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THE NEXT-GENERATION INFRARED SPACE MISSION: SPICA

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Abstract

We present an overview of SPICA (Space Infrared Telescope for Cosmology and Astrophysics), which is an astronomical mission optimized for mid- and far-infrared astronomy with a cryogenically cooled 3-m class (3.5 m in the current design) telescope. Its high spatial resolution and unprecedented sensitivity 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. To reduce the mass of the whole mission, SPICA will be launched at ambient temperature and cooled down on orbit by mechanical coolers on board with an efficient radiative cooling system, a combination of which allows us to have a 3-m class cooled (5 K) telescope in space with moderate total weight (4t). SPICA is an international mission. Japan is in charge of the whole integration of the system, and its activity is now approved as a pre-project at JAXA. The assessment study on the European contribution to the SPICA project has been carried out under the framework of the ESA Cosmic Vision 2015-2025. US and Korean participations are also being discussed extensively. The target launch year of SPICA is 2018.

Key words: Cryogenics – Missions: SPICA – Space missions – Space science

1. Introduction

Infrared astronomical satellites with cryogenically cooled telescopes (IRAS, Neugebauer et al. (1984); IRTS, Murakami et al. (1996); ISO, Kessler et al. (1996) Spitzer Space Telescope, Werner et al. (2004) and AKARI, Murakami et al. (2007)) have been proved to be very powerful tools in mid- and far-infrared astronomy. The telescopes onboard these missions were cooled with liquid He, since thermal emission from a telescope is a dominant noise source in the mid- to far-infrared region. This design required big cryostats and thereby reduced the telescope aperture size of the previous missions to smaller than 1 m. Thus their spatial resolution was relatively poor, which degraded point-source sensitivity, since the source confusion noise, set by the number of detectable sources in a spatial resolution element, becomes a dominant noise source in the far-infrared.

This situation has been dramatically improved by the Herschel Space Observatory (Pilbratt, 2008), which was launched in May 2009. Herschel carries a 3.5 m telescope, which is much larger than those of previous missions and has much better spatial resolution (and confusion-noise limited sensitivity) than previous missions with telescopes smaller than 1 m. However, Herschel's telescope is about 80 K, which is not cold enough for mid- and far-infrared astronomy, and its sensitivity at wavelengths shorter than 100 μm is limited by the fluctuation of thermal radiation from the telescope. On the other hand, James Webb Space Telescope (JWST; Gerdner, 2008) with a 6.5 m telescope will operate from 0.6 to 28 μm. JWST will represent a leap in the ability of observations in the near- and mid-infrared. However, the temperature of the JWST telescope is around 45 K, which is again too warm for sensitive observations in the far-infrared, and JWST does not cover wavelengths longer than 28 μm.

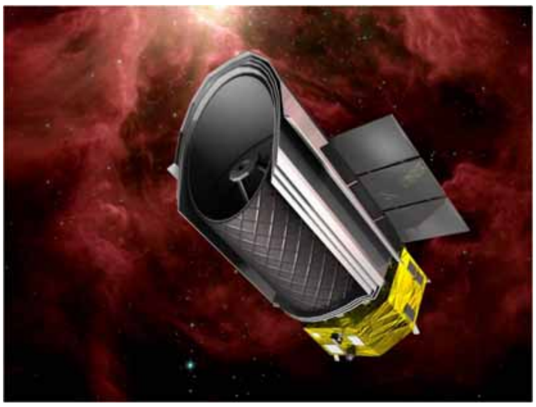

Figure 1. SPICA in orbit

To improve both sensitivity and spatial resolution in the mid- and far-infrared, cryogenically cooled, large telescopes in space are required. For this purpose, we are proposing the mission SPICA (Space Infrared Telescope for Cosmology and Astrophysics; Fig. 1): SPICA is optimized for the mid- and far-infrared astronomy by employing a cryogenically cooled 3 m class (3.5 m in the current

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design) telescope. In this paper, we present an overview of the SPICA mission.

2. Scientific Objectives

Various scientific areas, in which SPICA is expected to play essential roles, were discussed during the conference. In the following, we make a brief summary of SPICA's main scientific objectives.

2.1. Birth and evolution of galaxies

SPICA can address the birth and evolution process of galaxies in many ways. SPICA is expected to play a crucial role by resolving the Cosmic Infrared Background near its energy peak; SPICA can resolve more than 90% of the Cosmic Infrared Background into individual sources at 70 μm.

The mid- to far-infrared wavelength range is very rich with many important fine-structure lines, which are quite useful for the estimate of star-formation activities and AGN activities. Since these lines are less sensitive to extinction, they are expected to bring us essential information on the activities especially in obscured galactic nuclei.

One more challenging goal for SPICA is to reveal the formation of the first-generation of stars, i.e. Population III (Pop III) stars. Since the Pop III stars are formed from primordial pre-stellar gas without metals, the gas cannot be cooled through metal lines but is expected to be cooled through molecular hydrogen lines. SPICA will challenge the detection of H2 emission from large pre-galactic clouds that form metal-free stars.

2.2. Stellar and planetary formation

SPICA is expected to play an essential role in the study of the formation and evolution processes of stars and planetary systems.

The study of star-formation has been a big task for infrared astronomy, and SPICA is also expected to play a significant role in this area. Photometric and spectroscopic studies of evolved stars are another important area for SPICA. SPICA is also expected to address the formation processes of planetary systems. SPICA can make very sensitive observations both for gas phase and for solid state matter in the proto-planetary and debris disk systems, which are essential for the understanding of planetary formation process.

One of the biggest challenges of SPICA is the direct detection and spectroscopy of exoplanets. The typical contrast between a central star and planets around it is estimated to be 10^{10} in the optical but to be reduced to 10^6 in the mid-infrared. Thus the mid-infrared is an optimum region to try direct detection of exoplanets. Moreover, SPICA has a smooth, well characterized Point Spread Function, since the SPICA's telescope employs a monolithic mirror, which is very important for effective coronagraphic observations. Taking the best use of these advantages, SPICA will make direct observations of exoplanets including their spectra, which is essential to characterize their nature.

2.3. Chemical evolution of the universe

The infrared wavelength is also unique in a sense that both gas phase and solid phase chemistry can be investigated. With its wide spectral coverage and excellent sensitivity, SPICA can observe important features (e.g. PAH and Silicate) over a wide range of red-shifts to investigate the chemical evolution of the universe.

3. Mission Requirements

In this section, we summarize requirements of the mission to achieve the scientific objectives mentioned above.

3.1. Telescope Size

The telescope size is an essential parameter for astronomical observations. SPICA has various scientific goals which require a large telescope. For example, Fig. 2 shows that a 3-m class telescope is required to resolve cosmic infrared background at its peak energy,

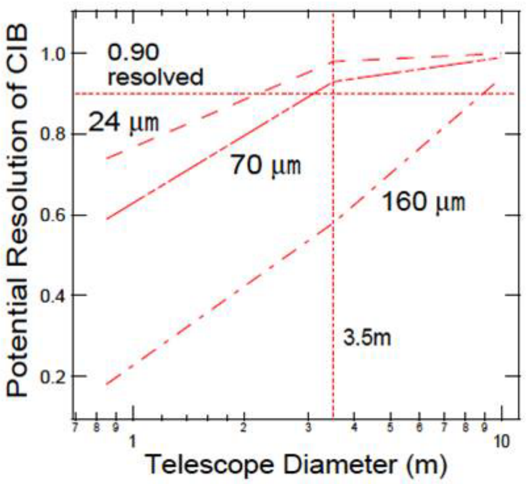

Figure 2. How much fraction of the Cosmic infrared background (CIB) can be resolved into individual sources. Confusion limited sensitivity is assumed as a function of wavelength and aperture size (Dole et al., 2004). A 3-m class or larger telescope is required to resolve more than 90% of CIB into individual sources at near (70 μm) the peak of CIB.

3.2. Telescope temperature

The telescope temperature is another important factor. Fig. 3 compares the radiation from the telescope (solid lines), as a function of temperature, to natural background sources (dotted lines: zodiacal emission, Galactic cirrus, and cosmic microwave background). A telescope temperature of around 5 K is required to achieve natural background-limited observations in the mid- and far-infrared.

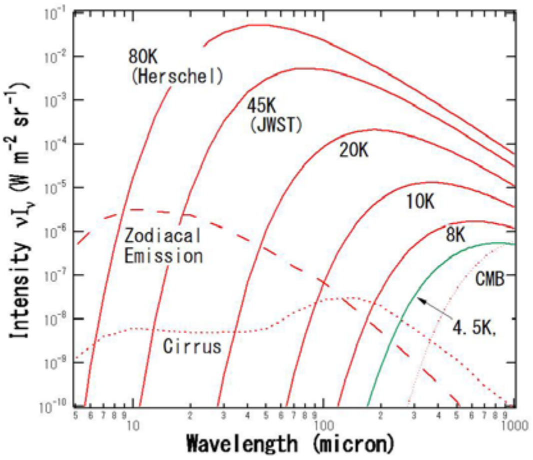

Figure 3. Thermal radiation from telescopes as a function of the telescope temperature, which is compared with natural background radiation (zodiacal emission, cirrus, and CMB). A cryogenically cooled ($T \sim 5$ K) telescope is required to achieve natural-background limited sensitivity.

4. Mission Overview

4.1. Mission specifications

Following the above discussions, we have determined the specifications of the SPICA mission as summarized in Table 1. The most important point is that SPICA incorporates a 3-m class, cryogenically cooled telescope. The combination of the low temperature and large aperture size of the telescope makes the SPICA mission the most sensitive instrument in the mid- and far-infrared.

To achieve high sensitivity in the mid- and the far-infrared, we have to cool the whole telescope and the focal plane instruments. All of the infrared astronomical satellites flown so far carried liquid helium for cooling; this made the satellites big and heavy and reduced the sizes of the telescopes significantly. Moreover, their mission lives were forced to be short by limited hold time of liquid helium. To overcome these difficulties, we propose a "warm-launch, cooled telescope" design concept, i.e., the telescope and focal plane instruments (FPIs) are "warm" at launch since SPICA will not carry any cryogen. The telescope and the FPIs are to be cooled in orbit by a combination of effective radiative cooling and modest

Table 1. SPICA Mission Specifications

Observation Instrument	
Telescope Aperture Size	3-m class (3.5 m in the current design)
Telescope Temperature	5 K (during observation) 300 K (at launch)
Telescope Accuracy	Diffraction Limit > 5 μm
Core Wavelength	$5 - 210$ μm
Cryogenics	Mechanical Cryocoolers Effective Radiative Cooling
Total Mass	~4 t
Launch	
Orbit	S-E L2 Halo
Year	2018

mechanical cryocoolers. Fig. 4 shows its conceptual view. The cryogenic system is discussed in detail by Sugita et al. (2008).

The "warm launch" concept without any cryogen significantly reduces the total size and enables payload fairings of existing launching vehicles to accommodate a telescope with a 3-m class primary mirror. The "warm-launch" concept dramatically reduces the total mass of the mission; 3.5 m SPICA weighs around 4 t.

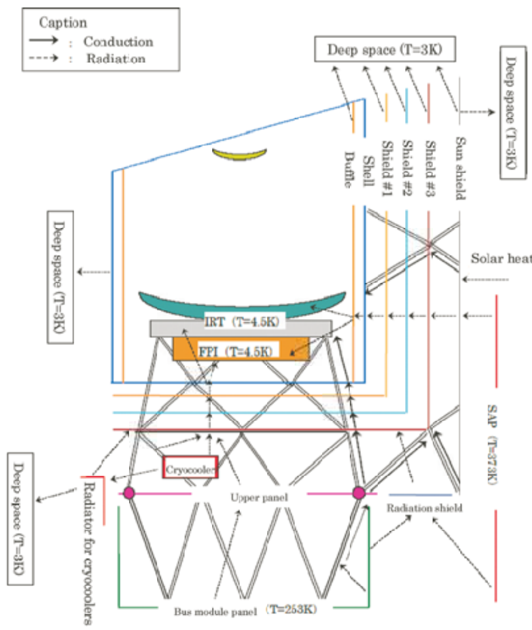

Figure 4. Schematic view of the SPICA cryogenic system.

4.2. Telescope

The baseline specifications of the SPICA telescope assembly (STA) are summarized also in Table 1. The baseline model consists of a 3.5 m single aperture, primary mirror. The primary mirror of STA is a monolithic mirror, which can be accommodated within fairings of existing launching vehicles, and no deployable mechanism is required to reduce the complexity in the operation at cryogenic temperatures in space. Because of the high demands on the SPICA telescope system, the selection of the mirror material is of prime importance. At the current study stage, we have two candidate materials, sintered silicon carbide (SiC) and carbon-fiber reinforced SiC (C/SiC composite), for the SPICA telescope mirrors.

Sintered SiC mirrors are employed by Herschel, and thus benefit greatly from the heritage of their development programs. However, the SPICA requirement on the wavefront error (0.35 μm rms) is by an order of magnitude more stringent than that for Herschel (6 μm rms). The C/SiC composite has relatively high fracture toughness since carbon fibers are incorporated into SiC. It is easily machined in the carbon-fiber carbon-matrix (C/C) composite stage. These characteristics enable a very light-weighted design of the 3.5 m blank.

4.3. Focal Plane Instruments

Fig. 5 shows an overall view of the SPICA focal plane instruments, which are required to fulfill the scientific requirements described in the previous section.

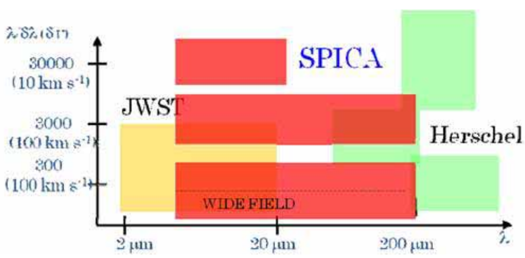

Figure 5. Representative parameters of the SPICA focal plane instruments.

To cover the core wavelength, we need at least two instruments. One is a mid-infrared camera/spectrometer using multiple Si:As and Si:Sb detector arrays. The other is a far-infrared camera/spectrometer using Ge:Ga and stressed Ge:Ga array detectors. Bolometer systems are discussed as an option for the second instrument. It is being discussed that the first instrument incorporates a mid-infrared stellar coronagraph, which enables the direct observations of exoplanets. Details of each instrument is described in other papers in this conference.

5. Current Status of the Project

5.1. Status in Japan

In Japan, the SPICA working group has been working on the design and strategic, technology development programs for SPICA for about ten years. In June 2007, ISAS/JAXA issued a call for mission proposals to be launched in the 2010s. In response to this call the SPICA working group submitted a mission proposal in September. The proposal was successfully accepted by ISAS in March 2008 after the Mission Definition Review (MDR) process. Then, JAXA/HQ made a management review called "Project Preparation review" in 2008. Following these reviews, JAXA officially formed a SPICA pre-project team in July 2008. SPICA is now in the midst of a 3-year full Phase-A study phase, which is now scheduled from 2008 to 2011 with the start of phase-B foreseen in 2011 for the launch in 2018.

5.2. International Collaboration

To enable European participation in the SPICA project, the European SPICA Consortium (P.I.: B. Swinyard, RAL, UK) submitted a proposal to ESA in June 2007 under the framework of the ESA Cosmic Vision 2015-2025. The proposal assumes ESA's roles in SPICA as follows: (1) SPICA Telescope Assembly, (2) European Ground Segment, (3) Management of SPICA Far-Infrared Instrument (SAFARI), and (4) SPICA Mission support. The proposal also assumes the SAFARI is to be developed by the European Consortium. The proposal was successfully selected by ESA in October, 2007, as one of candidates for future missions. The assessment activity on SPICA lead by ESA started in November 2007 and ended in August 2009. Jagemann et al. (2008) discussed this activity.

A harmonized overall schedule incorporating the ESA Cosmic Vision M-class mission schedule, the Japanese SPICA schedule, and the SAFARI schedule has been drafted. The fundamental assumption for this schedule is that SPICA is selected by ESA as an M-class mission.

Collaboration with US and Korea is also under discussion.

References

Dole, H. et al. ApJS, 154, 93
Gardner, J.P. 2008, SPIE, 7010, 18
Jagemann, T., Rando, N., Doyle, D., Heras, A., Nakagawa, T., & Swinyard, B. 2008, SPIE, 7082, 26
Kessler, M.F. et al. 1996, A&A 315, L27
Murakami, H., et al. 1996, PASJ, 48, L41
Murakami, H. et al. 2007, PASJ, 59, S369
Nakagawa, T. & Murakami, H. 2007, AdSpR, 40, 684
Neugebauer, G. et al. 1984, ApJ 278, L1
Pilbratt, G.L. 2008, SPIE, 7010, 1
Sugita, H. et al. 2008, Cryogenics, 48, 258
Swinyard, B. et al. 2009, Exp. Astron., 23, 193
Werner, M.W. et al. 2004, ApJS 154, 1