

## THE NEXT-GENERATION INFRARED SPACE MISSION SPICA: PROJECT UPDATES

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## ABSTRACT

We present project updates of the next-generation infrared space mission SPICA (Space Infrared Telescope for Cosmology and Astrophysics) as of November 2015. SPICA is optimized for mid- and far-infrared astronomy with unprecedented sensitivity, which will be achieved with a cryogenically cooled (below 8 K), large (2.5 m) telescope. SPICA is expected to address a number of key questions in various fields of astrophysics, ranging from studies of the star-formation history in the universe to the formation and evolution of planetary systems. The international collaboration framework of SPICA has been revisited. SPICA under the new framework passed the Mission Definition Review by JAXA in 2015. A proposal under the new framework to ESA is being prepared. The target launch year in the new framework is 2027/28.

*Key words:* Space vehicles — Space vehicles: instruments — Telescopes

## 1. INTRODUCTION

Since most of the star-formation activities take place in heavily obscured regions and star-forming galaxies are often heavily dust obscured, mid- to far-infrared observations are expected to play essential roles to reveal the history of star-formation in the universe. The effectiveness of mid- and far-infrared observations has been clearly demonstrated by the previous infrared missions (IRAS, IRTS, ISO, SPITZER, AKARI, and Herschel).

Among the missions, AKARI (Murakami et al., 2007) played unique roles (see many papers in this volume) by carrying out the second-generation all-sky survey (along with pointed observations) in the mid- to far-infrared. AKARI provided us with extensive point-source catalogs. However, more than half of the sources in the

AKARI catalogs are still unidentified, and follow-up observations in the mid- to far-infrared have been strongly required. Moreover, the recent, great success of the Herschel Space Observatory (Pilbratt et al., 2010) has clearly shown the effectiveness of far-infrared observations in space with a large telescope.

Following the successful missions, we are proposing the SPICA (Space Infrared Telescope for Cosmology and Astrophysics) mission, which is optimized for mid- and far-infrared astronomy with a cryogenically cooled 2.5 m telescope (Figure 1 and Table 1). Although Herschel was a very powerful observatory, its telescope was not cold enough (80 K), and its thermal emission was brighter than natural background radiation by many orders of magnitude (Figure 2). Hence the fluctuation of this thermal emission caused degradation of the sensitivity. To achieve superior sensitivity, SPICA's tele-

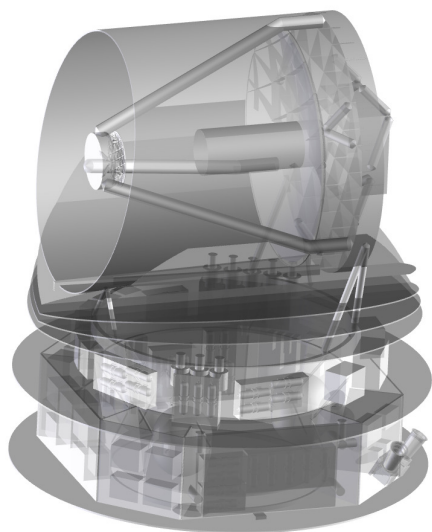


Figure 1. The new configuration of SPICA

scope is cooled below 8 K (Table 1), and the thermal emission from the telescope is reduced down to the level smaller than or comparable to natural background radiation (Figure 2). Hence, being basically limited only by the fluctuation of natural background radiation, the sensitivity of SPICA is expected to show huge improvement. The combination of a large-aperture telescope (2.5 m) and the very low-background condition achieved by a cryogenically cooled instrument enables unprecedented sensitivity in the mid- and far-infrared. This is the main advantage of the SPICA mission.

Nakagawa et al. (2015) discussed the SPICA mission as of the summer of 2014. In this paper, we summarize the latest status of the SPICA mission as of November 2015, updating the information after the AKARI conference.

## 2. SCIENCE RATIONALE

### 2.1. Science Goals

This section discusses science rationale of SPICA on the basis of SPICA Team (2015).

How our universe has evolved since the Big Bang and how our solar system became habitable as it is in the present-day universe are among the most fundamental questions that modern astronomy strives to answer. We hence set the top-level science goal of SPICA to answer this question, i.e., “to reveal the process that enriched the universe with metal and dust, leading to the formation of habitable worlds.”

The top-level goal consists of two distinct science goals. One is to unveil how stars have formed in galaxies and enriched the universe with metal and dust in

Table 1  
Main specifications of the SPICA mission

Item	Description
Telescope	Effective aperture of 2.5 m Actively cooled below 8 K
Focal-Plane Instruments	SPICA Mid-infrared Instrument (SMI) SPICA Far-infrared Instrument (SAFARI)
Orbit	Halo orbit around S-E L2
Launch Year	2027/28

the history of the universe (Metal and dust enrichment through galaxy evolution). The other is to unveil how planets have formed in disks around forming stars and how they have evolved to become habitable (Planetary system formation to habitable systems).

In the following subsections, we discuss details of the two science goals.

### 2.2. Metal and Dust Enrichment through Galaxy Evolution

At the very beginning of the universe, the first stars were born in a metal-poor environment. These stars are thought to be very massive because the cooling processes provided by dust grains and heavy elements were not efficient at that time and thus a large mass was required to start stellar contraction. The situation changed quickly when dust grains were formed, as their thermal emission provided efficient cooling of gas, triggering fragmentation of the gas of even less than one solar mass. Hence, although the dust and metal are the products of the star formation activity, the enrichment of dust and metal consequently influences the efficiency of radiation feedback to star formation and the subsequent evolution of galaxies.

Following the early period mentioned above, the star formation activity increased, peaking at around 8 - 11 Gyr ago (at redshifts ( $z$ ) between 1 and 3). The majority of present-day stars have been produced in that period in obscured galaxies. Hence the enrichment of the universe with heavy metal progressed most efficiently during this period, probably because the metal enrichment was more accelerated by the active interplay between the dust enrichment and galaxy evolution.

In spite of the importance of this interplay, we have very limited knowledge about its true nature. This is primarily due to the effect of dust absorption on stellar radiation; most galaxies with active star formation are

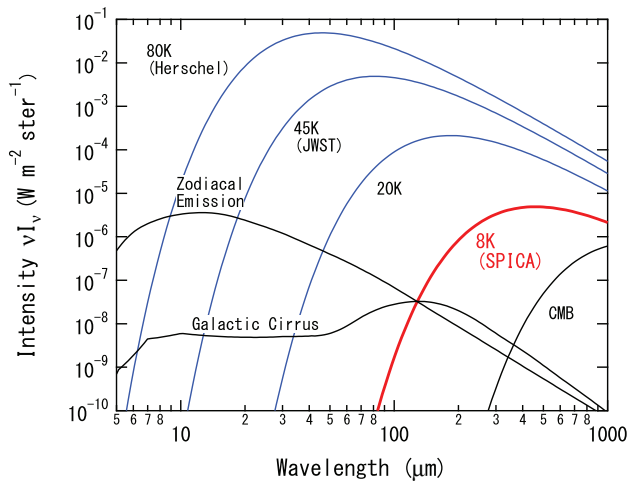


Figure 2. Natural background radiation (black lines) and radiation from telescopes as a function of temperature (blue and red lines). The telescope on-board SPICA is to be cooled below 8 K, so that the background radiation is to be reduced significantly compared with that of Herschel in the far-infrared. The low background condition is expected to improve the sensitivity of SPICA dramatically.

heavily obscured by dust. Especially, in the peak period of star formation activity, most of the energy emitted in the star formation process was converted into the infrared and less than 10% remained visible at the ultraviolet to optical wavelengths (Madau & Dickinson, 2014). The era of the highest star formation activity is really a “dusty era”.

SPICA is the must tool to reveal the true nature of interplay between galaxy evolution and dust/metal enrichment in the universe, since SPICA has unprecedented sensitivity in the mid- to far-infrared, where we have excellent diagnostics both for the star formation activity and nature of dust.

Another important factor that has been thought to affect evolution of galaxies is black hole accretion activity or the Active Galactic Nuclei (AGNs). The current theoretical models have great difficulty in reproducing a small number of observed high-mass galaxies without the AGNs feedback by outflows especially for the formation of high-mass galaxies. However, very little is known about AGN outflows at  $z = 0.5 - 2$ , where the outflow is supposed to start dominating in regulating the star formation in the universe.

SPICA is quite powerful for the study of AGN feedback, since (1) majority of the AGNs were heavily obscured at  $z = 0.5 - 2$  and (2) SPICA covers important lines, such as those of OH, for the study of AGN feedback.

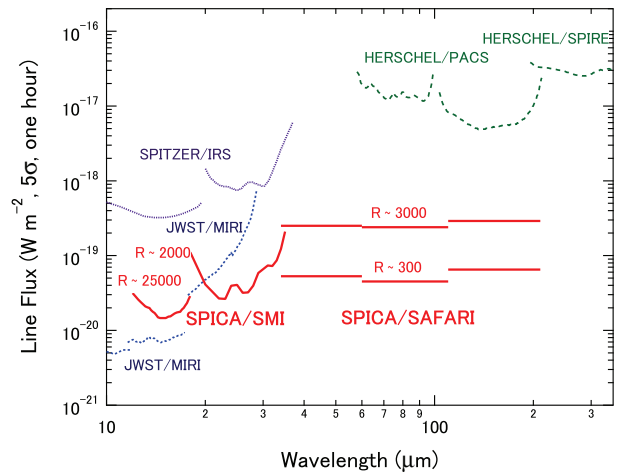


Figure 3. Comparison of the updated SPICA’s sensitivity (solid lines) with those of other missions (dotted lines). The SPICA’s sensitivity is preliminary and is subject to change in the future study.

### 2.3. Planetary-System Formation to Habitable Systems

Planets are believed to form while the proto-planetary disk (PPD) evolves. In the process of evolution of the PPD, dust grains grow and settle down on the mid-plane, while gas is dissipated either by photo-evaporation or by the disk wind. A PPD becomes a debris disk at the end of its evolution (Williams & Cieza, 2011). This is our rough idea how planets are formed and how planetary systems evolve. However, we have very little knowledge on what the critical elements to determine the diversity of planets observed in our Galaxy are.

During the planet formation process, the gas plays a crucial role in constraining the dust motion and growth, while the dust controls the energy balance and chemistry of the gas. Hence, to obtain a complete picture of the planet formation process, we have to reveal the evolution processes both in gas and solid phases.

Firstly, we need to understand the gas properties and dissipation process in terrestrial planet forming regions ( $\sim 1$  AU) of individual PPDs. This is essential to obtain a complete picture of the planet formation process, since the gas dissipation critically affects planet-formation and the properties of forming planets. SPICA is expected to play crucial roles in this area by revealing the gas dissipation in planet-forming disks; SPICA offers the most robust estimate of the mass of molecular gas as a whole with infrared rotational lines of hydrogen deuteride, HD. SPICA is expected also to reveal the dissipation process of molecular gas in 1-2 AU regions of evolved disks with velocity-resolved observations of  $H_2$

lines.

Secondly, it is also essential to reveal the evolution of physical properties and transport of dust grains within disks along the evolution from PPDs to debris disks. This is a key element for the understanding of the formation of our solar system and habitable environments. For this study, SPICA has a perfect wavelength coverage, which contains most of important dust and ice features.

### 3. SPICA MISSION

#### 3.1. Mission Overview

Figure 1 shows the configuration of the updated design of the SPICA satellite under the new framework. The configuration is based on ESA (2015) with additional study mainly on PLM by JAXA.

The satellite consists of the Payload Module (PLM) and the Service Module (SVM). PLM contains the SPICA Telescope Assembly (STA), which is a 2.5 m telescope cooled below 8 K and is set horizontally above SVM. Attached to STA are two focal plane instruments: SPICA Mid-infrared Instrument (SMI) and SPICA Far-Infrared Instrument (SAFARI). With the two instruments, SPICA covers the the mid- to far-infrared (17 to 210 $\mu$ m) wavelength range continuously.

Figure 3 shows comparison of the expected sensitivity of SPICA with those of other missions. SPICA is expected to exceed the other missions in the sensitivity by orders of magnitude in the far-infrared.

#### 3.2. Cryogenics

One of the biggest technical challenges for SPICA is to cool the large telescope below 8 K. The required cooling capability is obtained by a combination of passive cooling (via dedicated Sun and thermal shields combined with radiators) and active cooling (including mechanical coolers).

Mechanical coolers for SPICA consist of a set of advanced Joule-Thompson and Stirling coolers. We plan to use two types of Joule-Thompson coolers: one is for the 4.5 K stage (with  $^4\text{He}$  as working gas) and the other for the 1.7 K stage (with  $^3\text{He}$  as working gas). Two-stage Stirling coolers (2ST) are used as precoolers for the Joule-Thompson coolers.

#### 3.3. SPICA Mid-Infrared Instrument (SMI)

SMI (SPICA Mid-infrared Instrument) is the instrument dedicated to mid-IR spectroscopy in a wavelength range from 12 to 36  $\mu$ m. Table 2 summarizes current

specifications of SMI. SMI has three spectroscopic channels: low-resolution spectroscopy (LRS), mid-resolution spectroscopy (MRS), and high-resolution spectroscopy (HRS). LRS is a multi-slit spectrometer with  $R = 50$ –120 for effective surveys of extragalactic sources mainly with PAH features. MRS is a general-purpose spectrometer optimized for line-spectroscopy with  $R = 1300$ –2300. HRS covers shorter wavelength range (12–17  $\mu$ m), which contains important molecular lines such as  $\text{H}_2$  and  $\text{H}_2\text{O}$ . With very high spectral resolution of  $R = 25000$ –26000, we expect to derive kinematic information from proto-planetary disks.

#### 3.4. SPICA Far-Infrared Instrument (SAFARI)

The SPICA Far-Infrared Instrument (SAFARI) is a spectrometer that covers the far-infrared part (34–210  $\mu$ m) of SPICA with the spectral resolution of  $R \sim 300$  and  $\sim 3000$ . Table 3 summarizes the current specifications of SAFARI. The current design of SAFARI employs a grating spectrometer with Transition-Edge Sensors (TES). With combination of sensitive TES and the large cryogenically cooled telescope, the SAFARI instrument provides unprecedented sensitivity in the far-infrared.

### 4. NEW FRAMEWORK

SPICA is an international mission, originally proposed as a JAXA-led project with important contribution by ESA.

In order to ensure a more secure (feasible and affordable) program, extensive efforts have been made both in programmatic and technical aspects of SPICA, and the international collaboration framework is being revisited. In the new framework, ESA is expected to play a larger role than that in the original plan. The renewed project plan of SPICA passed the Mission Definition Review by JAXA in 2015. A new SPICA proposal for the medium-class mission in the ESA Cosmic Vision program is under preparation. The current target launch year of SPICA is 2027/28.

### ACKNOWLEDGMENTS

The travel support by JSPS is greatly appreciated.

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Table 2  
Specifications of SPICA Mid-Infrared Instrument (SMI)

Parameter	Channel		
	LRS	MRS	HRS
Wavelength Range	17–36 $\mu\text{m}$	18–36 $\mu\text{m}$	12–17 <sup>a</sup> $\mu\text{m}$
Spectral Resolution <sup>b</sup>	50–120	1300–2300	25000–26000
Field of View	600'' $\times$ 3.7'' $\times$ 4 slits	60'' $\times$ 3.7'' (slit)	4'' $\times$ 1.7'' (slit)
Detector	Si:Sb 1K $\times$ 1K	Si:Sb 1K $\times$ 1K	Si:As 1K $\times$ 1K
Continuum Sensitivity(1hr, 5 $\sigma$ )	20–140 $\mu\text{Jy}$	200–4000 $\mu\text{Jy}$	2–4.2 mJy
Line Sensitivity(1hr, 5 $\sigma$ ) <sup>c</sup>	(6–23) $\times 10^{-20}$ W m <sup>-2</sup>	(3–40) $\times 10^{-20}$ W m <sup>-2</sup>	(1.5–3) $\times 10^{-20}$ W m <sup>-2</sup>

<sup>a</sup> Continuous coverage up to 17.3  $\mu\text{m}$  with partial coverage for H<sub>2</sub>O 17.77 and 18.66  $\mu\text{m}$  lines. <sup>b</sup> Spectral resolution for point sources.

<sup>c</sup> Sensitivity for unresolved lines of point sources. The instrument parameters are those as of November 2015. Details are subject to change in the future study.

Table 3  
Specifications of SPICA Far-Infrared Instrument (SAFARI)

Parameter	Band		
	SW	MW	LW
Band Center	47 $\mu\text{m}$	85 $\mu\text{m}$	160 $\mu\text{m}$
Wavelength Range	34–60 $\mu\text{m}$	60–110 $\mu\text{m}$	110–210 $\mu\text{m}$
Band Center Beam FWHM	4.7''	8.6''	16''
Point Source Spectroscopy with $R \sim 300$ (1hr, 5 $\sigma$ )			
Continuum Sensitivity	0.25 mJy	0.36 mJy	0.92 mJy
Line Sensitivity	5.3 $\times 10^{-20}$ W m <sup>-2</sup>	4.5 $\times 10^{-20}$ W m <sup>-2</sup>	6.5 $\times 10^{-20}$ W m <sup>-2</sup>
Point Source Spectroscopy with $R \sim 3000$ (1hr, 5 $\sigma$ )			
Continuum Sensitivity	12 mJy	20 mJy	41 mJy
Line Sensitivity	2.5 $\times 10^{-19}$ W m <sup>-2</sup>	2.4 $\times 10^{-19}$ W m <sup>-2</sup>	2.9 $\times 10^{-19}$ W m <sup>-2</sup>

The instrument parameters are those as of November 2015. Details are subject to change in the future study.

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