Mid-infrared Camera and Spectrometer on board SPICA

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ABSTRACT

SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is an astronomical mission optimized for mid- and far-infrared astronomy, envisioned for launch in early 2020s. The core wavelength coverage of this mission is 5 to 200 micron. Mid-infrared Camera and Spectrometer (MCS) will provide imaging and spectroscopic observing capabilities in the mid-infrared region with 4 modules. WFC (Wide Field Camera) has two 5 arcminutes square field of view and covers the wavelength range from 5 to 38 micron. MRS (Mid Resolution Spectrometer) has integral field units by image slicer and covers the wavelength range from 12.2 to 37.5 micron simultaneously using dichroic filter and two sets of spectrometers. HRS (High Resolution Spectrometer) covers the wavelength range from 12 to 18 micron with resolving power 20000 to 30000, and it has optional short wavelength channel which covers from 4 to 8 micron with resolving power 30000. LRS (Low Resolution Spectrometer) adopts prism disperser and covers the wavelength range from 5 to 38 micron with resolving power 50 to 100. Here, we present detailed specifications of MCS, optical design, and estimated performance on orbit.

Keywords: SPICA, space telescope, infrared, astronomy, optics, instrumentation

1. INTRODUCTION

SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is a next-generation infrared astronomical mission in space optimized for mid- and far-infrared astronomy. Overview of the mission concepts, current status of the project are described in Nakagawa.[1] SPICA is envisioned for launch in early 2020s. At this age, mid- to far- infrared astronomy with large cooled telescope will bring in a breakthrough in astronomy.

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Key scientific objectives of the SPICA mission are (1) Resolution of birth and evolution of galaxies, (2) Thorough understanding of planetary system formation, and (3) Resolution of transmigration of dust in the universe.

To achieve above objectives, the payload module of SPICA is designed.[2] SPICA Telescope Assembly(STA) and the Focal-Plane Instruments Assembly(FPI) are cooled down by Cryogenic system.[3] STA has a telescope with 3.2m diameter (EPD 3.0m). FPIA consists of focal plane instruments and the Instrument Optical Bench(IOB). The FPI suite for SPICA will be equipped to achieve significant progress for these key scientific objectives. Proposed instruments are a mid-IR coronagraph (SCI), a mid-IR camera and spectrometer (MCS), an imaging Fourier-transform spectrometer operating in the far-IR (SAFARI), and a focal plane camera (FPC) used for fine guidance. We are now in the international reviewing process of FPIs. Here, we present a design of MCS with referring the mid-term report of the review.

2. INSTRUMENT OVERVIEW

Mid-infrared Camera and Spectrometer (MCS) will provide imaging and spectroscopic observing capabilities in the mid-infrared region with 4 modules. Each module has two channels (-S for short wavelength and -L for long wavelength) to cover wide wavelength ranges. WFC (Wide Field Camera) has two 5 arcminutes square filed of view. WFC-S covers the wavelength range from 5 to 25 micron and WFC-L covers the wavelength range from 20 to 38 micron. MRS (Mid Resolution Spectrometer) has integral field units by image slicer and covers the wavelength range from 12.2 to 23.0 micron by MRS-S and 23.0 t0 37.5 micron by MRS-L. They share the same field of view (FOV) by means of a dichroic filter. HRS (High Resolution Spectrometer) covers the wavelength range from 12 to 18 micron with resolving power 20000 to 30000 (HRS-L), and we studied optional short wavelength channel which covers from 4 to 8 micron with resolving power 30000 (HRS-S). LRS (Low Resolution Spectrometer) adopts prism disperser and covers the wavelength range from 5 to 38 micron with resolving power 50 to 100. LRS also has two channels, LRS-S and LRS-L. These channels share the same field of view like MRS.

Instrument structure is shown in Figure1 and the specifications are summarized in Table1. Each module of MCS has its own field in the telescope focal plane. Selection of module will be done by telescope pointing.

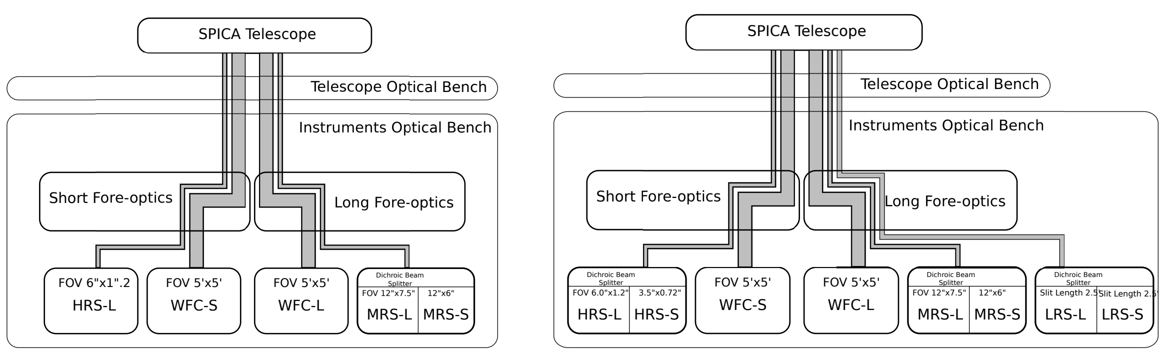

Figure 1. Structure of MCS. Left panel shows modules identified as mandatory or high rated option in the mid term report of on-going review. Right panel shows all modules we proposed.

WFC	WFC-L	WFC-S
Array format	Si:Sb (1 K × 1 K)	Si:As (2 K × 2 K)
Wavelength coverage	20 – 38μm	5 – 25 μm
Filter bands	20 – 38μm R=10	5 – 25 μm R=5
Pixel scale	0".293 / pix	0".146 / pix
FOV size	5' × 5'	5' × 5'
MRS	MRS-L	MRS-S
Array format	Si:Sb (1 K × 1 K)	Si:As (2 K × 2 K)
Wavelength coverage	23.0 – 37.5μm	12.2 – 23.0 μm
Spectral resolution	1060 @ 36.0μm	1930 @ 22μm
Pixel scale	0".485 / pix	0".403 / pix
Slit length × width × slices	12" × 2".5 × 3	12" × 1".2 × 5
FOV size	12" × 7".5	12" × 6"
HRS	HRS-L	HRS-S
Array format	Si:As (2 K × 2 K)	Si:As (2 K × 2 K)
Wavelength coverage	12 – 18μm	4 – 8μm
Spectral resolution ($R = \lambda/\delta\lambda$)	20,000 – 30,000	30,000
Pixel scale	0".48 / pix	0".288 / pix
Slit length × width	6".0 × 1".2	3".5 × 0".72
Main disperser	CdTe or CdZnTe immersion grating	ZnSe immersion grating
LRS	LRS-L	LRS-S
Array format	Si:Sb (1 K × 1 K) Option - Si:As High-dope(1K×1K)	Si:As (2 K × 2 K)
Wavelength coverage	20 – 38μm (option 25–48μm)	5 – 20 μm
Disperser	CsI Prism	KBr Prism
Spectral resolution	50–100	50–100
Pixel scale	0".34 / pix	0".73 / pix
Slit length × width	2'.5 × 2".66	2'.5 × 1".40

Table 1. Specifications of MCS

3. OPTICAL DESIGN

3.1 Fore-optics

Fore-optics is a relay optics which re-image telescope focal plane image on the entrance focal plane of camera and slits of spectrometers. It has a wide field of view (FOV) which covers both camera FOV and that of spectrometers. We adopt the same design of fore-optics using reflective mirror optics for both short and long wavelength module. Reflective mirror optics has no chromatic aberration and system transmission (reflectance) is high within the full infrared wavelength region. Furthermore, all mirrors and IOB will be made with the same aluminium alloy material, we can expect similar thermal contraction between mirrors and optical bench.

Figure2 shows the designed fore-optics. Three free-form mirrors make a parallel beam and make an internal pupil plane which is the image of the telescope secondary. Around this plane, we will have several band-path filters and cold shutter on filter wheels. This wheel in the only one moving parts for the spectrometers. Then, three free-form mirrors re-image at the exit focal plane. Just before this exit focal plane, field of view for spectrometer is branched by hyperboloid mirror and re-image on the entrance field of spectrometer.

Field of view for this fore-optics is defined as shown in figure3. FOV for WFC is 5 arcminutes square and its center is 10 arcminites off-setted from the telescope optical center. Field of view for spectrometers, MRS and HRS, is 3.75 arcminites away from the WFC FOV center. Strehl ratio at any point in WFC FOV / spectrometer FOV is larger than 0.93 / 0.97 respectively at 5 μm wavelength. When LRS option is adopted, FOV of LRS is located opposite side of MRS FOV with respect to WFC FOV. Slit length of LRS is 2.5 arcminutes and end point of the slit has worst strehl ratio of 0.86. This fore-optics remove optical aberration of the telescope at these off-axis position from the optical center.

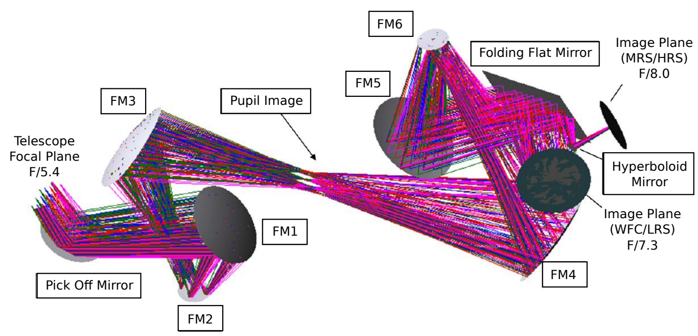

Figure 2. MCS fore-optics. Two sets of three free-form mirrors relay telescope image plane to camera entrance image plane. Field of view for spectrometer is branched near the exit focal plane.

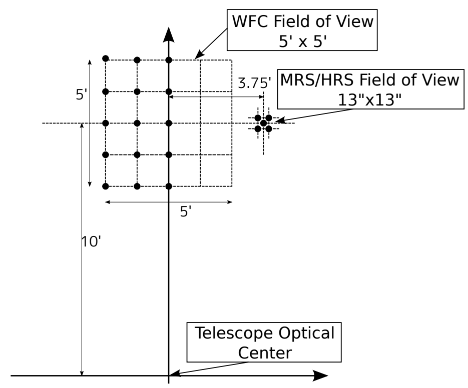

Figure 3. Definition of the objects position for MCS.

3.2 WFC: Wide Field Camera

WFC is recognized by on-going review process as a general purpose mandatory function, enabling many of the SPICA science goals. It has two modules WFC-L and WFC-S and has individual 5 arcminutes square FOV.

Figure4/5 shows optical structure of WFC-L/WFC-S respectively. Using a pair of high order free-form surface mirrors, beam is collimated and secondary internal pupil plane is generated. Around this pupil plane, we will insert filter wheels. For WFC-L, four free surface mirrors re-image objects on the detector plane with small F-number F/4.2. For WFC-S, three free surface mirrors re-image with F-number F11.7. Each F-number corresponds to the pixel size of the detector.

In case of WFC-L/WFC-S, strehl ratio at the detector plane is larger than 0.87/0.88 at 5μm wavelength. This strehl ratio includes telescope, fore-optics, and WFC-S itself. The large enough strehl ratio in WFC-L enables us to use this module to observe even at 5 μm wavelength.

3.3 MRS: Mid-Resolution Spectrometer

MRS is an Echelle Grating spectrometer with IFU by image slicer and consists of two modules, MRS-L and MRS-S. The same FOV is shared between the two modules by means of a dichroic beam splitter. Detailed

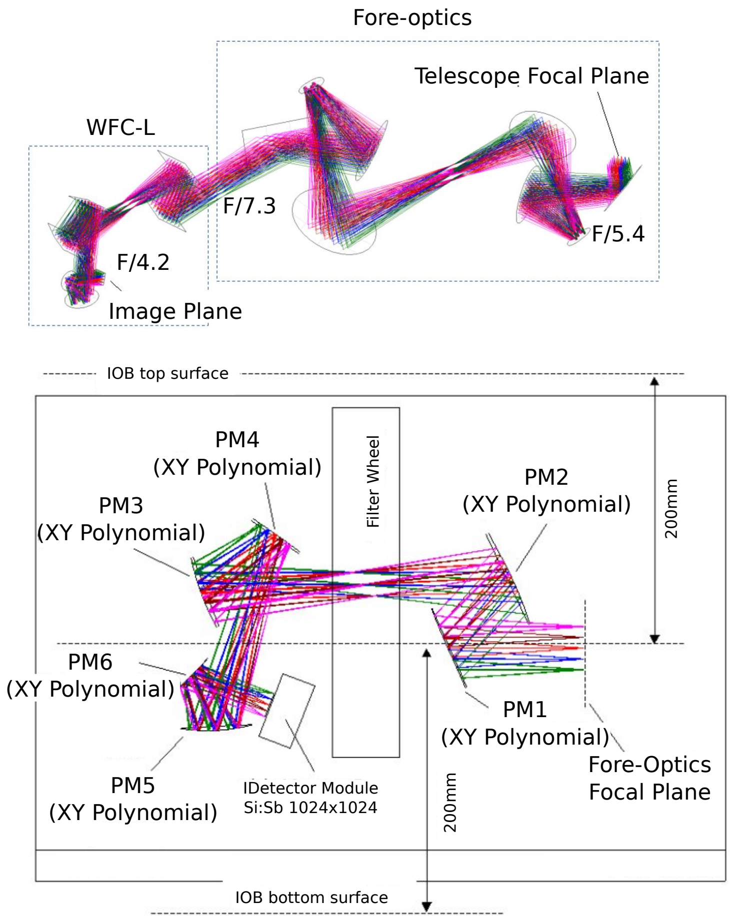

Figure 4. Optical structure of WFC-L. Upper panel show both fore-optics and WFC-L. Lower panel shows WFC-L only.

description of MRS is given by Sakon.[4] This function is also judged to be unique and to provide a mandatory function for SPICA by on-going review.

3.4 HRS: High-Resolution Spectrometer

HRS adopts immersion grating to realize high resolution spectrometer within a limited volume for instruments onboard SPICA. We have studied two modules HRS-L and HRS-S. HRS-L covers from 12μm to 18μm wavelength region and HRS-S covers from 5μm to 8μm wavelength region. Our proposing design shows that both modules are feasible at least optical design. Figure6 shows HRS structure.

HRS-L is considered to be a high priority function but within the on-going review, technical feasibility is thought not yet well established. Recently, we made major progress in the development of CdZeTe immersion grating[56] for HRS-L. Now, HRS-L became more feasible.

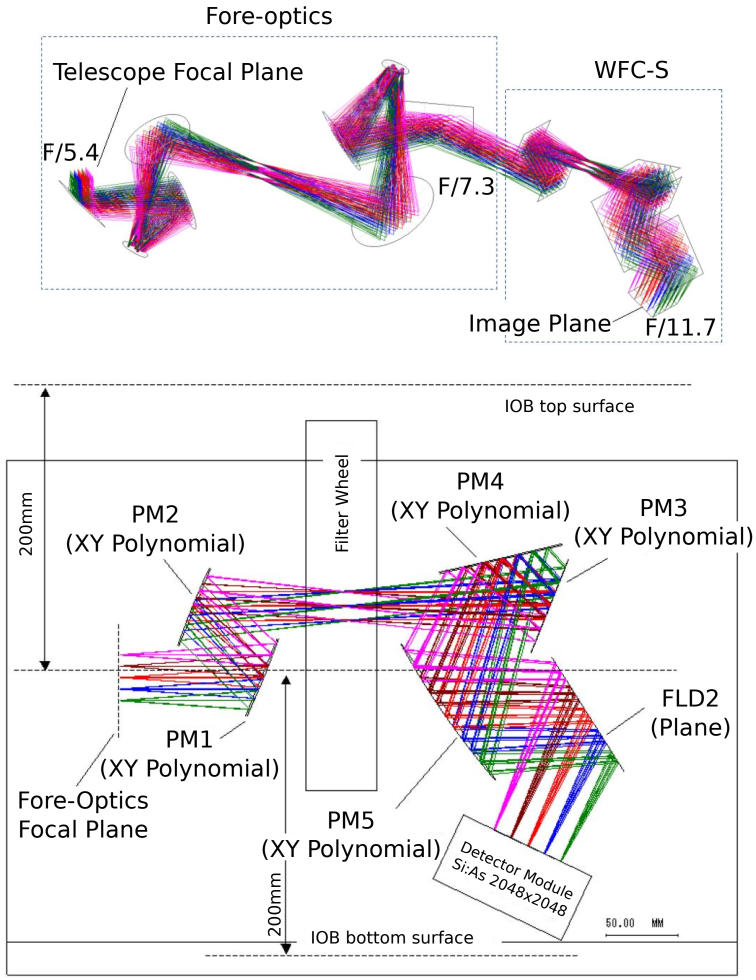

Figure 5. Optical structure of WFC-S. Upper panel show both fore-optics and WFC-S. Lower panel shows WFC-S only.

4. EXPECTED PERFORMANCES

WFC use Si:As for shot wavelength region and Si:Sb for long wavelength region. Here, expected performances are estimated with following assumptions for both wavelength regions. Read noise is 20 electrons/pixel, and the dark current is 1 electron/pixel/sec. Pixel scale is 0.36 arcsec. Optical efficiency including telescope is 0.35 and detector efficiency is 0.5. Frame integration time is 617.3 seconds which is limited by cosmic ray event rate at the L2 environment. Background (zodiacal light) is modeled by 261K black body spectrum normalized to 18MJy/str at 25μm . Total integration time is 3600 seconds. And aperture photometry with size of the first diffraction null ring should be done.

Figure7 shows the sensitivity for point sources compared with that of JWST/MIRI.[7] MCS is more sensitive compared with JWST/MIRI over wavelengths of 20μm because of SPICA's cooled aperture telescope.

MRS expected performances are described by Sakon[4] in this volume.

HRS uses Si:As detector and we assumed following assumptions to estimate performances. Read noise

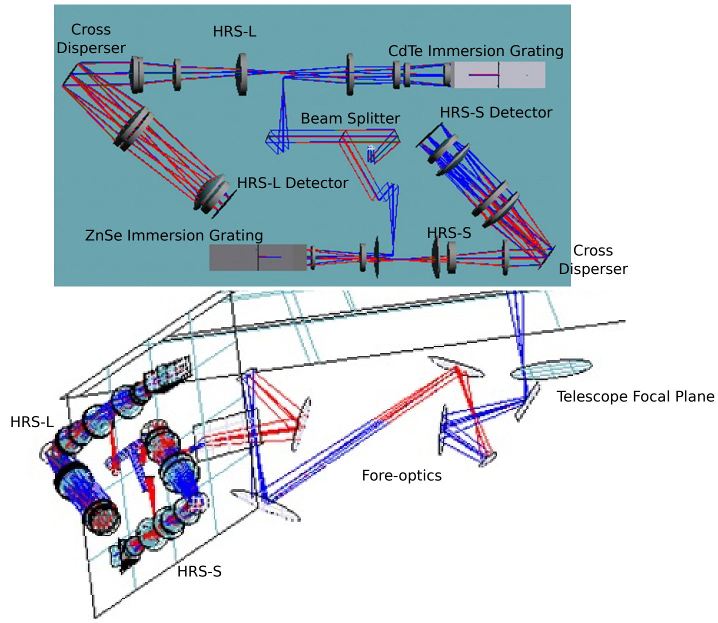

Figure 6. Optical structure of HRS-S and HRS-L. Upper panel shows HRS-S and HRS-L, Lower panel shows HRS and fore-optics.

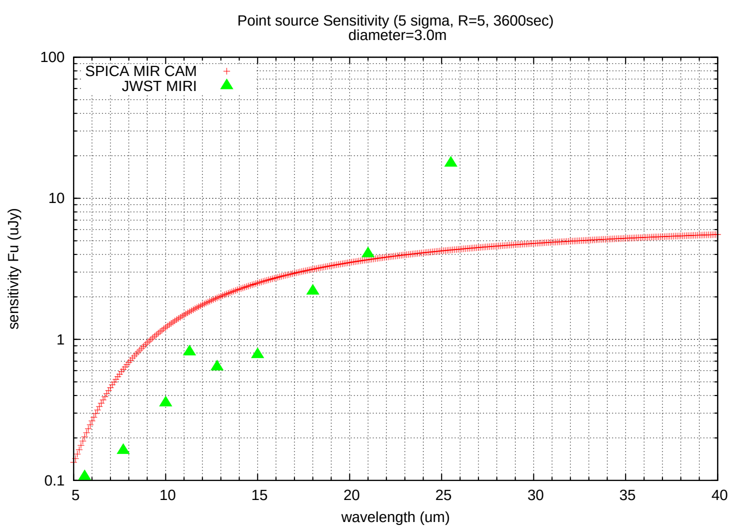

Figure 7. Red plus signs show point source sensitivity (5 σ) of WFC/MCS with one hour observing time in the imaging observations (spectral resolution R=5) as a function of wavelengths. Green crosses show point source sensitivity of JWST/MIRI with the same integration.

if reduced to 5 electron / read-out by means of Fowler-16 sampling. Dark current is 0.5 electron/pixel/sec. Detector efficiency is 0.70. Frame integration time is 300 seconds. Back ground emission is dominated by zodiacal emission and the high background case is modeled with blackbody of $T = 268.5$K normalized to 80 MJy/sr at 25μm while the low background case is molded with blackbody of $T = 274.0$K normalized to 15 MJy/sr at 25μm .[89] Pixel scale and band width in wavelength for each pixel is calculated from optical design.

The 3600sec on-source 5-σ sensitivities of HRS/MCS for a continuum of a point source are plotted in Figure8.

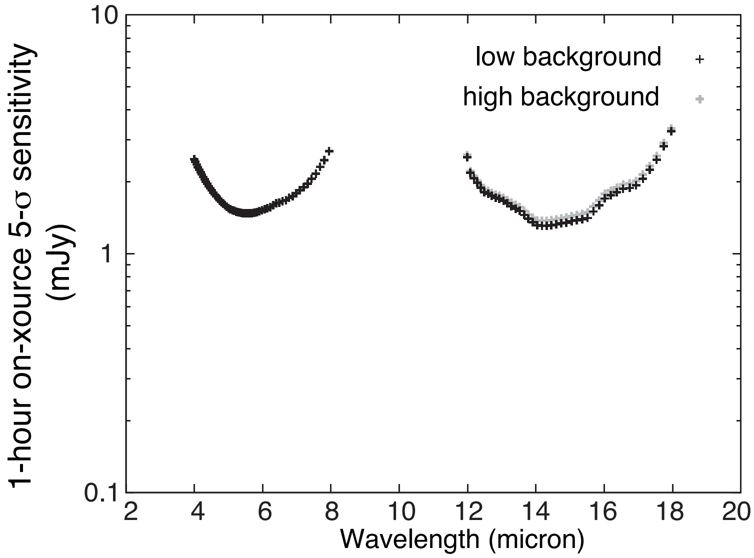

Figure 8. The 3600 sec on-source 5-σ sensitivity of HRS for a continuum of a point source for the cases. The expected sensitivities for low-background case are shown with gray and those for high-background case are shown with black.

5. CONCLUSIONS

We have studied Mid-infrared Camera and Spectrometer MCS) on board SPICA with four modules; wide field camera (WFC), high resolution spectrometer (HRS) using immersion grating, mid resolution spectrometer (MRS) with integral field unit by image slicer, and low resolution spectrometer (LRS). All modules are now feasible, but SPICA has only 2.5 years planned nominal length of the observation. Life time limit of SPICA forces us to minimize the instrument functions. On-going international review emphasize this point and in the mid term report, WFC and MRS are recognized as mandatory functions, HRS-L is recognized as a high rated optional function and LRS and HRS-S are recognized as options. We are now in the final stage to select the instrument functions. At the end of the current phase, which we call as risk mitigation phase, we will select the functions of MCS.

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