Interstellar and Circumstellar physics and chemistry targeted by MIR Medium Resolution Spectrometer

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Abstract and Summary
Science Target of SPICA/MCS/MRS

Understanding of physical transitions among various phases of the Interstellar Medium (ISM) and their chemical reaction networks

Tools; Spectral Features present in the Mid-Infrared wavelengths
- Fine-structure lines from ionized atomic gas
- Emission lines from neutral molecular gas
- Band features due to vibration transitions of solid phase molecules
- Thermal emission from dust grains

Step 1; To Characterize the physical and chemical properties of the ISM
- Strength and hardness of the input energy into the ISM
- Excitation and ionization state of gas-phase atoms
- Elemental abundance in the gas-phase ISM
- Chemical composition of the dust grains
- Size distribution of the dust grains

Step 2; To illustrate the physical phase transition processes and chemical reaction networks among the ISM
- Formation of molecules and dust grains and grain growth
- Elemental depletion in the gas-phase
- Destruction of dust grains
- Chemical reactions in the gas phase
- Chemical reactions on the grain surface

Pioneering Challenges by ISO and Spitzer Space Telescope

Infrared Space Observatory (ISO)/ Short Wavelength Spectrometer(SWS)

Band order no.		aperture	det.	Wavelength(μm)	resolution
SW-gr	1A	14”-20”	InSb	2.38 - 2.61	1870-2110
SW-gr	1B	14”-20”	InSb	2.60 - 3.03	1470-1750
SW-gr	1D	14”-20”	InSb	3.02 - 3.53	1750-2150
SW-gr	1E	14”-20”	InSb	3.52 - 4.06	1290-1540
SW-gr	2A	14”-20”	Si:Ga	4.05 - 5.31	1540-2130
SW-gr	2B	14”-20”	Si:Ga	5.30 - 7.01	930-1250
SW-gr	2C	14”-20”	Si:Ga	7.00 - 12.1	1250-2450

Band order no.		aperture	det.	Wavelength(μm)	resolution
LW-gr	3A	14”-27”	Si:As	12.0 - 16.6	1250-1760
LW-gr	3C	14”-27”	Si:As	16.5 - 19.6	1760-2380
LW-gr	3D	14”-27”	Si:As	19.5 - 27.6	980-1270
LW-gr	3E	14”-27”	Si:As	27.5 - 29.0	980-1270
LW-gr	4	20”-33”	Ge:Be	28.9 - 45.2	1020-1630

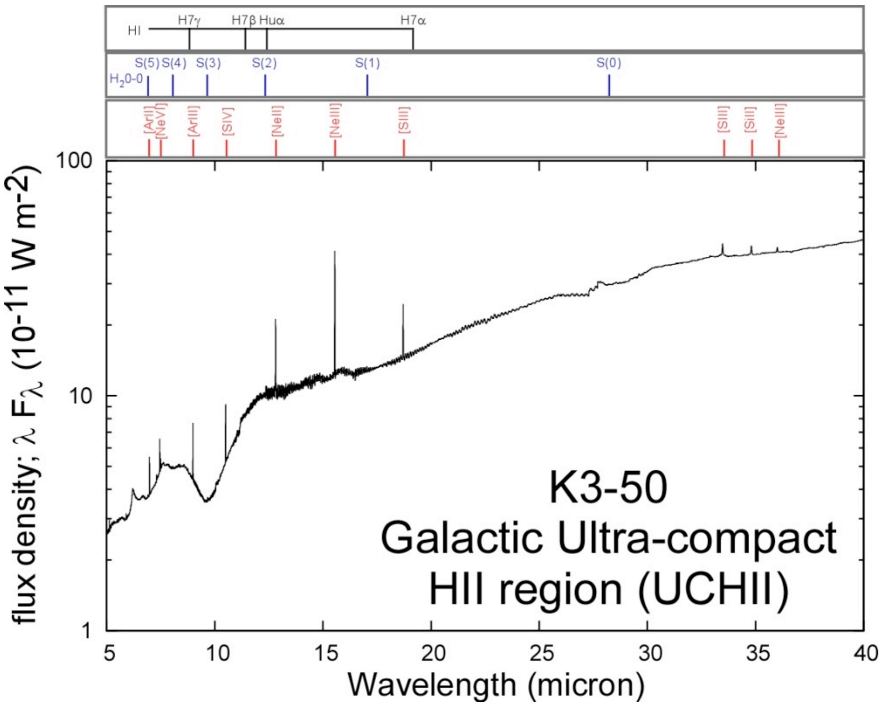
The SWS has 3 entrance apertures and each of the entrance apertures is used for two wavelength ranges
Dichroic beam splitters behind the apertures split the incoming radiation in SW (2.4-12μm) and LW(12-45μm)
The actual entrance slits (14”x20” for SW, 14”x27” and 20”x33” for LW) are located behind the beam splitters
Two wavelength ranges can be observed simultaneously

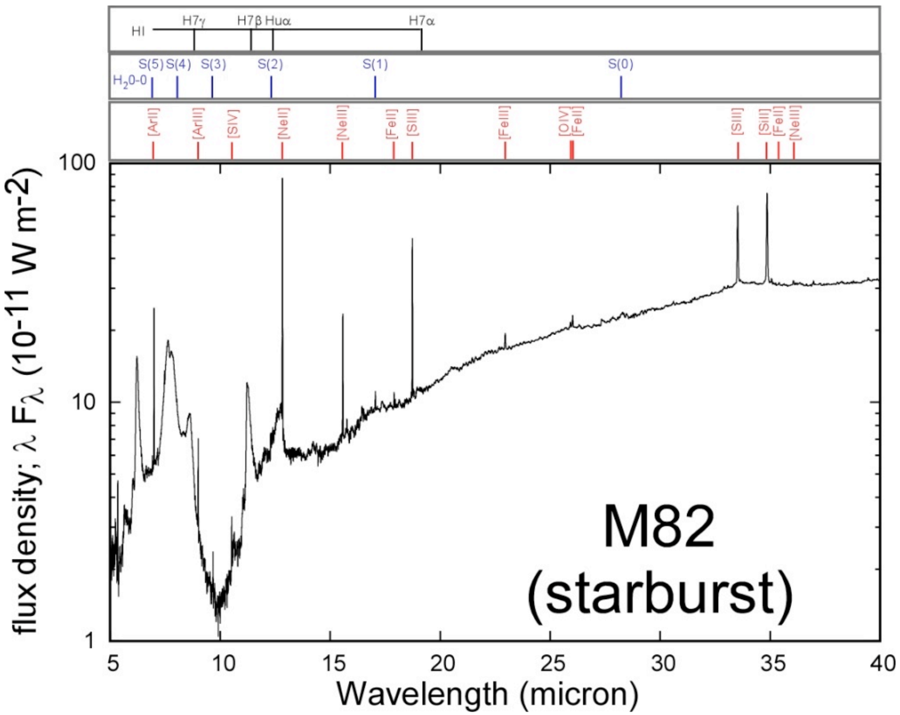
Spitzer Space Telescope/ Infrared Spectrograph (IRS) SH and LH

Band ID	aperture	plate scale	det.	Wavelength(μm)	resolution
SH	4.7”x11.3”	2.3”/pix	Si:As	9.9 – 19.6	~600
LH	11.1”x22.3”	4.5”/pix	Si:Sb	18.7 – 37.2	~600

Much more improved sensitivity than ISO/SWS
Different field-of-view locations and aperture areas projected on the sky between SH and LH
Insufficient mapping capability

Infrared Spectral Features detected by MIR Medium Resolution Spectrometers





ionized gas ; [NeII] 12.81μm, [Ne III] 15.56μm, 36.01μm, [NeV] 14.32 μm, [S III] 33.48μm, 18.71μm, [SIV] 10.51μm, [PIII] 17.89μm, [ArIII] 21.83μm,[ArV] 13.07μm, [OIV] 25.89μm, [SiII] 34.82μm, [Fe II] 25.99 μm, 35.35μm, 17.94μm, 24.5μm, [FeIII] 22.93μm, 33.04μm

molecular gas ; H_2 S(0) 28.219μm, S(1) 17.035μm, S(2) 12.279μm, C_2H_2 (ν_5=1-0)13.7μm, HCN (ν_2=1—0) 14.04μm, $^{12}CO_2$ 14.9μm

solid phase molecules and dust grains ; GEMS, MgS, FeS, PAHs

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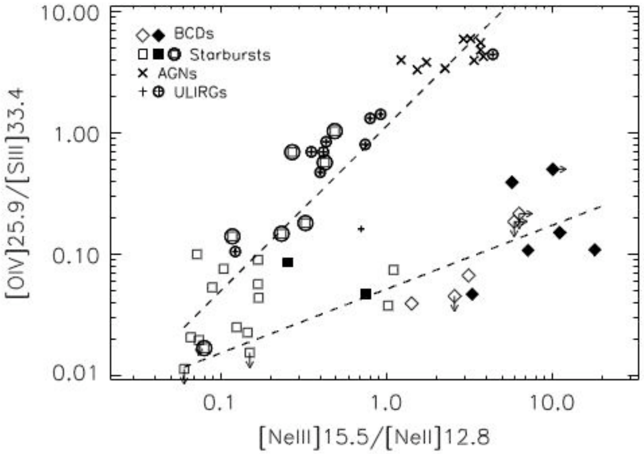
MIR Line Diagnostics made by Medium Resolution Spectrometers

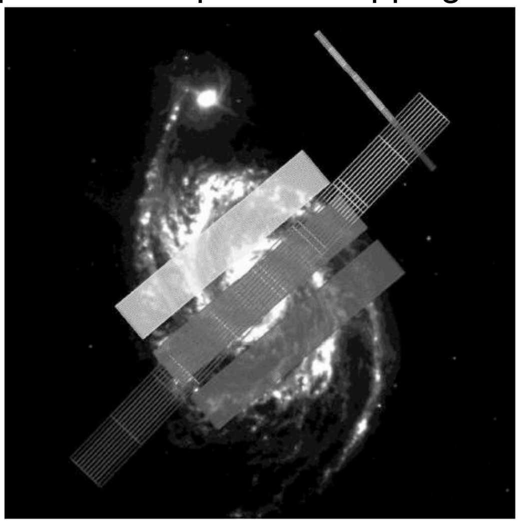
Identifying the dominant energy source of external galaxies (Lei Hao et al. 200)

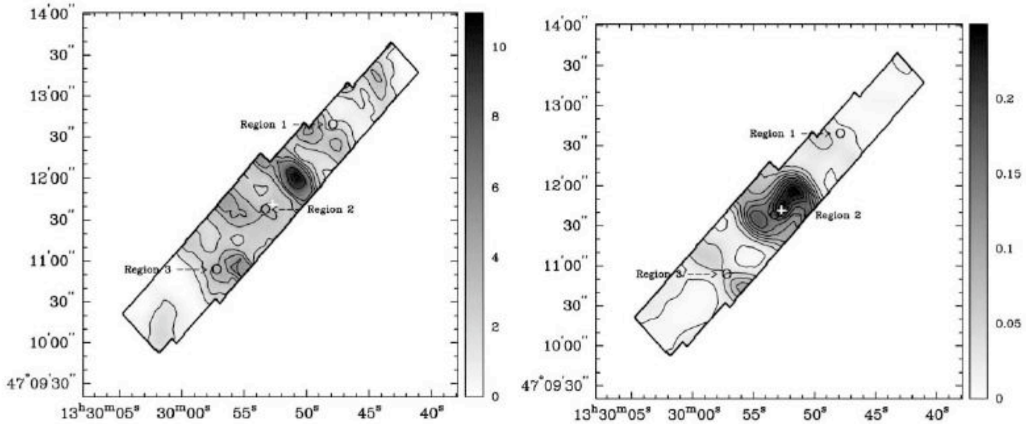
Diagnostics Fine-structure lines

[NeII] 12.81μm (ε_{ip}=21.6eV)
[Ne III] 15.56μm, 36.01μm (ε_{ip}=41.0eV)
[NeV] 14.32 μm, 24.32μm (ε_{ip}=97.1eV)
[S III] 33.48μm, 18.71μm (ε_{ip}=23.3eV)
[SIV] 10.51μm (ε_{ip}=34.8eV)
[OIV] 25.89μm (ε_{ip}=54.9eV)
[SiII] 34.82μm (ε_{ip}=8.2eV)
[Fe II] 25.99 μm, 35.35μm, 17.94μm, 24.5μm (ε_{ip}=7.9eV)



Spitzer IRS Spectral Mapping observations of H2 S(0), S(1), S(2), S(3), S(4) and S(5) in Nearby Galaxy M51





Surface Density Distributions of warm phase (T~100-300K) H2 gas (left)
and hot phase (T~400-1000K) H2 gas (Brunner et al. 2008, ApJ, 675, 316)

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Useful MIR line diagnostics and requirements for MRS Specifications

Understanding of physical transitions among various phases of the Interstellar Medium (ISM) and their chemical reaction networks

Examples of MIR Spectroscopic Diagnostics

[OIV]25.89μm/[SIII]18.71μm, [NeIII]15.56μm/[NeII]12.81μm, [SIV]10.51μm/[SIII]18.71μm (hardness of the radiation field)
[SiII]34.82μm/[SIII]33.46μm (gas-phase abundance of Si in the ionized gas)
[FeIII]34.82μm/[SIII]33.46μm (gas-phase abundance of Fe in the ionized gas)
H_2 S(0) 28.219μm / H_2 S(2) 12.279μm (useful to study the warm (T=~100—1000K) neutral phase of the ISM)

Requirements for Mid-Infrared Spectroscopic Capability

— Wide Wavelength Coverage in the Mid-Infrared (10-36μm)
— The consistency in the absolute flux calibration and the observational simultaneity between short and long wavelength modules shall be guaranteed
— The strength and the profile of fine structure and molecular lines shall be measured without blending
  R>1000 in 10-20μm (e.g., [FeII]17.94μm, [PIII] 17.885μm; $\Delta\lambda$~0.055μm)
  R>600 in 20-36μm (e.g., [OIV] 25.89μm, [FeII] 25.99μm; $\Delta\lambda$~0.098μm)
— The spectrometer shall be equipped with integrate field units (IFUs) of a wide field of view to achieve efficient spectral mapping observations (c.f., 2"x2" FOV size of JWST/MIRI)

Key Functions that shall be equipped to MRS to achieve the requirements above

— Dichroic Beam Splitter to split the incoming light into short (10-20μm) and long (20-36μm) modules
— Image Slicer as an integrate field unit in the fore-optics of each module

Sensitivity Requirement for SPICA/MCS/MRS

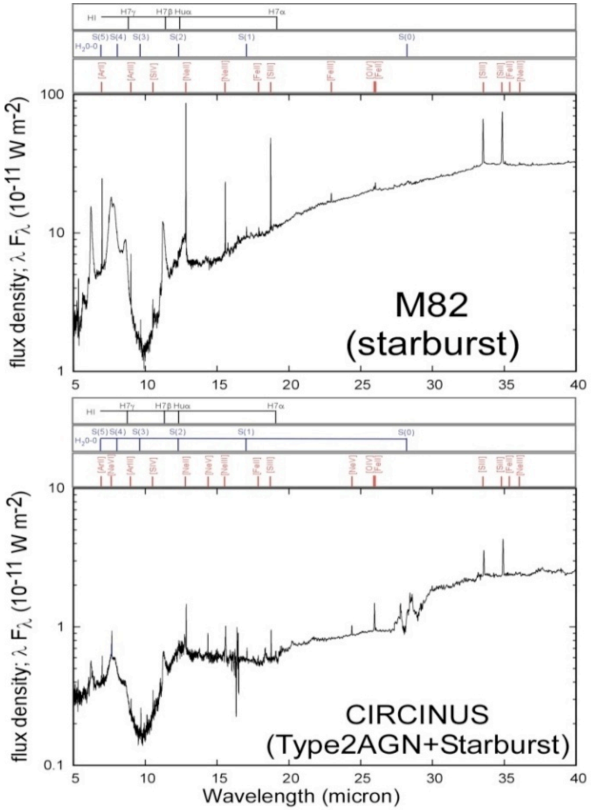
Sensitivity Requirement

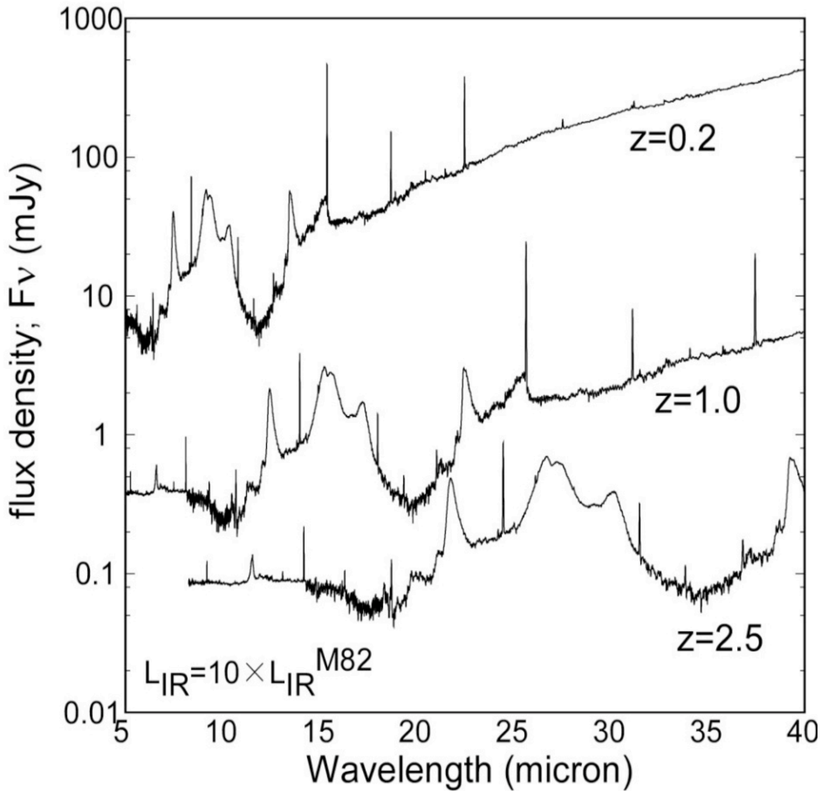
To measure the strengths of fine structure lines from the ISM of starburst galaxies at z~1;

5σ 1h line sensitivity of 10^{-19} Wm^{-2} for a point source

To examine the profiles of the spectral structures from the solid phase ISM at z~1;

5σ 1h continuum sensitivity of 100μJy for a point source





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Medium Resolution Spectrometer (MRS)

SPICA MCS/Medium Resolution Spectrometer (MRS)/Arm-S and Arm-L

Band ID	FOV	slitlet area	num. of slice	plate scale	det.	Wavelength(μm)	resolution
Arm-S	6”x12”	1.2”x12”	5	0.403”/pix	Si:As (2kx2k: 25μm/pix)	10.0 – 20.0	~1490@13μm
Arm-L	12.5”x12”	2.5”x12”	5	0.485”/pix	Si:Sb (1kx1k: 18μm/pix)	19.5 – 36.1	~680@27.8μm

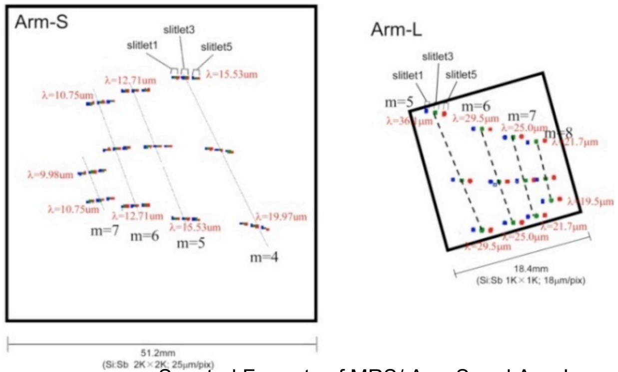
Arm-S

Echelle order	λ_{min} (μm)	λ_{max} (μm)
4	15.53	19.97
5	12.71	15.53
6	10.75	12.71
7	(9.98)	10.75

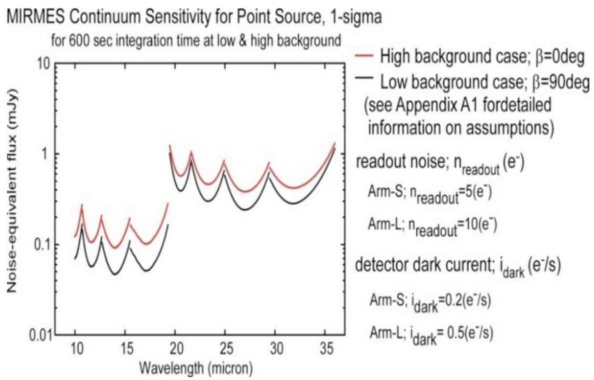
Arm-L

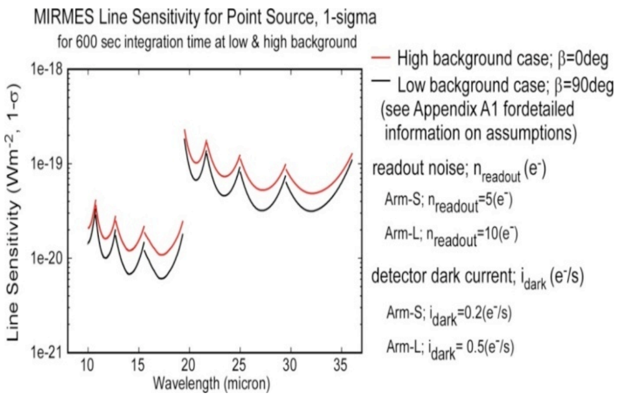
Echelle order	λ_{min} (μm)	λ_{max} (μm)
5	29.5	36.1
6	25.0	29.5
7	21.7	25.0
8	19.5	21.7

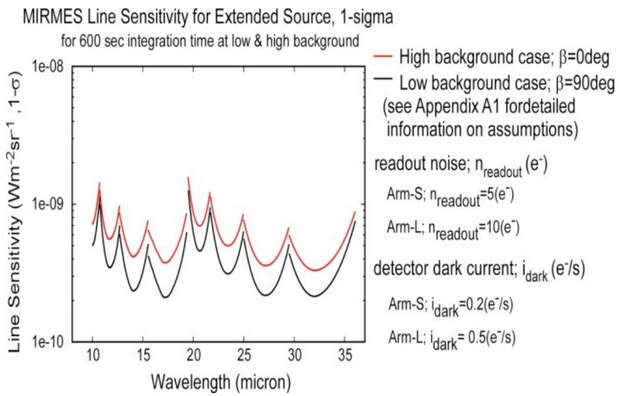
※ λ_{min} and λ_{max} are defined as the wavelength at which the grating efficiency drops to 40% of the peak



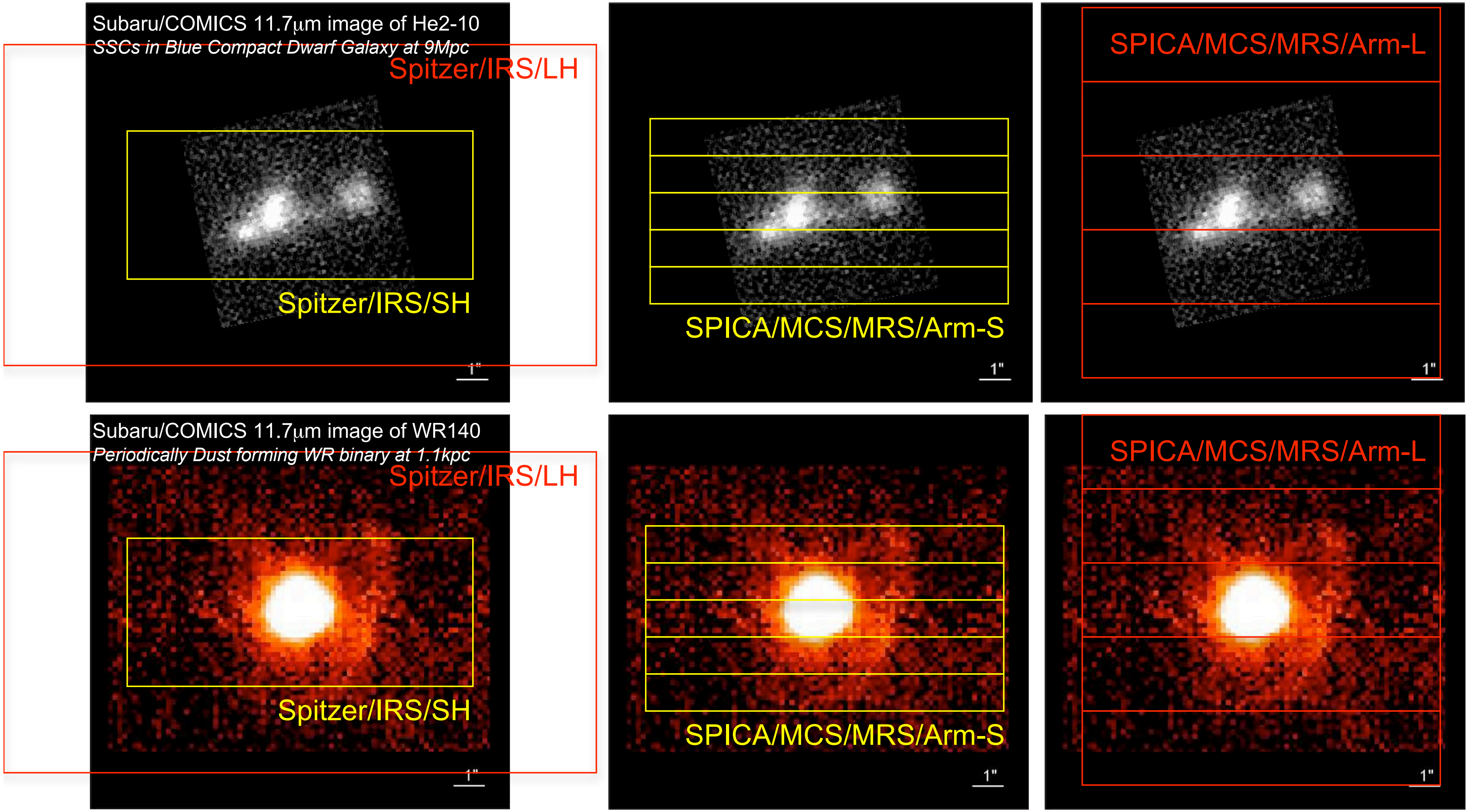
Spectral Formats of MRS/ Arm-S and Arm-L







Field of Views and Aperture areas



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Summary
Indispensable Capabilities and Key Functions

Understanding of physical transitions among various phases of the Interstellar Medium (ISM) and their chemical reaction networks

Current proposed design of SPICA/MCS/MRS fulfills the specification requirements to achieve the science target proposed here

Particularly, the following capabilities ***should not*** be lost from the MRS
- Wide Wavelength Coverage in the Mid-Infrared (10-36μm)
- The identity of the FOV aperture and the observational simultaneity between Arm-S and Arm-L
- Moderate spectral resolution power of R>1000 in 10-20μm and R>600 in 20-36μm
- The spectral mapping efficiency with IFUs and wide field of view coverage

Key Functions that shall be equipped to MRS to achieve the requirements above
- Dichroic Beam Splitter to split the incoming light into short (10-20μm) and long (20-36μm) modules
- Image Slicer as an integrate field unit in the fore-optics of each module