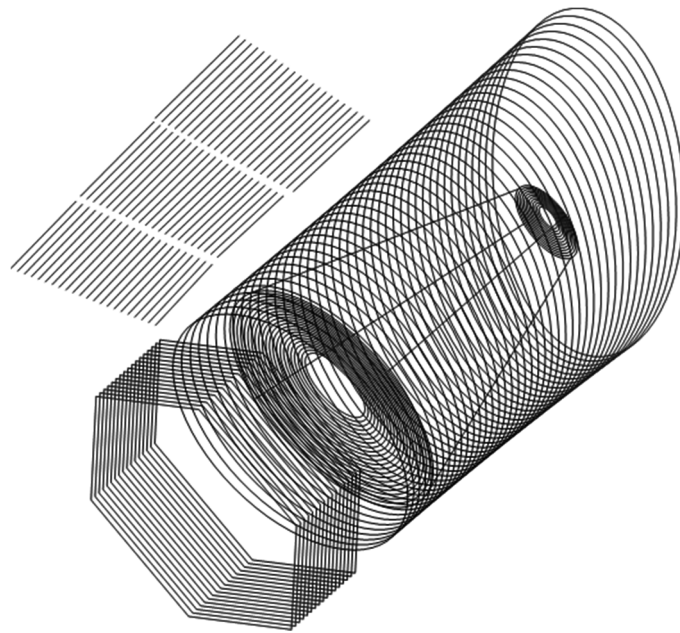


## **SPICA Science Conference**

# **From Exoplanets to Distant Galaxies: SPICA'S NEW WINDOW on the Cool Universe**

## **Proceedings (Appendix)**



**June 18 – 21, 2013  
Ito Hall, the University of Tokyo,  
Tokyo, Japan**

# **From Exoplanets to Distant Galaxies: SPICA's New Window**

Proceedings of the SPICA Science Conference held at  
Ito Hall, the University of Tokyo, Tokyo Japan  
18–21 June, 2013

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# Note to Appendix

This volume is an appendix to the proceedings of the SPICA conference held in Tokyo in 2013 (JAXA-SP-17-010E, published in March 2018). This appendix includes several papers providing a description of instrumentation as valid at the time of the conference. After the conference the mission configuration and the international collaboration framework were revisited and changed significantly. The current mission concept foresees an ESA-led mission with significant contribution from JAXA, with a configuration that has been updated to profit from the latest technological advances, both at platform level as well as in the instrument complement. This new SPICA concept has been selected as one of the candidates for the ESA Cosmic Vision M5 mission, and is currently in a phase A conceptual design study stage.

The editors of the proceedings believe the instrument descriptions in this appendix, even if outdated, are still valuable for discussions on future space infrared observatories. We sincerely apologize to all the contributors for the delay of publication.

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# APPENDIX

# The Next-generation Infrared Telescope Mission *SPICA*: Overview

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## COMMENTS ON THE PAPER

This paper describes overview of *SPICA* mission as valid at the time of the conference in 2013. After the conference the mission configuration and the international collaboration framework were revisited and changed significantly. The current mission concept foresees an ESA-led mission with significant contribution from JAXA, with a configuration that has been updated to profit from the latest technological advances. This new *SPICA* concept has been selected as one of the candidates for the ESA Cosmic Vision M5 mission, and is currently in a phase A conceptual design study stage.

Since the contents of the original paper is very much outdated, we have decided not to include the paper in the proceedings. Please refer to Nakagawa et al. (2012) and Matsuhara et al. (2012) for related information at the time of the conference and to Roelfsema et al. (2018) for the latest information on the *SPICA* project.

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- Roelfsema, P., et al. 2018, *Publications of Astronomical Society of Australia*, 35, e030

# The SAFARI Imaging Spectrometer on the *SPICA* Space Observatory; Revealing the Origins of the Universe, from Planets to Galaxies

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## COMMENTS ON THE PAPER

This paper describes *SPICA* far-infrared instrument as valid at the time of the conference in 2013. After the conference the mission configuration and the international collaboration framework were revisited and changed significantly. The current mission concept foresees an ESA-led mission with significant contribution from JAXA, with a configuration that has been updated to profit from the latest technological advances. This new *SPICA* concept has been selected as one of the candidates for the ESA Cosmic Vision M5 mission, and is currently in a phase A conceptual design study stage.

Since the contents of the original paper is very much outdated, we have decided not to include the paper in the proceedings. Please refer to Roelfsema et al. (2012) for related information at the time of the conference and to Roelfsema et al. (2018) for the latest information on the *SPICA* project.

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Roelfsema, P., et al. 2018, *Publications of Astronomical Society of Australia*, 35, e030

# The *SPICA* MCS (Mid-infrared Camera and Spectrometer) Instrument

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## COMMENTS ON THE PAPER

This paper describes *SPICA* mid-infrared instrument as valid at the time of the conference in 2013. After the conference the mission configuration and the international collaboration framework were revisited and changed significantly. The current mission concept foresees an ESA-led mission with significant contribution from JAXA, with a configuration that has been updated to profit from the latest technological advances. This new *SPICA* concept has been selected as one of the candidates for the ESA Cosmic Vision M5 mission, and is currently in a phase A conceptual design study stage.

Since the contents of the original paper is very much outdated, we have decided not to include the paper in the proceedings. Please refer to Kataza et al. (2012, 2015) for related information at the time of the conference and to Roelfsema et al. (2018) for the latest information on the *SPICA* project.

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- Roelfsema, P., et al. 2018, *Publications of Astronomical Society of Australia*, 35, e030



## The *SPICA* Coronagraph Instrument (SCI): Overview

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### ABSTRACT

The *SPICA* Coronagraph Instrument (SCI) is proposed for *SPICA* for the purpose of studying small-scale structures surrounding bright stars and galactic nuclei, which specifically include exoplanets (not only detection but also characterization of the atmosphere), protoplanetary and debris disks, dusty tori in active galactic nuclei, and interstellar matter around bright small-scale structures. High contrast images are produced in the SCI by using binary pupil-mask coronagraphs together with an image subtraction technique. The SCI is designed to have both the function of imaging ( $1' \times 1'$  field of view) and spectroscopic capability ( $R = 200$ ). The SCI possesses the capability of low-background spectroscopic coronagraphy over the continuous wavelength range from 4 to 28  $\mu\text{m}$ . These specifications make the SCI a unique instrument for observations over a high dynamic range in the 2020s. After years of review in Japan and international review, the design of the instrument has been modified and simplified to reflect the scientific requirements. The SCI presently has neither a short channel nor a deformable mirror, both of which were present in the previous design. <sup>a)</sup>

### 1. INTRODUCTION

The *SPICA* Coronagraph Instrument (SCI) is proposed for *SPICA* for studies of small-scale structures surrounding bright stars and galactic nuclei, e.g., exoplanets (not only detection but also characterization of the atmosphere), protoplanetary and debris disks, dusty tori in active galactic nuclei, and interstellar matter around bright small-scale structures (Enya et al. 2011, and its references). This paper briefly introduces scientific objectives, specification, and design of the SCI.

### 2. SCIENTIFIC OBJECTIVES

<sup>a)</sup> This paper describes instrumentation as valid at the time of the conference in 2013. After the conference the mission configuration and the international collaboration framework were revisited and changed significantly. The current mission concept foresees an ESA-led mission with significant contribution from JAXA, with a configuration that has been updated to profit from the latest technological advances. This new *SPICA* concept has been selected as one of the candidates for the ESA Cosmic Vision M5 mission, and is currently in a phase A conceptual design study stage.

**Table 1.** The core science objectives and the requirements for each.

Scientific study	Mode <sup>†</sup>	Wavelength coverage	$R^{\ddagger}$
Planetary formation process revealed by the thermal history	S	4 – 12 $\mu\text{m}$	200
H <sub>2</sub> and He in the atmosphere of Jovian exoplanets	S	10 – 28 $\mu\text{m}$	50
Atmospheric structure of Jovian exoplanets	S	4 – 20 $\mu\text{m}$	200
Constraining heavy element abundance	S	4 – 20 $\mu\text{m}$	200
Direct detection and characterization of icy giants	I	10 – 28 $\mu\text{m}$	2
Solid matter in planetary formation systems	S	6 – 28 $\mu\text{m}$	200
Formation and supply of solid matter from old stars to the ISM	S	6 – 28 $\mu\text{m}$	200
	I	6 – 28 $\mu\text{m}$	2
Galactic nuclei	S	6 – 28 $\mu\text{m}$	200

<sup>†</sup> S: spectroscopy. I: imaging. <sup>‡</sup> Spectral resolving power.

Table 1 summarizes the core scientific objectives which determine the requirements for the instrument specification. As shown in this table, there are various important scientific objectives, not only exoplanets but also circumstellar disks, Active Galactic Nuclei (AGN), and InterStellar Matter (ISM) around bright point-like sources. This paper describes just one of the core scientific objectives, i.e., “Planetary formation process revealed by the thermal history”, as an example, simply to limit the number of pages. For more details relating to other core scientific objectives, see the proceedings in this volume, e.g., by Takami et al. (a review on planetary sciences), Kotani et al., Ida (exoplanets), Ishihara et al, Fukagawa et al. (circumstellar discs), Oyabu et al. (AGN), and Kaneda et al. (ISM). The SCI, for which the specification has been determined by the core scientific objectives, can also be used for various other purposes, as shown in the proceedings by Narita et al., Honda et al., and so on.

### 2.1. Planetary Formation Process Revealed by the Thermal History

It is an important issue to reveal the planetary formation process by observations and especially to examine core accretion and disk instability models. The atmospheric temperature is considered to impose constraints on the amount of gas accreted onto the planet, which takes place in the final stages of formation of gas giants. Marley et al. (2007) and Spiegel & Burrows (2012) indicated that the initial conditions on the planet depend on the formation process, i.e. core accretion or disk instability, and the atmospheric temperatures of the planets formed through these two models are different. Planets are known to retain their initial conditions for 1 Gyr after gas accretion onto the core has been completed. In addition, a satellite system would be born in the disk formed around the planet in the final stages of gas accretion (e.g., Machida et al. 2008). Thus the planetary temperature in the gas accretion stage is very important for understanding both the formation of the planet and the satellites. With the SCI, it is possible to estimate the initial conditions of the planet by measuring the planetary temperature as a function of the age of the planet as described below.

The spectral features of atmospheric molecules are crucial indicators of the planetary temperature. There are several important molecular absorption lines within the wavelength coverage of the SCI: CO (4.7  $\mu\text{m}$ ), CH<sub>4</sub> (6.5  $\mu\text{m}$ , 7.7  $\mu\text{m}$ ), NH<sub>3</sub> (6.1  $\mu\text{m}$ , 10.5  $\mu\text{m}$ ), and H<sub>2</sub>O (6.2  $\mu\text{m}$ ). CO and N<sub>2</sub> are stable at temperatures higher than 1500 K. As the temperature decreases, CO and N<sub>2</sub> react with H<sub>2</sub> to form CH<sub>4</sub> and NH<sub>3</sub>. As a result, CH<sub>4</sub> and NH<sub>3</sub> become the dominant carbon- and nitrogen-bearing species at low temperatures, respectively. At a total gas pressure of 1 atmosphere, CH<sub>4</sub> and NH<sub>3</sub> mainly form at temperatures below 1000 K and 700 K, respectively. In addition, the mixing fraction of H<sub>2</sub>O increases by releasing the oxygen tied up in CO. Thus, while CO is an indicator of high-temperature objects, CH<sub>4</sub>, NH<sub>3</sub>, and H<sub>2</sub>O are indicators of low-temperature objects. Based on such temperature dependence of the molecular absorption features, the atmospheric temperature can be determined precisely by spectroscopic studies of the planetary atmosphere.

In order to restrict observations to planetary formation processes according to the atmospheric temperature in the final stages of gas accretion, both the age and dynamic mass of the planetary system need to be known in advance. Therefore nearby young moving groups and open clusters, whose ages can be determined by the H-R diagram, are observational targets for the SCI. Future precise astrometric observations with ground-based or space telescopes such as LBTI, VLTI, and GAIA, would discover planetary-mass objects even around young systems to determine those dynamic masses. Following this up with spectroscopic studies with the SCI would enable us to determine the atmospheric temperatures of planets whose ages and masses have already found.

This study requires a spectral resolution,  $R$ , of 200 and wavelength coverage from 4 to 12  $\mu\text{m}$  to resolve the molecular absorption features. A high contrast ( $\sim 5 \times 10^{-6}$ ) is needed because a planet formed by the core-accretion process is already faint even in the final stage of gas accretion. It should be noted that such a high contrast can be realized by employing the point spread function (PSF) subtraction technique. JWST will provide function of coronagraphic imaging

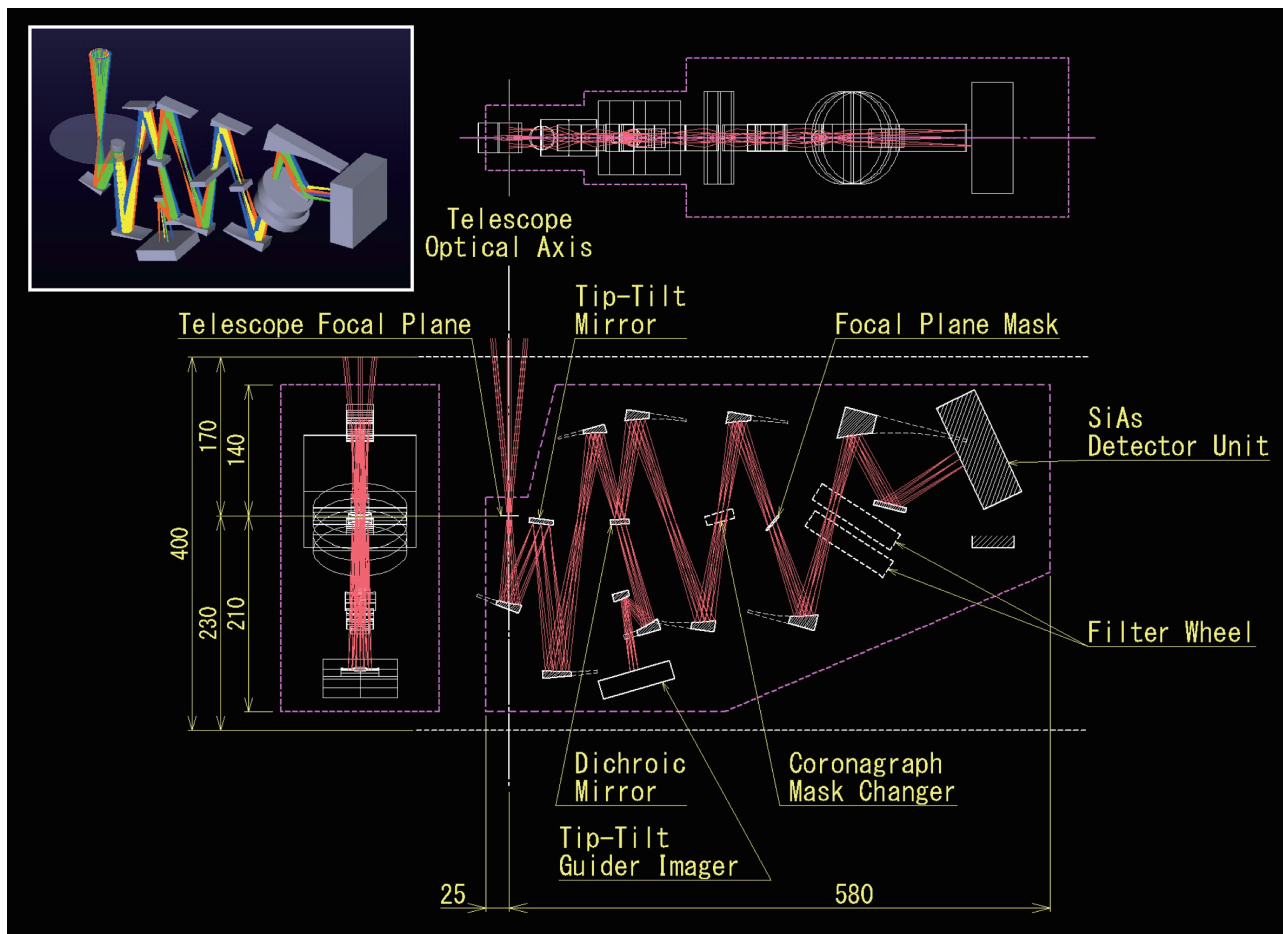


Figure 1. Overview of the optical design of the SCI.

in Mid-infrared. Mid-IR coronagraphic imagers for extremely large telescopes such as TMT/MICHI and E-ELT/METIS have been proposed so far. However, only the *SPICA*/SCI will realize coronagraphic spectroscopy with such high-contrast and wide wavelength coverage. Therefore the SCI provides a unique opportunity for discovering the planetary formation process through measurement of the atmospheric temperature.

### 3. INSTRUMENT DESIGN

An overview of the design of the SCI is shown in Figure 1. The specification of the SCI is summarized in Table 2. The SCI is designed as a stand-alone focal-plane instrument for *SPICA* rather than providing one of the functions of a more general-purpose mid-IR instrument because the wavefront error requirements are considerably stringent. The SCI simply contains one channel with one detector for science data acquisition, and also contains an internal tip-tilt mirror (TTM) to realize high pointing accuracy. Parts installed in the optical path between the entrance and the detector are a TTM, a binary pupil coronagraph mask, a focal plane mask, a filter and/or a grism. The cold part of the SCI system to be installed on the Instrument Optical Bench (IOB) of the *SPICA* telescope is designed to be < 20 kg with margin to spare. The SCI is passively cooled by thermal conduction to the IOB (i.e. an internal cooler is not needed).

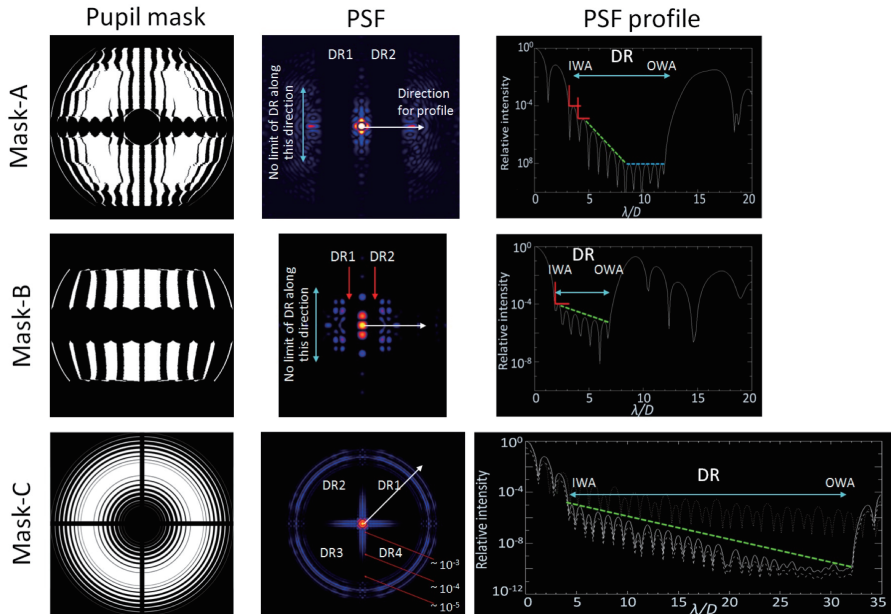
The binary shaped pupil mask installed in the SCI produces a high-contrast coronagraphic image (Figure 2. See also the proceeding in this volume, Haze et al., and its references). Higher contrast can be realized by applying the PSF subtraction technique. The binary pupil mask coronagraph has several advantageous properties for the SCI; first, it is extremely resilient against (almost insensitive to) telescope pointing errors. Secondly, it works in a very wide wavelength region. Thirdly, recent progress in mask design has allowed us to apply binary masks to a pupil with obscuration by the secondary mirror and the support spider of the telescope. The important properties of the coronagraph, such as the contrast, the Inner Working Angle (IWA), and the throughput, are in relation of trade-off. Therefore, three pupil masks with complementary designs are installed in the wheel exchanger.

The optics of the SCI have been designed with a combination of off-axis mirrors for collimation and focusing, rather than the use of lenses, to obtain the best solution for wide wavelength coverage and to avoid optical ghosts as much as possible. To minimize thermal deformation of the optics at cryogenic temperatures, all the mirrors and the support structures are made of aluminum, the same material with which the whole of the SCI is assembled. Tandem wheels for the filters and grisms are installed in series to enable the coronagraphic imaging and spectroscopy. The detector is a Si:As detector with

**Table 2.** The specification of the SCI.

Coronagraph spectroscopy			
Observation modes	Coronagraph imaging		
Wavelength coverage	4–28 $\mu\text{m}$		
Coronagraph method	Binary pupil mask		
	<u>Mask A</u>	<u>Mask B</u>	<u>Mask C</u>
Inner Working Angle	$3.3\lambda/D^\dagger$	$1.7\lambda/D$	$4.4\lambda/D$
Outer Working Angle	$12\lambda/D$	$6.5\lambda/D$	$32\lambda/D$
Spectral resolving power	200 (spectroscopy mode)		
Field of View (FoV)	$1' \times 1'$ at the center of the FoV of the telescope		
Detector	$1\text{k} \times 1\text{k}$ Si:As array (Raytheon)		
Sensitivity	$5\sigma$ , 1h exposure, w/o speckle noise, low zodi. case		
	<u>Case of <math>R = 5</math>: (mJy)</u>	<u>Case of <math>R = 200</math>: (mJy)</u>	
	$5 \times 10^{-4}$ ( $\lambda = 5 \mu\text{m}$ )	$2 \times 10^{-2}$ ( $\lambda = 5 \mu\text{m}$ )	
	$2 \times 10^{-3}$ ( $\lambda = 10 \mu\text{m}$ )	$3 \times 10^{-2}$ ( $\lambda = 10 \mu\text{m}$ )	
	$5 \times 10^{-3}$ ( $\lambda = 20 \mu\text{m}$ )	$4 \times 10^{-2}$ ( $\lambda = 20 \mu\text{m}$ )	
Contrast	$5\sigma$ , 1h exposure, K5V primary star, $3.3\text{--}12\lambda/D$ average		
	<u>Limit with PSF subtraction</u>	<u>Raw contrast limit</u>	
	$1.4 \times 10^{-6}$ ( $\lambda = 5 \mu\text{m}$ )	$3.6 \times 10^{-4}$ ( $\lambda = 5 \mu\text{m}$ )	
	$2.8 \times 10^{-6}$ ( $\lambda = 10 \mu\text{m}$ )	$1.6 \times 10^{-4}$ ( $\lambda = 10 \mu\text{m}$ )	
	$3.2 \times 10^{-5}$ ( $\lambda = 20 \mu\text{m}$ )	$1.6 \times 10^{-4}$ ( $\lambda = 20 \mu\text{m}$ )	

$^\dagger$   $\lambda$  and  $D$  are observing wavelength and the telescope aperture, respectively.

**Figure 2.** The designs of complementary binary-pupil masks.

a  $1024 \times 1024$  format, while an InSb detector with  $512 \times 412$  format has been adopted for the pointing guider for the TTM. Both detectors are made by Raytheon. (See the proceeding in this volume, Oseki et al., and its references).

After years of review in Japan and international review, the design of the instrument has been modified and simplified to reflect the scientific requirements. The SCI presently has neither a short channel nor a deformable mirror, both of which were present in the previous design. Also, observations of transiting exoplanets is no longer a design driver of the SCI. On the other hand, optional studies to challenge the detection of habitable exoplanets and biomarkers, and analysis with the objective of upgrading the instrument design are ongoing.

The SCI team is grateful to JAXA and various Japanese national funds supporting the SCI. We also thank all colleagues related to *SPICA*, especially the *SPICA Telescope Optical Working Group*.

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Spiegel, D. S., & Burrows, A. 2012, *ApJ*, 745, 174

# Focal Plane Camera (FPC) for Fine Guiding and NIR Observation Onboard *SPICA*

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## ABSTRACT

FPC (Focal Plane Camera) consists of two NIR (Near Infrared) cameras: FPC-G (FPC-Guidance) for fine guiding with an accuracy of less than  $0''.075$ , and FPC-S (FPC-Science) for a back-up of FPC-G as well as for scientific observations. FPC-S has 10 filters which enable the observation of the *JHKLM* bands and the NIR ( $0.8\text{--}5.2\ \mu\text{m}$ ) spectroscopy with 3 LVFs (Linear Variable Filters). With the large field of view ( $5' \times 5'$ ) and imaging spectroscopic capability, we propose near-infrared spectroscopic survey for the studies of formation and evolution of first stars in the Universe and the star formation history at high redshift detecting. We expect the scientific throughput will be greatly enhanced by carrying out parallel observations with other instruments, e.g. MCS or SAFARI.<sup>a)</sup>

## 1. INTRODUCTION

*SPICA* is a next-generation international space observatory that will provide imaging and spectroscopic capabilities optimized for mid- and far-infrared wavelength (Nakagawa et al. 2012). As for Korean participation, we propose FPC (Fine-guiding and astroPhysics Camera) as focal plane instruments. FPC is composed of two NIR (Near Infrared) cameras: FPC-G (FPC-Guidance) is a fine guiding camera complementary to the AOCS (Attitude and Orbit Control System) of the spacecraft, and FPC-S (FPC-Science) is a science observation camera with the capability of imaging and spectroscopy covering NIR ( $0.8\text{--}5.2\ \mu\text{m}$ ) band (Lee et al. 2012). Using a same diffuser and filter, FPC-S can be a back-up of FPC-G. In this paper, we present requirements and specifications of FPC-G/S and describe the scientific goal of FPC-S.

## 2. REQUIREMENT AND SPECIFICATION OF FPC-G

The purpose of FPC-G is to provide fine attitude information of the focal plane to the spacecraft bus for fine-guiding of the telescope. Among the 3 major candidates for the *SPICA* focal plane instruments — SAFARI (*SPICA Far-infrared Instrument*) (Roelfsema et al. 2012), MCS (Mid-infrared Camera and Spectrometer) (Kataza et al. 2012), and SCI (*SPICA Coronagraph Instrument*) (Kotani et al. 2012) — MCS requires most fine guiding knowledge during its imaging mode, which is  $0''.075$  from 0 to peak. Since the pointing accuracy of the AOCS (Attitude and Orbital Control Systems) in the spacecraft bus is  $\sim 0''.1$ , it needs more accurate attitude information. Therefore, the requirement of the FPC-G pointing accuracy becomes  $0''.036$  ( $3\sigma$ , 0.5 Hz), considering the Nyquist sampling of pixel images. Table 1 shows the specifications of FPC-G.

FPC-G is suggested to be located 12 arcminutes away from the optical axis due to various limitations. For this reason, the slight complicated optical design is required in order to get the required optical performance. Four out of totally seven optical elements are aspheric. The material is a typical glass which can be obtained easily. The spot size is usually around 10 arcsec and the pixel scale is less than 0.3 arcsec. However, the spot size reaches 35 arcsec at the place where is the farthest from the optical axis of telescope. Since GSCII catalog is used for the guiding purpose, the optical performance satisfies the requirement in *I* band (Lee et al. 2012). All the structure is made of aluminium alloy (A6061-T6). The body of FPC-G is directly installed on the IOB (Instrument Optical Bench), whose temperature is stable at 4.5 K. However, operation temperature of InSb detector array is  $> 10$  K. In order to keep this temperature, FPA should be thermally isolated from telescope, and its temperature is controlled to be constant using a heater on FPA. Since main heat source is self heating to operate the array, total heat load to IOB is less than 1 mW.

<sup>a)</sup> This paper describes instrumentation as valid at the time of the conference in 2013. After the conference the mission configuration and the international collaboration framework were revisited and changed significantly. The current mission concept foresees an ESA-led mission with significant contribution from JAXA, with a configuration that has been updated to profit from the latest technological advances. This new *SPICA* concept has been selected as one of the candidates for the ESA Cosmic Vision M5 mission, and is currently in a phase A conceptual design study stage.



### 3. REQUIREMENT AND SPECIFICATION OF FPC-S

The primary role of the FPC-S is to provide back-up to the FPC-G. It was therefore recognized that the science requirements come second to the overriding need for the FPC-S to provide full redundancy to the FPC-G, besides the fact that near infrared is not a core wavelength of *SPICA*. However, the proposed wavelength coverage and large FoV (Field of View) of the FPC-S present the opportunity to undertake large photometric and low-resolution spectroscopic surveys in the *JHKLM* bands. FPC-S/LVF (Linear Variable Filter) spectroscopic mode has two advantages. A large field of view and a capability of surface spectroscopy. As a result, the FPC-S/ LVF has about 20 times larger throughput compared to the *JWST* for the spectroscopy of the diffuse light. Therefore, the science programs focus on surface spectroscopy: (1) detection of Lyman-break galaxies (LBG) and other exotic objects at high- $z$ , and (2) association of the excess in the Cosmic Near Infrared Background (CNIRB) with Population III stars. Also, the composition and thermal history of comets can be studied in detail with near infrared spectroscopy by observing the incoming comets several times at different heliocentric distances. The scientific throughput will be greatly enhanced by carrying parallel observations with other instruments. For example, parallel imaging survey with MCS or SAFARI can deliver unique data set that covers wide area and spectral range with extraordinary photometric depth. Large number of well identified sample of LBGs and high redshift quasars are expected from this parallel survey.

The specification of FPC-S is identical with that of FPC-G, except that there is a filter wheel in front of the sensor for various scientific observations. Table 2 shows the filter allocation of FPC-S.

### 4. SCIENTIFIC OBJECTIVES OF FPC-S

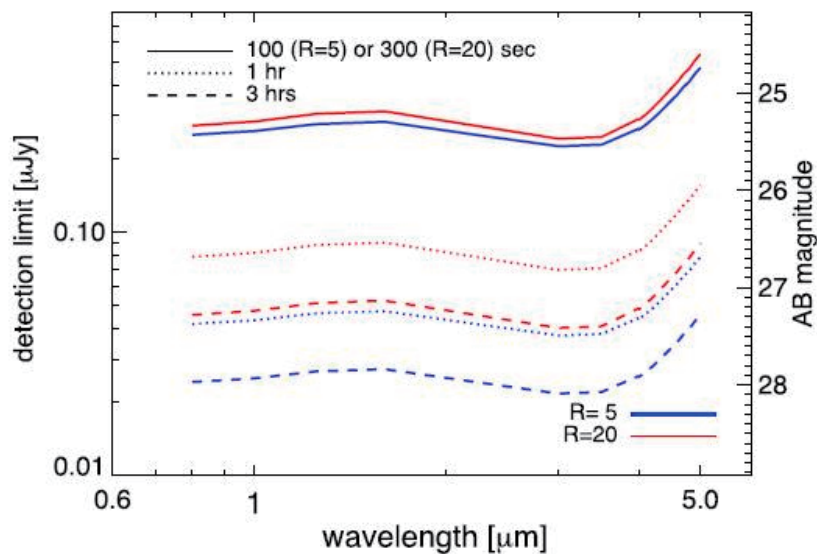
We propose FPC-S dedicated observation of CNB(Cosmin Near-infrared Background) as a main science target. With LVF observation, we will be able to examine formation and evolution of first stars of the universe and to delineate the dark age of the universe. Large area survey of star forming region is another observation program that utilizes the characteristics of FPC-S. There could be other smaller programs. For example, the composition and thermal history of comets can be studied in detail with near infrared spectroscopy by observing the incoming comets several times at different heliocentric distances. The sensitivity of FPC-S is shown in Figure 1. The readout noise is assumed to be reduced down to 10 and 7 electrons for 100 and 300 sec integration, respectively.

**Table 1.** Specifications of FPC-G

Parameter	Specification
Wavelength range	<i>I</i> band
Detector	InSb $1024 \times 1024$ pixels
Field of View	$5' \times 5'$
Pixel resolution	$0''.3$
Sensitivity ( $5\sigma$ )	21.5 mag (AB)
Pointing determination accuracy	Random: $0''.036$ ( $3\sigma$ , 0.5 Hz readout)

**Table 2.** Filter allocation of FPC-S

Filter position	Filter
F1	blank (cold shutter)
F2	diffuser + <i>I</i> ( $0.8\ \mu\text{m}$ ), backup of FPC-G
F3	LVF-1 ( $0.7\text{--}1.4\ \mu\text{m}$ )
F4	LVF-2 ( $1.4\text{--}2.8\ \mu\text{m}$ )
F5	LVF-3 ( $2.6\text{--}5.2\ \mu\text{m}$ )
F6	<i>J</i> ( $1.2\ \mu\text{m}$ , tentative)
F7	<i>H</i> ( $1.6\ \mu\text{m}$ , tentative)
F8	<i>K</i> ( $2.2\ \mu\text{m}$ , tentative)
F9	<i>L</i> ( $3.5\ \mu\text{m}$ , tentative)
F10	<i>M</i> ( $5.0\ \mu\text{m}$ , tentative)



**Figure 1.** Calculated sensitivity of FPC-S.

In addition, owing to acceptable heat dissipation at 4.5 K stage, the parallel observation of the FPC-S with other instruments is possible. The parallel observation with other instrument greatly enhances the scientific output by increasing an areal coverage. The imaging observational mode using the several wide-band filters can be used to study various objects such as LBGs, high redshift quasars and ULIRGs, distant galaxies, nearby galaxies, stars, brown dwarfs, solar system objects etc. Although near-infrared wavelength is not the core wavelength of *SPICA*, it provides supplementary important information to MIR and FIR observations. Coordinated observation should be planned to maximize the science outputs of *SPICA* mission.

#### 4.1. Probing First Stars of the Universe

Since direct detection of the Pop.III stars is almost impossible, observation of near -infrared background has been attempted to detect the light of first stars as one of background component. *COBE*, and *IRTS* showed the existence of the excess near infrared emission, when the contributions from zodiacal light, Galactic cirrus, and unresolved stars are carefully subtracted (e.g., (Hauser et al. 1998), (Matsumoto et al. 2005)). Recently, preliminary result of sounding rocket experiment, *CIBER*, found excess brightness at the wavelength longer than  $0.8 \mu\text{m}$  that is consistent with *IRTS* and *COBE*. *CIBER* also proved the excess brightness cannot be attributed to zodiacal light.

#### 4.2. Star Formation History at High Redshift

The cosmic star formation history has been studied using various means, but the measurement of star formation rate (SFR) becomes increasingly difficult as redshift becomes higher. We should be able to extend the estimation of SFR beyond  $z > 6$  with the FPC-S because of high sensitivity and spectroscopic capability, complimented by MIR and FIR instruments onboard *SPICA*, by detecting large number of Lyman break galaxies (LBGs), quasars and super massive black holes beyond the current redshift limit and accurately constructing SEDs. The SED over wide wavelength is useful to classify the population of LBGs and quasars. The survey of distant objects gives us a hint to reveal the initial phase of galaxy formation, which is also one of very important issues in the observational cosmology.

#### 4.3. Parallel Imaging Survey for the Detection of Rare Objects

Parallel observation of FPC-S with other instruments, especially with MCS, opens a new parameter space to investigate the deep universe. With a nominal integration of 1 hour and 5 narrow band filters, FPC-S on *SPICA* can reach down to the point source sensitivity of 26.3 AB magnitude in  $1\text{--}5 \mu\text{m}$  bands at  $5\sigma$ . The possible areal coverage should be determined based on the observational plan of other instruments. The important point is that the parallel survey adds up extra data in near infrared, which gives us wider both areal and spectral coverage without any additional telescope time.

As a simple estimate, the total area covered by FPC-S sums up to  $\sim 46 \text{ deg}^2$  of the sky during 2.5 year *SPICA* operation, if the observation is done all the time at different direction.

#### 4.4. Thermal Evolution of Ices in the Solar System

Near infrared spectroscopy in  $2.5\text{--}5 \mu\text{m}$  region is a powerful tool for the study of chemical composition of cometary ices. FPC-S providing unique capability of imaging spectroscopy as well as the throughput much greater than that of *JWST* is powerful to examine the spatial distribution of these molecules in comet atmosphere. Since comet molecules can either



have a “native” source, which have been sublimed directly from the nucleus itself, and an “extended” source, due to the decomposition of large organic particles or molecules, it is possible to distinguish the extended molecules from the native ice by the imaging spectroscopy. Finally we will be able to link the comet volatiles with the interstellar ices with good accuracy. This kind of science should be carried out as a target of opportunity program since we cannot predict exactly what kind of comet will be visible during the mission period of *SPICA*.

#### 4.5. Warm Mission

It is possible to operate FPC-S for NIR observation during the warm mission of *SPICA*. The following objectives are possible sciences observed with FPC-S.

- Spectroscopic survey of Star forming regions and nearby galaxies
- Survey of high-*z* supernovae in NIR
- Spectroscopic Survey of Supernova Remnants in NIR
- Deep and wide survey for the extragalactic study

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