and modest contributions to previous mid- and far-infrared space astronomy missions, starting with ISO through to Herschel, Canada has continued to grow in stature and is now recognized as a partner of choice by leading space agencies and scientific consortia embarking on the next generation of infrared space astronomy missions. Maintaining the critical mass of Canadian astronomers who drive the science requirements of, develop instrumentation for, and position themselves to exploit data from endeavours such as SPICA and Origins is essential. With SPICA firmly established as the front-runner to fill the infrared gap, there is no risk of the science being scooped by another mission.

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

Canadian scientific, technical and strategic leadership in the SPICA mission is well established. Since the competitive call by the CSA for potential contributions to missions being proposed to ESA's Cosmic

Vision Call in 2007, Canada has established a leading role within SPICA. This role not only builds on academic strengths in the technology central to the high-resolution spectrometer subsystem of the SAFARI instrument, but is also one that is recognized as a signature technology within Canadian industry. From the beginning, Naylor has served as the Canadian representative and co-investigator on the project, guiding Canada’s contribution as it has evolved to its present state. Canada is now poised to play a leading role in the mission if it is selected by ESA. Johnstone was one of the initial proposers and has become heavily involved in science planning. Other members of the team have a wealth of experience from science exploitation of Herschel data, some playing leading roles in Herschel key projects and many have been involved in developing the science cases for SPICA. All stand ready to assume leadership roles once the mission is selected by ESA and receives mission funding from the CSA.

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

It is challenging for Canadian scientists to spend their limited grant funding travelling themselves or sending their students, to international meetings to discuss a mission that will launch in the early 2030s. Yet, such long term engagement is the nature of space missions. While science is always the driver for any space mission, the early phases inevitably focus on the technological feasibility and budget. Since 2008, the SPICA consortium has worked continuously to raise the Technology Readiness Level (TRL) of critical components of the three instruments to make sure that it can deliver a suite of instruments that can operate within the spacecraft limitations (mass, thermal etc.) and within the budget, to meet the science questions that will be posed in 2030. Once SPICA is selected by ESA and assuming Canada joins the mission, part of the funding will support the activities of the Canadian science team. Using Herschel as a reference, in which there was competition for places on the Canadian science teams, and noting recent appointments in Canadian academia in SPICA science fields, it is fair to state that there exists broad interest within the Canadian community for participation in SPICA as we enter the multi-messenger era. The supporter list, which is open to all Canadian scientists, bears witness to this.

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

If selected, SPICA will launch in the early 2030s. Origins’ would launch later. Technical activities (building, assembling, integrating, verifying systems) are already well underway, as is the first round of science planning. Space missions are typically two decades from cradle-to-grave and it is essential to ensure, as far possible, that the capabilities of any instrument are such that they can tackle the questions that will be posed when it is launched, in this case the JWST, ALMA, TMT era.

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

Observatory-class space missions are billion-dollar endeavours. Canada is typically a small partner, welcomed for its expertise, that is valued well beyond monetary considerations alone. Using Herschel as an example, Canada hit far above its weight in terms of ROI. Given its larger proposed contribution, the Canadian ROI on SPICA will be between two and three times that of Herschel, which by the CSA’s independent analysis has been the highest science return of any CSA funded space astronomy mission in the last 15 years. As is typical with a space mission, future operating costs are factored into the cradle-to-grave budget and include the post operations phase. Cryogenic missions that employ consumable cryogens usually have a well-defined lifetime. Since SPICA will employ mechanical coolers whose lifetime may exceed the nominal 3 years mission duration, however, there could be some uncertainty in SPICA’s lifetime and final operating budget. If the mission is as successful as predictions suggest, however, it would be hard to imagine a scenario in which funding would be cut from a mission that will be outperforming Herschel by several orders or magnitude.

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

Building on the success of Herschel, between 2008 and 2019 the CSA and the University of Lethbridge have jointly invested over $5M to establish a leading role for Canada in SPICA. As a result of this investment, Canada is positioned to build the mission critical, high-resolution spectrometer for what will be the leading infrared observatory of the next decade if it is selected by ESA in 2021. At that time, Canada will have to make a decision on whether it will sign up for the mission, cradle-to-grave. This point will be the last off-ramp for any nation in the SPICA consortium. Perhaps the greatest risk at an agency level is to diminish the trust that ESA has in the CSA as a dependable partner after staying the course for over a decade. ESA has set the Mission Selection Review (MSR), which will pick the winner of the three M5 finalists to be in April 2021. Programmatically, a letter will be required before this date (i.e. early 2021) from the CSA to ESA effectively stating that if ESA chooses SPICA, Canada is committed to the project. Securing mission funding requires approval from the Treasury Board of Canada. A strong statement of endorsement for SPICA in the LRP is a necessary prerequisite.

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

As noted elsewhere, participation in SPICA builds on specific strengths in Canadian academia and industry. As envisaged, the SAFARI high-resolution spectrometer would be built in Canadian industry and tested in a Canadian university. Along this path there exists abundant training opportunities for HQP at all levels (undergrad, co-op, graduate, postdoc). In the short-term this would be primarily through contributions to the development and testing of the various instrument models (prototype, engineering, flight, flight spare, etc.). In the long-term it would be through data analysis and science exploitation. In the case of the Canadian Herschel-SPIRE team which consisted of six professors spread across Canada, over 50 HQP received training in fields ranging from astrophysics to computer science, optics, and cryogenics. It is reasonable to expect these numbers to at least double in the case of SPICA. While the SIP is still being negotiated, it is expected that at least 15 professors would have direct access to data from the SPICA commissioning and GT programs. Moreover, since all future far-infrared space astronomy missions, be they single dishes or interferometers, will require cryogenic instrumentation, the skills learned by HQP trained in SPICA instrument development will be in high demand in the years ahead as far-infrared interferometers become a reality.

With support from the CSA and the province of Alberta, outreach activities were a focus of Canada's participation in SPIRE [26]. This effort was well received by schools across the province. In addition, each SPIRE associate scientist led local outreach efforts. It is reasonable to expect the outreach effort for SPICA would at least double, given the increased size of the Canadian team.

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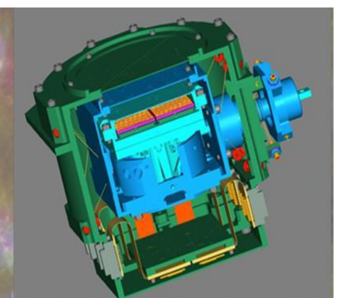
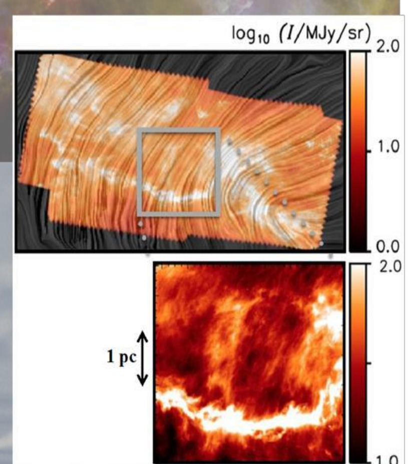
[24] SPICA science papers appear in a special issue of Pub. of the Astronomical Society of Australia, **35** (2018)
[25] Martin D. & Puplett E., Infrared Physics, **10**, 105 (1970)
[26] http://spire.uleth.ca/

SPICA - SAFARI/POL Fact Sheet

A polarimetric camera with
3 simultaneous bands 100, 200 & 350 μm
on the same FOV : 2,6’ x 2,6’ @ 0,6 f#λ sampling



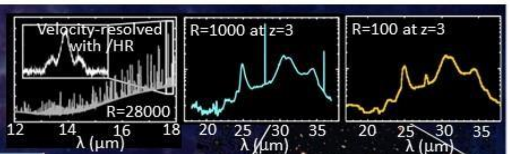
	100μm	200μm	350μm
Band edges	75—125μm	150—250μm	280—420μm
# of pixels	32 x 32 (x 2)	16 x 16 (x 2)	8 x 8 (x 2)
Pixel size	5" x 5"	10" x 10"	20" x 20"
Band centre beam FWHM	9"	18"	32"
PS sensitivity 5σ/1h/FOV (unpolarised)	21μJy	42μJy	85μJy
PS sensitivity in Stokes (Q,U) 5σ/1h/FOV (polarised)	30μJy	60μJy	120μJy
PS sensitivity 5σ/10h/1deg² (unpolarised)	0.16 mJy	0.32 mJy	0.65 mJy
PS sensitivity in Stokes (Q,U) 5σ/10h/1deg² (polarised)	0.23 mJy	0.46 mJy	0.92 mJy
Surface brightness sensitivity 5σ/10h/1deg² (unpolarised)	0.09 MJy/sr	0.045 MJy/sr	0.025 MJy/sr
Sensitivity to map Stokes parameters (Q,U) at 5% level 5σ/10h/1deg²	2.5 MJy/sr	1.25 MJy/sr	0.7 MJy/sr



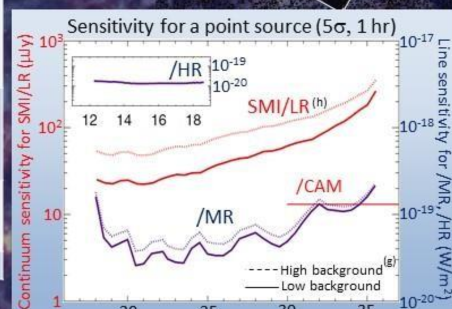
The filamentary structure of
Star forming regions:
Combined images from
Herschel SPIRE @ 250 μm and
Planck polarisation @ 850μm

SPICA / SMI Fact Sheet

SPICA Mid-infrared Instrument (SMI) covers the wavelength range of 12–36 μm with four channels: spectroscopy (SMI/LR, /MR, /HR) and imaging (/CAM).



Parameter	SMI /LR	/CAM Slit viewer for SMI/LR	/MR	/HR
Band centre - μm	27	34	27	15
Wavelength - μm	17 – 36	34	18 – 36	12 – 18 (a)
Spectral resolution R	50 – 120 (b)	5	1300 – 2300 (b)	28000 (c)
(diffuse source)	(20 – 110)		(1100 –1400)	
Field of view	600" x 3.7" 4 slits	600" x 720"	60" x 3.7" 1 slit	4" x 1.7" 1 slit
Band centre FWHM	2.7"	3.5"	2.7"	2"
Pixel scale	0.7" x 0.7"	0.7" x 0.7"	0.7"	0.5"
Detector 1K x 1K	Si:Sb	Si:Sb	Si:Sb	Si:As
Point source sensitivity (5 σ/1 hr)				
Continuum - μJy	50	13	400	1500
Line - 10^{-20} W/m^2 (d)	8		4	1.5
Survey speed - arcmin^2/hr (e)	~16	~5900	~1.5	
Diffuse source sensitivity (5σ/1 hr)(f)				
Continuum - MJy/sr	0.05	0.05		
Line - 10^{-10} W/m^2/sr			1	1.5
Saturation limit - Jy	~20	~1	~1000	~20000



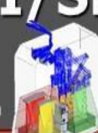
(a) continuous coverage up to 17.3 μm + partial coverage for H_2O 17.77, 18.66 μm.
(b) λ/δλ = 120 (SMI/LR) and 1300 (/MR) at λ = 36 μm.
(c) designed for λ20 μm diffraction limited PSF.
(d) sensitivity for an unresolved line.
(e) survey speed for the 5 σ detection of a point source with the continuum flux of 100 μJy for SMI/LR at λ = 30 μm (/CAM at 34 μm) and the line flux of 3×10^{-19} W/m² for /MR at λ = 28 μm, both in the low background case (see the right-hand figure).
(f) sensitivity for a diffuse source in a 4" x 4" (SMI/LR, /MR) or 2" x 2" area (/HR).
(g) background levels are assumed to be 80 MJy/sr (High) and 15 MJy/sr (Low) at 25 μm.
(h) continuum sensitivity rescaled with R = 50.

SMI Factsheet v10 – 4 Jan 2016

SPICA-SAFARI/SPEC Fact Sheet

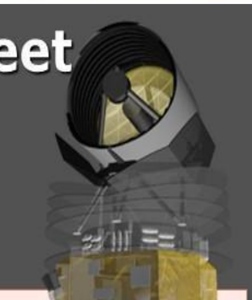
SAFARI Overview

- Four band *grating spectrometer*
- Continuous spectroscopic capability from 34-230 μm



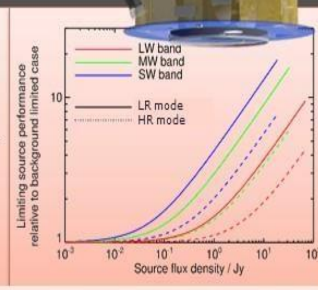
SPICA Mission

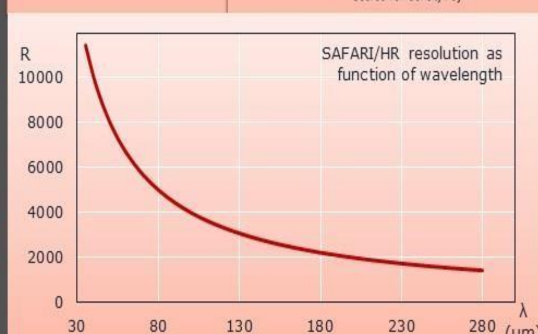
- ESA/JAXA collaboration
- Telescope effective area 4.6 m²
- Primary mirror temperature 8K
- Goal mission lifetime – 5 years



Parameter		Waveband SW	MW	LW	LLW
Band centre / μm		45	72	115	185
Wavelength range / μm		34-56	54-89	87-143	140-230
Band centre beam FWHM		4.5″	7.2″	12″	19″
Point source spectroscopy (5σ-1hr)					
LR	**Limiting flux** / x10^{-20} Wm^{-2}	7.2	6.6	6.6	8.2
LR	**Limiting flux density** / mJy	0.31	0.45	0.72	1.44
HR	**Limiting flux** / x10^{-20} Wm^{-2}	13	13	13	15
HR	**Limiting flux density** / mJy	18	17	17	19
Mapping spectroscopy* (5σ-1hr)					
LR	**Limiting flux** / x10^{-20} Wm^{-2}	84	49	30	23
LR	**Limiting flux density** / mJy	3.6	3.3	3.3	4.1
HR	**Limiting flux** / x10^{-20} Wm^{-2}	189	113	73	51
HR	**Limiting flux density** / mJy	253	151	97	67
Photometric mapping* (5σ-1hr)					
Limiting flux density / μJy		209	192	194	239
Confusion limit (5σ)		15 μJy	200 μJy	2 mJy	10 mJy

System performance v.s. target flux density, relative to the background limited case
- The sensitivity decrease is due to the increased photon noise from the target source
- Data given up to the instrument saturation limits for each band (31, 51 and 87 Jy for the SW, MW and LW bands respectively.





Sensitivities based on detector NEP 2×10^{-19} W/√Hz
* Mapping performance is for a reference area of 1 arcmin²

SRON
SAFARI

SAFARI GS Factsheet V1.0 – 30th September 2016