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THE NEXT-GENERATION INFRARED ASTRONOMY MISSION SPICA UNDER THE NEW FRAMEWORK

Takao Nakagawa[1], Hiroshi Shibai[2], Takashi Onaka[3], Hideo Matsuhara[1], Hidehiro Kaneda[4], Yasuhiro Kawakatsu[1], and SPICA Team

[1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Kanagawa 252-5210, Japan
[2]Graduate School of Science, Osaka University, Osaka 560-0043, Japan
[3]Department of Physics, University of Tokyo, Tokyo 113-0033, Japan
[4]Graduate School of Science, Nagoya University, Aichi 464-8602, Japan

E-mail: nakagawa@ir.isas.jaxa.jp

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ABSTRACT

We present the current status (as of August 2014) of SPICA (Space Infrared Telescope for Cosmology and Astrophysics), which is a mission optimized for mid- and far-infrared astronomy with a cryogenically cooled 3m-class telescope. SPICA is expected to achieve high spatial resolution and unprecedented sensitivity in the mid- and far-infrared, which will enable us to address a number of key problems in present-day astronomy, ranging from the star-formation history of the universe to the formation of planets. We have carried out the "Risk Mitigation Phase" activity, in which key technologies essential to the realization of the mission have been extensively developed. Consequently, technical risks for the success of the mission have been significantly mitigated. Along with these technical activities, the international collaboration framework of SPICA has been revisited, which resulted in la arger contribution from ESA than that in the original plan. To enable the ESA participation under the new framework, a SPICA proposal to ESA is under consideration as a medium-class mission under the framework of the ESA Cosmic Vision. The target launch year of SPICA under the new framework is the mid-2020s.

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

1. INTRODUCTION

SPICA (Space Infrared Telescope for Cosmology and Astrophysics, Figure 1) is an astronomical mission to reveal the evolutionary history of the universe ranging from the birth and evolution of galaxies, the formation and evolution of stars and planetary systems to the chemical evolution of the universe. On the basis of the heritages of previous infrared missions including AKARI and Herschel, SPICA aims to address a variety of key issues in current astrophysical problems.

SPICA is optimized for mid- and far-infrared astronomy with a cryogenically cooled 3 m-class telescope (Table 1). To achieve superior sensitivity, SPICA's telescope is cooled down to 6K and the thermal emission from the telescope is reduced down to the level smaller than natural background radiation. Hence, being basically limited only by the fluctuation of natural background radiation, the sensitivity is expected to show huge improvement from those of previous missions (Figure 2). The combination of a large-aperture telescope (3m class) and the very low-background conditions to be achieved by a cryogenically cooled telescope enables unprecedented sensitivity in the mid- and far-infrared. This is the main advantage of the SPICA mission.

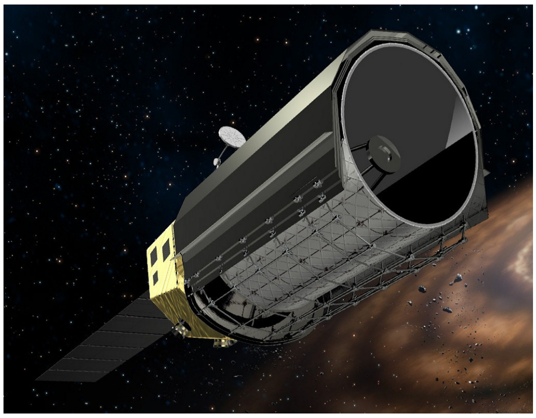

Figure 1. SPICA in orbit, an artistic view

2. SCIENCE GOALS

With the unique capability of SPICA, we have three big science goals. Here we present a short summary of SPICA science goals, of which details are discussed by Nakagawa et al. (2014).

2.1. *Formation and Evolution of Galaxies*

Recent infrared and optical observations have revealed that the bulk of the galaxy star formation (SF) and su-

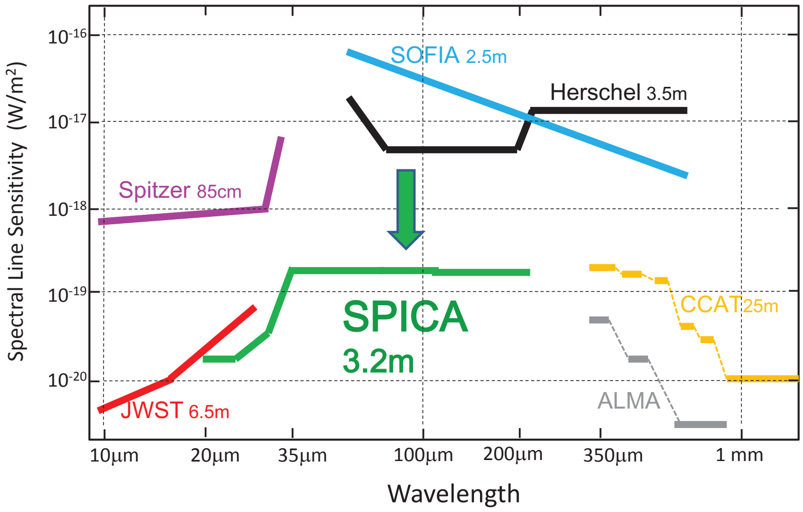

Figure 2. Line sensitivity of SPICA compared with those of other facilities.

permassive black hole (SMBH) accretion in the Universe occurred from redshift $z \sim 1$ to $z \sim 3$. However, details of this process are still far from being understood.

Since both star-formation and black-hole accretion are characterized by severe dust obscuration around the peak of their cosmic evolution, the mid- to far-infrared wavelength window is essential for the study of the formation and evolution of galaxies.

SPICA is specifically designed to address these topics with unprecedented sensitivity and unique spectroscopic capabilities in mid- to far-infrared wavelengths. Main and crucial objectives that only SPICA can reach are:

- To trace the co-evolution of star formation and black hole accretion in thousands of galaxies at $z \sim 1-3$ by measuring their contribution to the total infrared emission
- To study the mutual feedback between star formation and black hole growth by detecting outflows and inflows of atomic and molecular gas in hundreds of galaxies
- To determine the major physical processes that regulate the star formation in galaxies through a complete characterization of their mid-/far-infrared spectral properties
- To investigate the production of heavy elements and dust in the interstellar medium and their evolution as a function of cosmic time.

2.2. *Interaction between Star-Formation and Material Evolution in Galaxies*

Systematic observations of near-by galaxies are also important themes for SPICA especially as anchor datasets for the extragalactic survey.

The SPICA wavelength range covers plenty of important gas/dust evolution indicators, by which we expect to reveal important parameters such as metallicity and gas-dust mass ratio in galaxies.

SPICA is expected to carry out unbiased observations of near-by galaxies and to cover the parameter space of star-formation rate in every morphology (spirals, ellipticals, lenticulars, dwarf/irregular/others) over a wide range of optical luminosity (stellar mass, age). This data set is expected to play an essential role in the study of interaction between star-formation and material evolution in galaxies.

2.3. *Formation of Planetary Systems Near and Far*

Our goal is to understand how protoplanetary disks evolve into planetary systems and whether there exist multiple pathways to planetary systems.

SPICA is to provide unique access to the entire wavelength range 20-210 μm, where the strongest gas cooling lines reside. SPICA covers the crucial wavelength gap between JWST and ALMA with superior sensitivity to obtain a complete view of the gas and ice involved in planet formation processes by connecting the inner and outer disks. In particular, SPICA will be the first and only mission which can investigate not only the relation between ices and dust mineralogy but also the relation between disk structure and the presence of ices for stars similar to our Sun.

The followings are five areas that can be uniquely addressed by SPICA:

- Which processes drive the gas evolution of planet forming young disks?
- How do the main water reservoirs (gas, ice) evolve during the planet forming process?
- What is the thermal and chemical history of the building blocks of planets (dust and ice)?
- What are the composition (gas, dust, ice) and architecture of nearby resolved debris disks?
- How does the Kuiper belt compare dynamically and chemically to debris disks?

Table 1
MAIN SPECIFICATIONS OF THE SPICA MISSION

Parameter	Specifications
Scientific Instrument Assembly	
Telescope	Aperture: 3.2 m, Operating Temperature: 6 K
Core Wavelength	20 – 210 μm
Focal Plane Instruments	(1) SPICA Mid-Infrared Instrument (SMI, 20–37 μm)
	(2) SPICA Far-Infrared Instrument (SAFARI, 34–210 μm)
Bus Module	
Attitude Control System	3-axis-stabilized system
Power Requirements	EOL > 2800W
Satellite System	
Size of the Satellite	At launch: 4,020(w)$\times$4,500(D)$\times$6,144(H) mm
	In orbit: 4,020(w)$\times$4,962(D)$\times$16,020(H) mm
Mass of the Satellite	Wet 3600 kg (with margin)
Launch and Orbit	
Launch Year	mid 2020's
Launch Vehicle	H-IIA-204 with 5S Fairing
Orbit	Halo orbit around Sun-Earth L2 libration point
Mission Life	3years (nominal), 5years (goal)

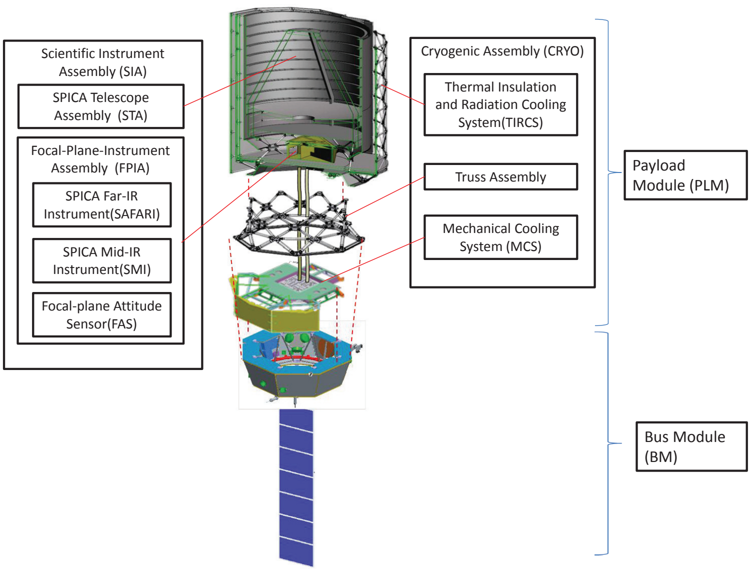

Figure 3. Schematic view of the configuration of the SPICA satellite

3. MISSION OVERVIEW

3.1. Configuration of the Mission

The SPICA satellite consists of the Payload Module (PLM), which contains the Scientific Instrument Assembly (SIA), and the Bus Module (BM) as shown in Figure 3.

PLM is a key element to fulfill science requirements. PLM is composed of the Cryogenic Assembly (CRYO) and the Scientific Instruments Assembly (SIA). CRYO includes the Mechanical Cooler System and Thermal Insulation and Radiative Cooling System, which are required to cool down and maintain the temperature of the Scientific Instruments Assembly below 6K.

SIA is the core part of the SPICA mission and includes the SPICA Telescope Assembly (STA) and the Focal-Plane-Instrument Assembly (FPIA).

Table 1 shows main specifications of the mission.

On the L2 orbit, SIA is to be cooled without cryogen, which means it is cooled by the combination of the mechanical cryocoolers and the radiation cooling to the deep space, while the spacecraft keeps its attitude so as to align the telescope axis basically perpendicular to the direction of the Sun. We are planning to use three types of cyocoolers for SPICA: 4K-class Joule-Thomson coolers, 1K-class Joule-Thomson (JT) Coolers, and the 2-stage Stirling Coolers as precoolers for the JT Coolers. Most of the coolers have a good technical heritage from previous missions.

We have carried out the "Risk Mitigation Phase" activity, in which key technologies essential to the realization of the mission have been extensively developed. Consequently, technical risks for the success of the mission have been significantly mitigated. Shinozaki et al. (2014) describes details of the results of the "Risk Mitigation Phase" phase activity for the SPICA cryogenics.

Table 2
SPECIFICATIONS OF SPICA MID-INFRARED INSTRUMENT (SMI)

Parameter	Band		
	Cam	Spec-S	Spec-L
Wavelength Range	20–37 μm	20–27 μm	27–37 μm
Spectral Resolution	20	1000–2000 (point source) 1000 (diffuse)	
Field of View	$5' \times 5'$	$150'' \times 3''$ (slit)	
Detector	Si:Sb 1K×1K	Si:As 1K×1K	Si:Sb 1K×1K
Continuum Sensitivity(1hr, 5σ)	(9–50) μJy	(0.1–0.5) mJy	(0.2–1) mJy
Line Sensitivity(1hr, 5σ)	$(6–15)\times10^{-20}$ W m^{-2}	$(2–7)\times10^{-20}$ W m^{-2}	$(3–10)\times10^{-20}$ W m^{-2}

Table 3
SPECIFICATIONS OF SPICA FAR-INFRARED INSTRUMENT (SAFARI)

Parameter	Band		
	SW	MW	LW
Wavelength Range	34–60 μm	60–110 μm	110–210 μm
Pixel Scale	$5''$	$7''$	$13''$
Number of Detectors	43×43	34×34	18×18
Field of View	$2' \times 2'$	$2' \times 2'$	$2' \times 2'$
Continuum Sensitivity(1hr, 5σ)	14 μJy	21 μJy	32 μJy
Line Sensitivity(1hr, 5σ)	3.7×10^{-19} W m^{-2}	3.4×10^{-19} W m^{-2}	2.9×10^{-19} W m^{-2}

3.2. *Scientific Instrument Assembly (SIA)*

The Scientific Instruments Assembly contains the SPICA Telescope Assembly (STA), which is a 3m-class telescope cooled down to 6K, and two focal plane instruments: SPICA Mid-infrared Instrument (SMI) and SPICA Far-Infrared Instrument (SAFARI). With the two instruments together, mid- to far-infrared (20 to 210μm) wavelength range is to be covered continuously.

The SPICA Mid-Infrared Instrument (SMI, Table 2) covers the mid-infrared (20 to 37μm) range. SMI consists of one imaging channel and two spectroscopic channels (grating spectrometer). The imaging channel has both a wide-band (R ∼several) and a series of narrow-band ($R \sim$20) imaging capabilities. The latter is to be used for efficient mapping of PAH features at various redshifts. The spectroscopic channels are designed to have high spectroscopic survey efficiency for extragalactic studies.

The SPICA Far-Infrared Instrument (SAFARI, Table 3) covers the far-infrared part (34-210 μm) of SPICA. SAFARI is an imaging Fourier-Transform spectrometer with very sensitive Transition-Edge Sensors (TES). SAFARI has three bands, and natural-background limited operation is expected. To cool the TES below 100 K, SAFARI has its own sub-K cooler system, which consists of a ^{3}He sorption cooler and a Adiabatic Demagnetization Refrigerator (ADR). Roelfsema et al. (2014) describes details of SAFARI science capability.

SAFARI is to be procured by the SAFARI consortium led by SRON, the Netherlands, while SMI is to be procured by the SMI consortium in Japan.

4. NEW FRAMEWORK OF INTERNATIONAL COLLABORATION

SPICA is an international mission, and its collaboration framework is now being revisited.

SPICA was originally proposed as a JAXA-led mission with important contribution by ESA.

In order to ensure a more secure (feasible and affordable) program, extensive efforts has been made in programmatic 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. To enable ESA's participation in the new framework, a SPICA proposal to ESA is under consideration as a medium-class mission under the ESA Cosmic Vision program.

The target launch year of SPICA under the new framework is the mid 2020s.

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