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Dust Science with SPICA Mid-Infrared Camera and Spectrometers (MCS)

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Mid-Infrared Camera and Spectrometers (MCS) is one of the Focal-Plane Instruments proposed for the SPICA mission in the pre-project phase. SPICA MCS is equipped with two spectrometers with different spectral resolution powers (R=$\lambda/\delta\lambda$); medium-resolution spectrometer (MRS) which covers 12–38μm with R$\simeq$1100–3000, and high-resolution spectrometer (HRS) which covers either 12–18μm with R$\simeq$30000. MCS is also equipped with Wide Field Camera (WFC), which is capable of performing multi-objects grism spectroscopy in addition to the imaging observation. A small slit aperture for low-resolution slit spectroscopy is planned to be placed just next to the field of view (FOV) aperture for imaging and slit-less spectroscopic observation. MCS covers an important part of the core spectral range of SPICA and, complementary with SAFARI (SpicA FAR-infrared Instrument), can do crucial observations for a number of key science cases to revolutionize our understanding of the lifecycle of dust in the universe. In this article, the latest design specification and the expected performance of the SPICA/MCS are introduced. Key science cases that should be targetted by SPICA/MCS have been discussed by the MCS science working group. Among such science cases, some of those related to dust science are briefly intriduced.

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1. The Mid-Infrared Camera and Spectrometers (MCS) – Instrument Overview

The latest specification and expected performance of the MCS (Kataza et al. 2012) proposed for SPICA (Nakagawa et al. 2012) is summarized in Table 1.

Table 1: Specification and Expected Performance of MCS[a]

	WFC		MRS[b]		HRS
	WFC-S	WFC-L	(MRS-S)	(MRS-L)	
Detector	Si:As(2k×2k)	Si:Sb(1k×1k)	Si:As(2k×2k)	Si:Sb(1k×1k)	Si:As(2k×2k)
pixel scale	0".146×0".146	0".293×0".293	0".32×0".50	0".44×0".73	0".48×0".48
Wavelength(μm)	5–24	15–38	12.20–23.05	23.00–37.53	12–18
$R = \lambda/\Delta\lambda$	∼5(Img.)/50–200(Spc.)	4–8(Img.)/50(Spc.)	1,800–3,000	1,100–1,400	∼30,000
Field of View (FOV)	293"×300"	293"×300"	12.0"×8.0"		–
Slit information	Slitless; full FOV Slit; 7".0×2".18	Slitless; full FOV Slit; 7".0×3".19	IFU(5 slitlets) Slitlet; 12"×1".59	IFU(3 slitlets) Slitlet; 12"×2".65	Slit; 6.0"×1.2"
Cont. Sensitivity[c]	3μJy (Img. $R = 5$) 10μJy (Slit $R = 50$) 80μJy (Slitless $R = 50$)	10μJy (Img. $R = 5$) 30μJy (Slit $R = 50$) 80μJy (Slitless $R = 50$)	0.1mJy ($R = 2,200$)	0.4mJy ($R = 1,200$)	2mJy ($R = 30,000$)
Line Sensitivity[d]	5×10^{-20}Wm^{-2} (Slit $R = 50$) 3×10^{-19}Wm^{-2} (Slitless $R = 50$)	7×10^{-20}Wm^{-2} (Slit $R = 50$) 2×10^{-19}Wm^{-2} (Slitless $R = 50$)	1×10^{-20}Wm^{-2} ($R = 2200$)	5×10^{-20}Wm^{-2} ($R = 1200$)	8×10^{-21}Wm^{-2} ($R = 30,000$)
Saturation Limit[e]	1.5Jy (Img. $R = 5$) 50Jy (Slit/Slitless $R = 50$)	3Jy (Img. $R = 5$) 50Jy (Slit/Slitless $R = 50$)	150Jy ($R = 2,200$)	200Jy ($R = 1,200$)	3000Jy ($R = 30,000$)

[a] The specification is based on the design as of 2012.Sept. [b] MRS-S and MRS-S share the same field of view by means of the dichroic beam splitter and are operated simultaneously. [c d e] 5σ3600sec continuum sensitivity, line sensitivity and saturation limit for a point source. Values at 15μm are shown for WFC-S, MRS-S and HRS and those at 30μm are shown for WFC-L and MRS-L.

Medium Resolution Spectrometer (MRS: Sakon et al. 2012) is designed to carry out spectroscopy of various phases of the ISM in galaxies over a wide spectral range within 12–38μm. The MRS consists of two channels; MRS-S and MRS-L. Each channel employs an image slicer as the integral field unit (IFU). MRS-S and MRS-L share the same field of view area on the focal plane by means of a dichroic beam splitter, which allows us to obtain two-dimentional spectra of 12 arcsec by 8 arcsec FOV area continuously from 12μm to 38μm with a single pointed observation. The FOV area is covered with 5 slitlets in the case of MRS-S and 3 slitlets of MRS-L. Further information on the design and trial production of IFU for MRS is given in Sakon et al. (2013).

Each channel of Wide Field Camera (WFC: Wada et al. 2010) plans to employ double filter wheels. The number of filter slots in each wheel is designed to be 10 for WFC-S and 8 for WFC-L due to the technical reason. Each filter wheel must have "hole" position and either one of the filter wheel must have a "blind" position. At most 17 slots for the imaging filters and grisms are available in WFC-S and 13 slots in WFC-L. Table 2 shows the baseline set of filters and grisms proposed by the MCS Filter Working Group.

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Table 2: WFC photometric filters and grisms[a]

WFC-S				WFC-L[b]			
Slot	Band	$\lambda(\mu$m)	$\Delta\lambda(\mu$m)/Resolution	Slot	Band	$\lambda(\mu$m)	$\Delta\lambda(\mu$m)/Resolution
#1	S4.4	4.39	$0.88/R=4.5$	#1	L20.5	20.50	$2.56/R=8$
#2	S5.5	5.36	$1.07/R=4.5$	#2	L23.0	23.06	$2.88/R=8$
#3	S6.6	6.56	$1.31/R=4.5$	#3	L26.0	25.95	$3.24/R=8$
#4	S8.0	8.01	$1.60/R=4.5$	#4	L29.2	29.19	$3.65/R=8$
#5	S9.8	9.79	$1.96/R=4.5$	#5	L32.8	32.84	$4.10/R=8$
#6	S12.0	11.97	$2.39/R=4.5$	#6	L36.9	36.94	$4.62/R=8$
#7	S14.6	14.63	$2.93/R=4.5$	#7	L23W	23.0	$5.1/R=4.5$
#8	S17.9	17.88	$3.58/R=4.5$	#8	L28W	28.1	$6.3/R=4.5$
#9	S21.8	21.85	$4.37/R=4.5$	#9	L34W	34.4	$7.6/R=4.5$
#10	U11.2	11.20	$0.40/R=28$	#10	LG3	14–26	$R=50$
#11	SG1	5–9	$R=50$	#11	LG4	24–39	$R=50$
#12	SG2	8–15	$R=50$	#12–#13	TBD		
#13	SG1H	4–7.5	$R=200$				
#14	SG2H	7–13.0	$R=200$				
#15–#17	TBD						

[a] The specification is based on the design as of Sept. 2012.
[b] Alternative set of photometeric filters with $R=10.0$ for narrow bands is proposed by the MCS FIlter Working Group. The final selection of filters will be made later based on further science discussion and technical verification.

2. Dust Science with SPICA/MCS

2.1 Understanding chemical properties and the amount of dust formed in the SN ejecta

It is widely believed that massive stars, especially SNe, play an important role as the dust budget in the early universe due to their short lifetime during the main sequence. However, the process of dust formation and the properties of dust formed in SN ejecta have not been fully understood from the observational point of view. The largest difficulty lies in the decomposition of emissions carried SN-dust, pre-existing circumstellar dust (CS-dust), and swept-up ISM dust (IS-dust). Wide spectral coverage in the mid- to far-infrared is crucial to investigate the properties of dust at various temperatures and, thus, to descriminate the SN-dust emission from other components. Multi epoch observations of SNe within a few years after the explosion will be efficient approach for this purpose. More than several new dust-forming SNe are expected to be found in nearby galaxies during the SPICA's mission lifetime. Moreover, observations of very young supernova remnants (a few tens years) in nearby galaxies within 5 Mpc may also be useful in determining the properties of dust formed in the SN ejecta because the dominance of SN-dust emission over CS-dust and IS-dust emisions is expected at $\lambda > 30\mu$m at those epochs based on theretical simulation made with an appropreate environmental assumption (Tanaka et al. 2012). SPICA MCS/WFC and SAFARI will be able to detect $0.1M_\odot$ of dust cooled down to 50K at 5Mpc and, so far, more than a few tens targets are available within 5Mpc. Therefore, whether or not SNe can be the major contributer to the dust budget in the early universe should be conclusively answered by SPICA MCS and SAFARI.

2.2 Understanding the properties of UIR bands in the ISM emission of galaxies at z≃3–4

In order to utilize a series of unidentified infrared (UIR) bands as a tool to infer the star formation activities in high-redshift galaxies, the hypothesis that propose the delayed injection of dust synthesized in low- to intermediate-mass stars into the ISM compared with the case of those synthesized in massive stars (Galliano, Dwek & Chanial 2008) has to be taken into account. In order to test this hypothesis and to understand when and how the carriers of UIR bands, i.e. astronomical PAH, had been supplied into the ISM in galaxies, the infrared properties of UIR bands in remote galaxies should be investigated further in details. Continuous 10-40μm spectroscopy of galaxies at z=3-4 with SPICA MCS/MRS will demonstrate the history of astronomical PAH enrichment in the ISM of galaxies and, thus, provide us the knowledge on the lifecycle of astronomical PAHs along the timeline of galaxy evolution.

2.3 Understanding the lifeccycle of ISM in nearby galaxies

The ISM consists of various physical phases including ionized and neutral atomic gases, molecular gases, ices, and dust grains. MIR fine-structure lines have advantages over optical lines for the unambiguous diagnostics of physical conditions of obscured regions because they are less affected by extinction and they are not very sensitive to the electron temperature in the ionized gas. MIR spectrometers with moderate resolution power, therefore, should serve as indispensable and valid capabilities to investigate the evolution of ISM of various phases. Moreover, a study of the elemental depletion provides us key information on the chemical link between the elements in the gas and solid phases in astrophysical environments. Molecular lines are also important for the investigation of the warm ISM heated by UV photons or shocks. For the local universe, spectroscopic capability within 10–20μm is crucial for determining the chemical composition and properties of dust grains and to interpret the nature of the carriers of the unidentified dust features observed in $> 20\mu$m. SPICA MCS/MRS and SAFARI will achieve the spatially-resolved spectroscopic studies of dust and gas in disks & haloes of nearby galaxies and in various structures such as super star clusters in blue compact dwarf galaxies. Mapping observation of M31 with MCS/WFC enables a complete census of newly formed stars and the detection of nearly all evolved stars injecting mass into the interstellar medium (ISM).

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