Update on SPICA

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1. Introduction

Although impressive advances have been made in the last twenty years, our knowledge of how the Universe has evolved over cosmic time is far from complete. A full insight into the processes involved requires observations at far-infrared (FIR) wavelengths for it is here that astronomical objects emit most of their radiation as they form and evolve in regions where obscuration by dust prevents observations in the visible and near infrared. Over the past quarter of a century, successive space infrared observatories (IRAS [1], ISO [2], Spitzer [3] and AKARI [4]) have revolutionized our understanding of the evolution of stars and galaxies. Mid- to far-infrared observations have led to stunning discoveries such as the Ultra Luminous Infrared Galaxies, the basic processes of star formation from "class 0" pre-stellar cores through to the clearing of the gaseous proto-planetary discs and the presence of dust excesses around main sequence stars.

While these pioneering missions provided our first view of the FIR universe, their small apertures resulted in relatively low spatial resolution. Launched in 2009, the Herschel Space Observatory [5] employed a 3.5 m diameter passively cooled primary mirror located outside of the instrument payload, the instrument suite being cooled to ~4 K by an on-board supply of liquid helium. This design provided a major advance in both spatial resolution and sensitivity, however, the sensitivity remained limited by the photon noise from the relatively warm (~80 K), albeit low emissivity, telescope. Canadian scientists played prominent roles in developing two of the three instruments onboard Herschel and continue to exploit the unique data provided by the observatory. By any measure, Herschel has been an outstanding success [6]. It has provided new insight into the physics of star formation in our own galaxy and to the formation and evolution of galaxies at high redshift.

2. Background

The path forward for future FIR missions and must address two factors: increased sensitivity and increased spatial resolution [7]. The first can be readily achieved by actively cooling a large single aperture telescope. The second will require sub-arcsecond angular resolution spectral imaging over the FIR range, and is far more challenging. Several groups (including Canadians) are currently studying a FIR interferometer concept which combines the two well-known techniques of stellar interferometry and Fourier transform spectroscopy to achieve this.

The SPace Infrared telescope for Cosmology and Astrophysics (SPICA) mission [8] being studied by ESA and JAXA exploits the first factor. With its 3 m class primary mirror cooled to ~6 K, the thermal emission from the SPICA telescope will be six orders of magnitude less than either Herschel [5] or the JWST [9]. A new generation of superconducting transition edge sensor detectors has been developed to exploit this low background environment and will achieve sensitivities two orders of magnitude greater than those achieved with Herschel. A consortium of European and Canadian scientists are developing a FIR imaging spectrometer, the SPICA far-infrared instrument (Safari), to exploit these sensitive detectors. SPICA will also host a mid-IR instrument called SMI. Building on the success of Herschel and in particular the SPIRE instrument [10], the Safari consortium has selected an imaging Fourier transform spectrometer (iFTS) of the Mach-Zehnder design to provide imaging spectroscopy over the wavelength range 34–200 μm with an instantaneous, nyquist sampled, field of view of 2'x 2'[11]. In recognition of significant contributions to SPIRE, Canadian scientists were invited to join the SPICA/Safari team. Canada was a founding member of SPICA/Safari and with support from the CSA, has been working since 2009 on the design of the Safari instrument, developing the science cases and exploring potential Canadian contributions to the mission.

3. SPICA science objectives

The science objectives of SPICA are closely linked to three of the ESA Cosmic Vision Themes: What are the conditions for planet formation and the emergence of life? How does the Solar System work? How did the Universe originate and what is it made of?

The formation and evolution of planetary systems: By accessing key spectral diagnostic lines, SPICA will provide a robust and multidisciplinary approach to determine the conditions for planetary systems formation. This will include the first detection of the most relevant species and mineral components in the gas and dust of hundreds of transitional protoplanetary discs at the time when planets form. SPICA will also be able to trace the warm gas in the inner (< 30 AU) disc regions and by resolving the gas Keplerian rotation, will allow astronomers to observe the evolution of disc structure due to planet formation.

SPICA will study debris discs and make the first unbiased survey of the presence of zodiacal clouds in thousands of exoplanetary systems around all stellar types. It will detect both the dust continuum emission and the brightest grain/ice bands as well as the brightest lines from any gas residual present in the disc. SPICA will have the unique capability to observe water ice in all environments, and thus fully explore its impact on planetary formation and evolution and the emergence of habitable planets. In the closest debris discs, SPICA will spatially resolve the distribution of water ice and determine the position of the "snow line", which separates the inner disc region of terrestrial planet formation from that of the outer planets.

SPICA will drastically enhance our knowledge of the Solar System by making the first detailed characterization of hundreds of Kuiper Belt Objects, and of different families of inner, hotter centaurs, comets and asteroids. SPICA will provide the means to quantify their composition and determine unambiguously their size distribution; critical observational evidence for the models of Solar System formation. No other planned or present facility will be able to carry out these observations.

SPICA will provide direct imaging and low resolution mid infrared spectroscopy of outer young giant exoplanets (e.g., at ~ 9 AU of a star at 10 pc), which will allow astronomers to study for the first time the physics and composition of their atmospheres in a wavelength range particularly rich in spectral signatures (e.g., H_2O, CH_4, O_3, silicate clouds, NH_3, CO_2) and to compare it with the planets of our Solar System. In addition, mid infrared transit photometry and medium or high resolution spectroscopy of "hot Jupiters" will be routine with SPICA.

With its superior sensitivity, SPICA will provide a window into key aspects of the dust life-cycle both in the Milky Way and in nearby galaxies, from its formation in evolved stars, its evolution in the ISM, its processing in supernova-generated shock waves and massive stars, to its final incorporation into star forming cores and protoplanetary discs.

The formation and evolution of galaxies: SPICA observations will provide a unique insight into the basic questions about how galaxies form and evolve such as: What drives the evolution of the massive, dusty distant galaxy population, and what feedback/interplay exists between the physical processes of mass accretion and star formation? How and when do the normal, quiescent galaxies such as our own form, and how do they relate to (Ultra) Luminous Infrared Galaxies (ULIRGs)? How do galaxy evolution, star formation rate and AGN activity vary with environment and cosmological epoch?

Substantial progress in this area requires making the transition from large-area photometric to large-area spectroscopic surveys in the mid to far infrared. This is because the mid and far infrared spectral regions contain a unique suite of diagnostic lines which can be used to trace accretion and star formation, and to probe the physical and chemical conditions in different regimes from AGN to star-forming regions. Whereas the Herschel-PACS spectrometer detected the brightest far infrared objects at $z \sim 1$, SPICA will be able to carry out blind spectroscopic surveys out to $z \sim 3$. This will lead to the first statistically unbiased determination of the co-evolution of star formation and mass accretion with cosmic time. Spectroscopic surveys will provide direct and unbiased information on the evolution of the large scale structure in the Universe from $z \sim 3$ and the unprecedented possibility to investigate the impact of environment on galaxy formation and evolution as a function of redshift.

The high sensitivity of SPICA will enable photometric surveys beyond $z \sim 4$ that will resolve more than 90% of the Cosmic Infrared Background. SPICA will also observe Milky Way type galaxies in the far infrared out to $z \sim 1$, where the cosmic star formation rate peaks. To illustrate the impact of the increased sensitivity conferred by SPICA's cold telescope, models predict that in an observing time of 900 hours Safari will obtain fully spatially sampled spectra over the wavelength range 34–200 μm and a field of one square degree, enabling it to measure spectra of approximately 1000 times more extragalactic sources than the PACS instrument [12] on Herschel, the most sensitive space-borne spectrometer in this wavelength range to date.

4. Current status

While the SPICA project as initially conceived was to be led by JAXA with ESA contributing at the ~25% level under the *mission of opportunity* umbrella, in late 2013 it became apparent that due to programmatic and technical challenges the SPICA mission would need to be restructured to include a larger European contribution in the context of the ESA's Cosmic Vision program. In the new division of effort, JAXA would be responsible for the satellite procurement, its integration, launch, and operations, and ESA for the payload module (i.e. the telescope, with support structure, the payload cryogenics system, the instrument optical bench and instrument integration; importantly cryo-testing using ESA's solar/cryovac facility expertise so crucial to the success of Herschel and Planck).

The downside to this restructuring is that while a *mission of opportunity* could proceed outside of a formal competition, the larger European contribution would have to be funded through a competitive M-class call. While this incurs a schedule slip and carries the risk of the project not being selected, on the positive side the consortium has been working on the project for over 5 years, mitigating risks along the way, and has amassed an arsenal of material that will present a compelling case for selection. Moreover, achieving M-class status would put SPICA firmly on the Cosmic Vision map, an appropriate place to follow on the outstanding success of Herschel.

On 10 Feb. 2014, JAXA, ISAS Director Prof. Tsuneta and SRON (who have committed 18M€ to the mission) Director Prof. Waters issued a joint communique in which they expressed their strong support for the development of a new SPICA concept and the continued commitment of both institutes to support the mission. http://www.ir.isas.jaxa.jp/SPICA/SPICA_HP/index-en.html. Prof. Tsuneta underlined the importance of SPICA as the next large astrophysics mission of JAXA, in partnership with ESA. An important next step in the realization of the mission was to be the submission of a proposal in the context of ESA's M4 Cosmic Vision program call, due September 2014.

In the weeks leading up to the September 2014 SPICA/Safari consortium meeting held at Oxford University, there had been feedback from ESA/JAXA suggesting that the agencies believed that M4 was less appropriate for SPICA, but that the M5 call would be ideal and on an acceptable timescale. Budgetary constraints confirmed at ESA's June SPC meeting had reduced the scope of the M4 call. This was readily apparent in the call documentation which showed a firm and significantly reduced funding limit, as well as a schedule which turned out to be more aggressive than the original baseline SPICA/Safari schedule. At the consortium meeting, Favata (Head of the Coordination Office for the Directorate of Science and Robotic Exploration, ESA) and Tsuneta (Director general of ISAS and vice president of JAXA) gave a coordinated presentation entitled *progress towards a mission proposal for SPICA*.

Having seen cost overruns on the M1 and M2 missions, ESA has resorted to a cost capped mission criteria. Each project must first go through an ESA review in the Concurrent Design Facility (CDF) and if, in ESA's opinion, it is rejected at this step, the project is eliminated from the competition (i.e. it is never reviewed on either technical or scientific merits.) As a sign of their continued support for SPICA as a potential candidate M5 mission, the agencies committed to undertake a joint study using the ESA CDF this fall to determine what a realistic scale for the SPICA mission would be under the combined JAXA-L and ESA-M5 budgets. So in a strange turn of events, while SPICA is no longer in the M4 call it will undergo a review before missions that are.

The CDF review officially started in mid-November and is expected to be completed by the end of the year. The formally approved report will likely be available by late February/early March 2015. The next consortium meeting is scheduled for March 2015, which will review the report and plan the next steps towards an M5 submission expected in the fall 2015.

5. Unique opportunity for Canada

As the SPICA/Safari project has evolved, an opportunity for Canada to lead the development of arguably the most critical component of the Safari instrument, the cryogenic translation stage and metrology system, has been identified. Fourier transform spectroscopy is widely recognized as an area of strength in Canada and the CSA has awarded a contract to ABB to evaluate the cost and feasibility of developing this system. If the mission goes ahead and if Canada provides the translation stage, the return on investment to Canadian astronomers will be significant; at least twice the number of scientists represented on the Guaranteed Observing Time teams to that of Herschel, reflecting the recognition of Canada as a major player in the mission.

The cost of Canadian participation in SPICA is difficult to estimate. It depends on whether Canada provides flight hardware or contributes at a lower level through software development and AIV/ICC effort (as was the case with Herschel/SPIRE when the calibration shutter was descoped). Furthermore, in the cradle-to-grave mission funding model, the length of the mission is a key driver. While Herschel had a well-defined lifetime (due to the consumable liquid cryogen) the mechanical coolers on SPICA are slated to last a minimum of 3 years, but with redundant coolers may well last for 5 or more. If Herschel/SPIRE is used as a baseline, the best estimate without flight hardware for cradle-to-grave costs is likely to be in the range 7-10 M$. Since the cost for Canada to build the cryogenic translation stage/metrology system is one of the outcomes of the current CSA contract awarded to ABB, it is unwise to make predictions, but a factor of two would not appear unreasonable.

6. Summary

In summary, the SPICA project has undergone a major restructuring. ESA will assume leadership for the mission taking responsibility for the science payload, while Japan will be responsible for the service module, launch, operations, cryocoolers and one of the science instruments. The project remains the top priority within JAXA and is well regarded within ESA. Having to go through a competitive review incurs delays and carries the risk of not being selected. On the other hand, the Consortium is well positioned to present a compelling case to the M5 competition expected in late 2015 and the additional time is particularly beneficial to exploring the potential Canadian contribution of a cryogenic translation stage.

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