Mid-infrared Camera and Spectrometer on board SPICA

Hirokazu Kataza, Takehiko Wada (ISAS/JAXA),
Itsuki Sakon, Naoto Kobayashi (Univ. Tokyo),
and
SPICA MCS team from the universities and institutes in Japan and Taiwan

Instrument Overview

5 -- 38μm Camera and Spectrometer

- Wide Field Camera
  - 5 x 5 arc minutes square FOV x 2, λλ 5--25 and 20--38μm
    - Multi-band imaging
    - Slit-less spectroscopy R~50--100
- Mid Resolution Spectrograph
  - IFU by image slicer
  - *R*:(1900--3000)+(1100 --1500)
  - λλ (12.2--23.0)+(23.0--37.5)μm at once
- High Resolution Spectrograph
  - *R* : 20,000 ~ 30,000   λλ 12--18μm

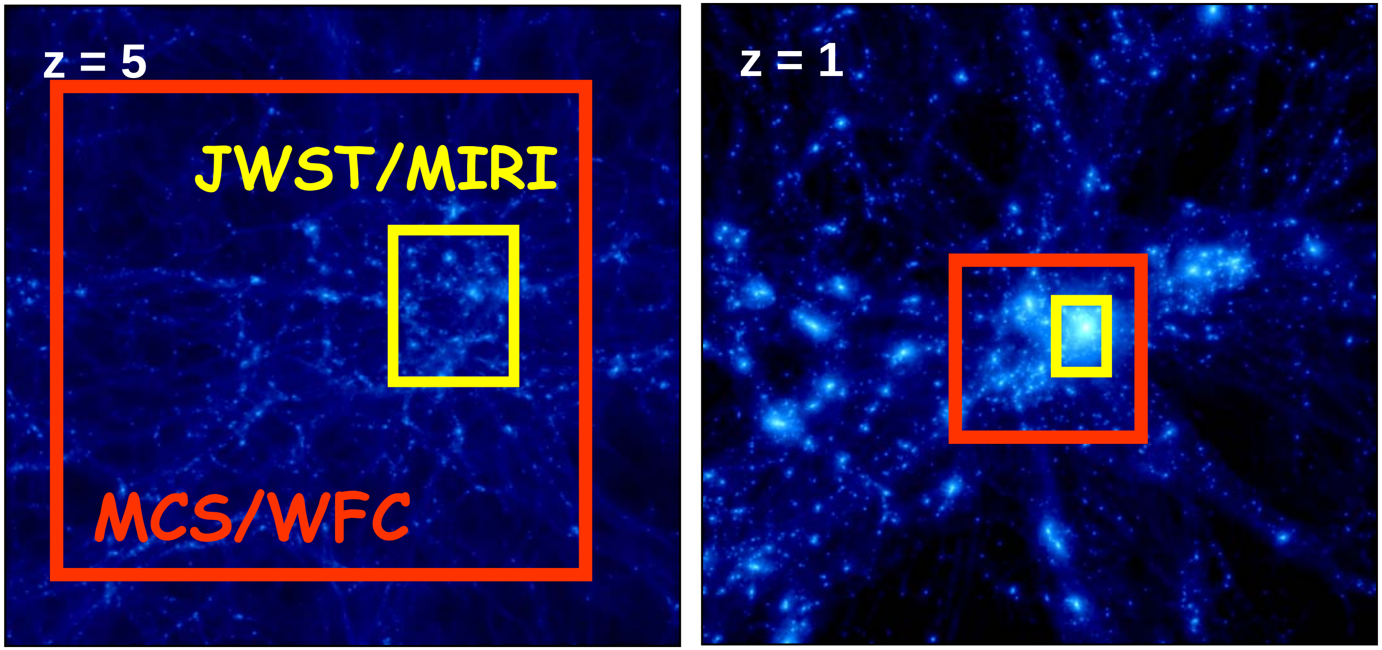
SPICA Scientific objectives

- Resolution of Birth and Evolution of Galaxies
- Transmigration of Dust in the Universe
- Thorough Understanding of Planetary System Formation

Unveiling the Role of Environment in the Early Universe

Wide Field of View 5’x5’ Imager

MCS explore the star formation activities of galaxies along the large-scale structures in the high-*z Universe up to z ~5,* taking advantage of wide-field imaging capability *and excellent sensitivity* at *> 20 micron.*



M=6×10^14 Msun, 20Mpc×20Mpc (co-moving)

Life cycle of dust revealed by Infrared Spectral Features in the MIR

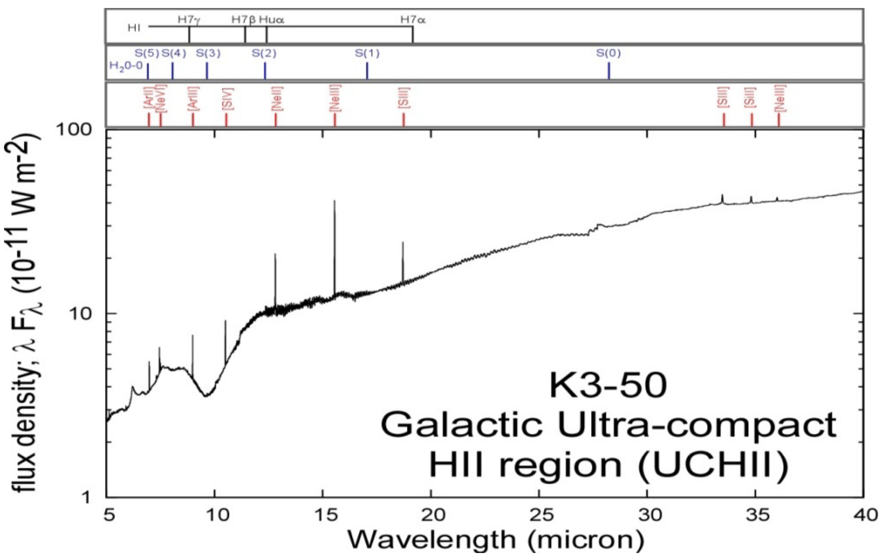
How the materials of various physical phases evolves in the Universe?

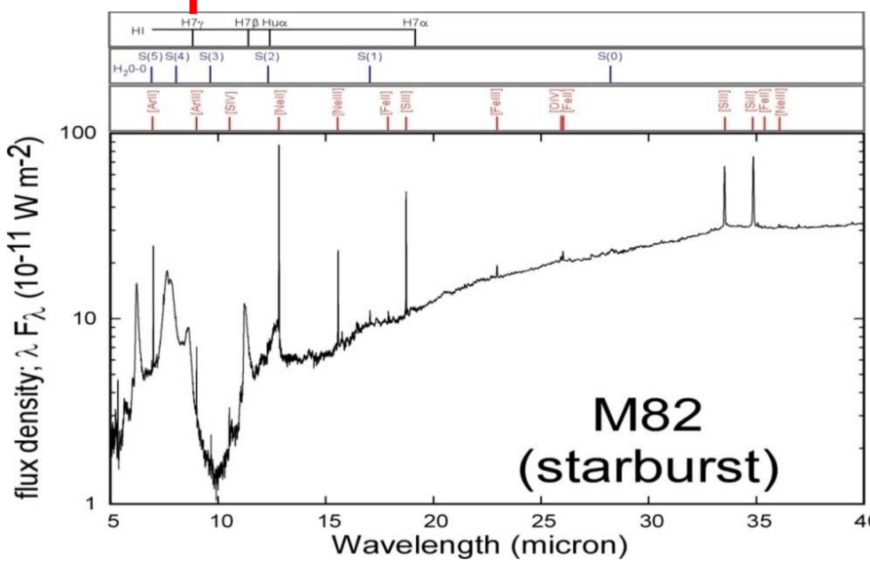
SNe as dust budgets in the early universe?

Process of dust nucleation, grain growth and destruction of Dust

Chemical Evolution of the ISM

Mid-R Spec. from 12 to 38μ





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, crystalline silicates

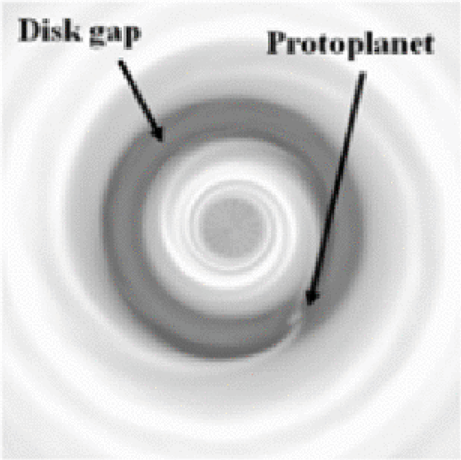
Formation Mechanism of Gas Giant Planets Initial Conditions Required for Terrestrial Planet Formation

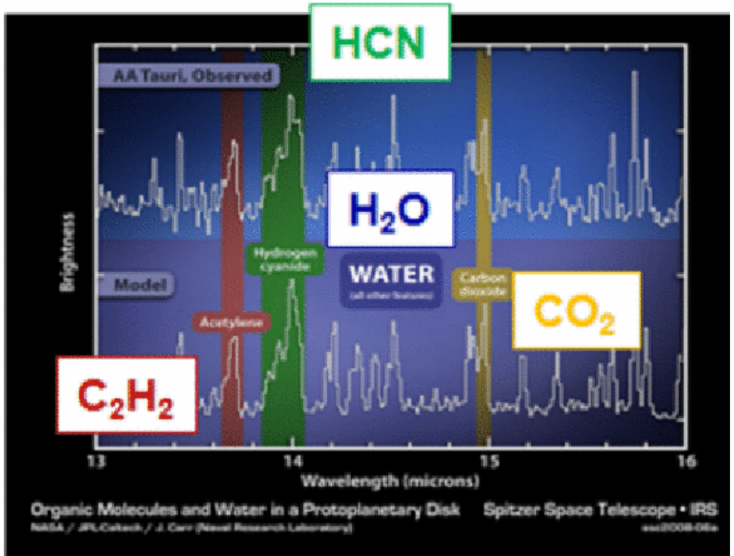
High-R Spec. at MIR

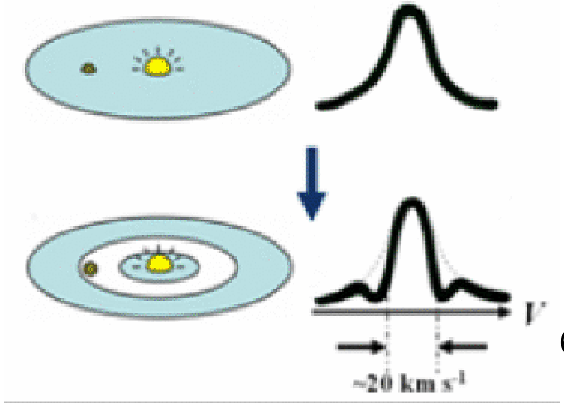
Observing the dissipation of gas and their structural evolution in planet-forming regions

The profiles of molecular emission lines (CO, H_2O, HCN, CO_2, C_2H_2) in the MIR

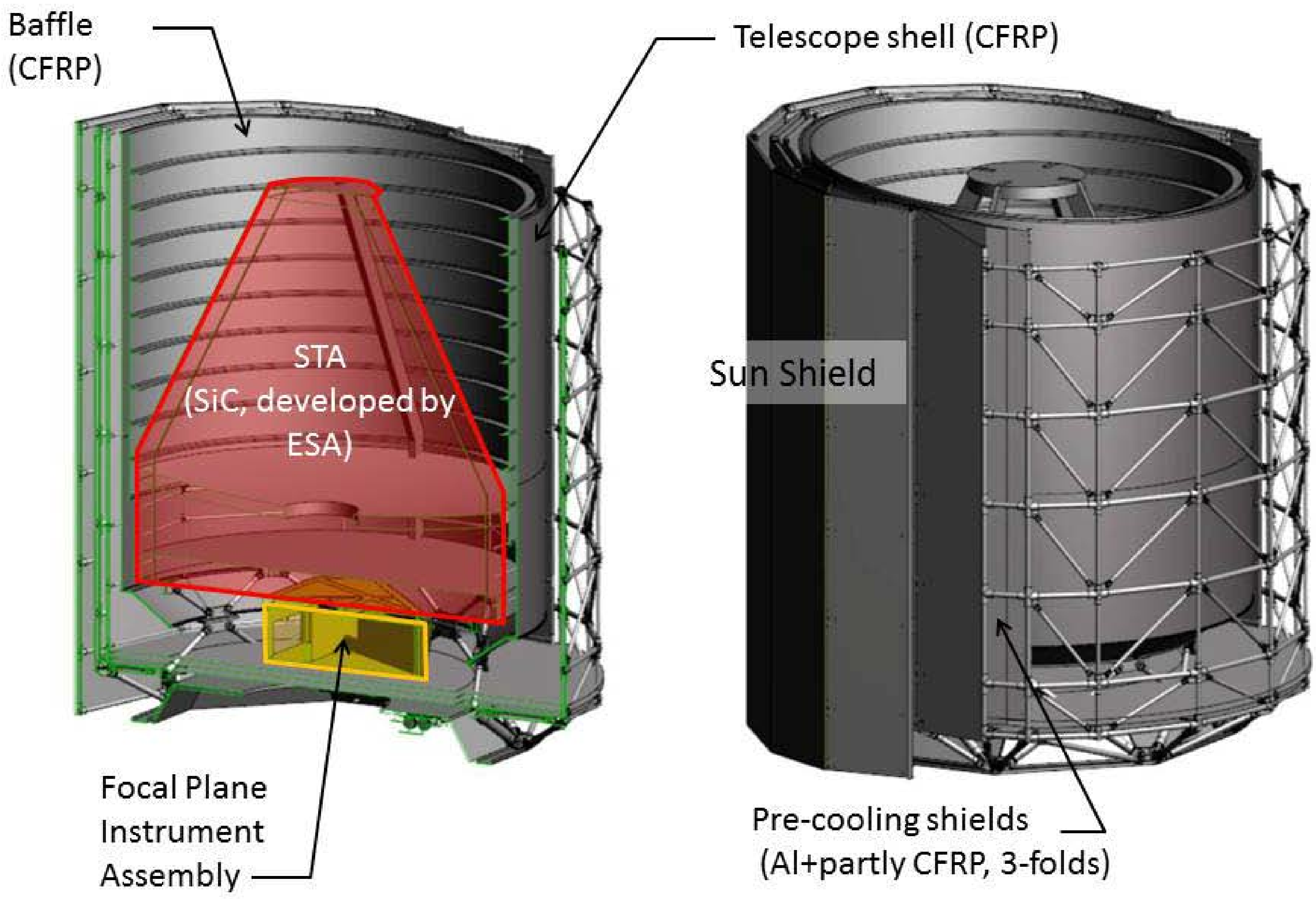
→ useful to understand how the structure of gas disks evolve in the course of planet formation



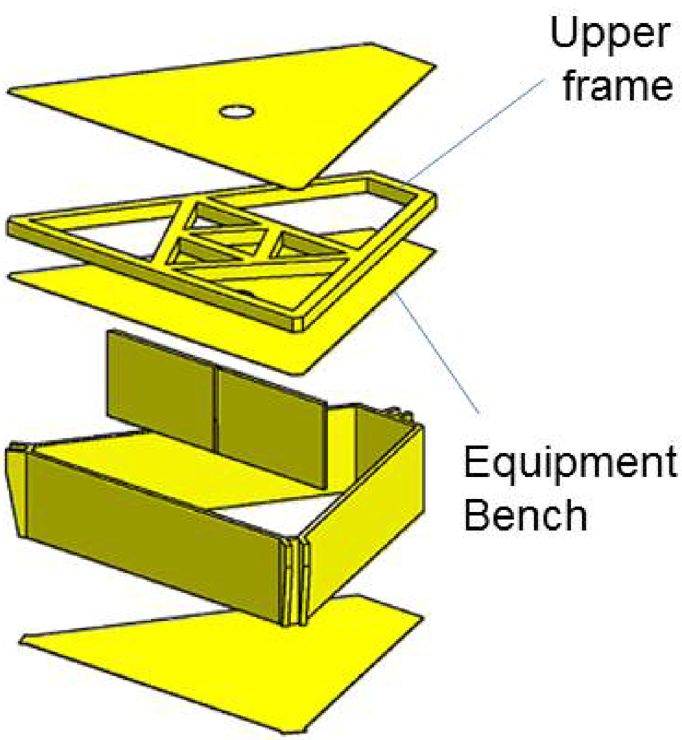


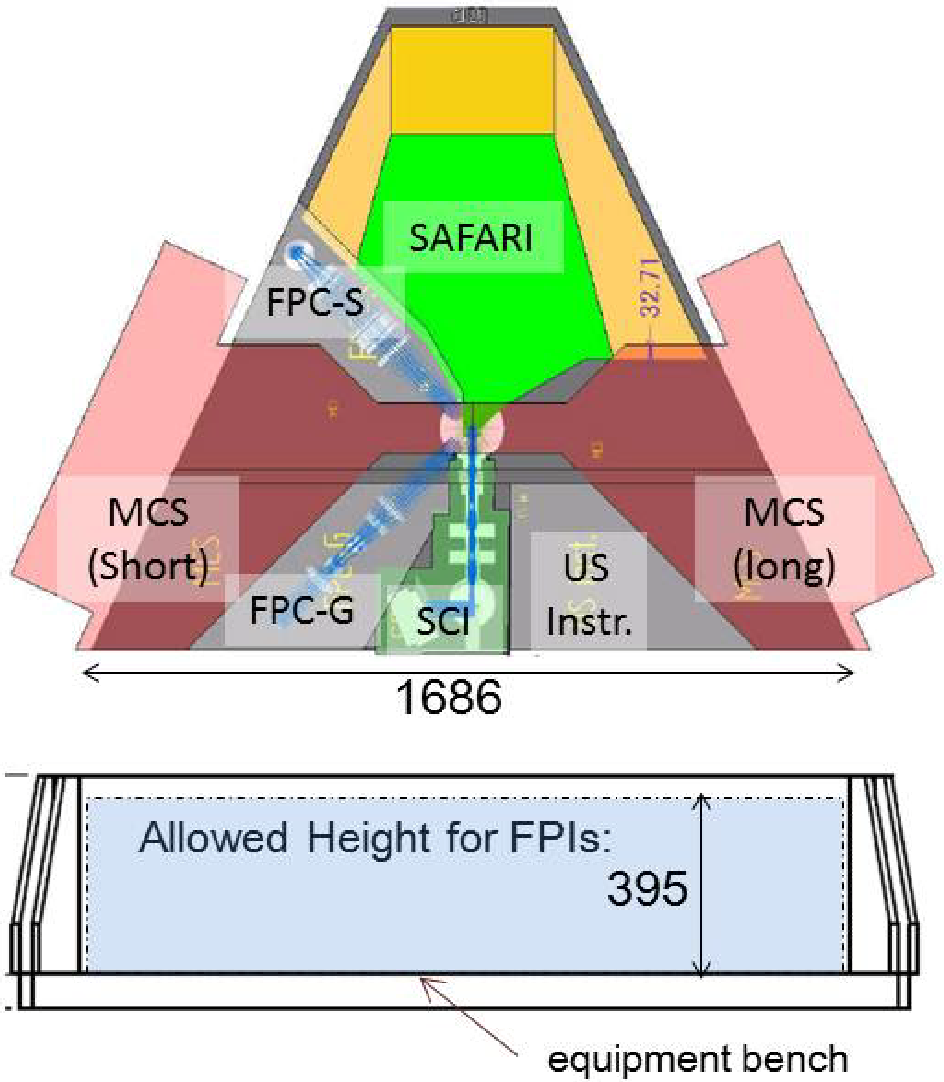


SPICA PLM (payload module)

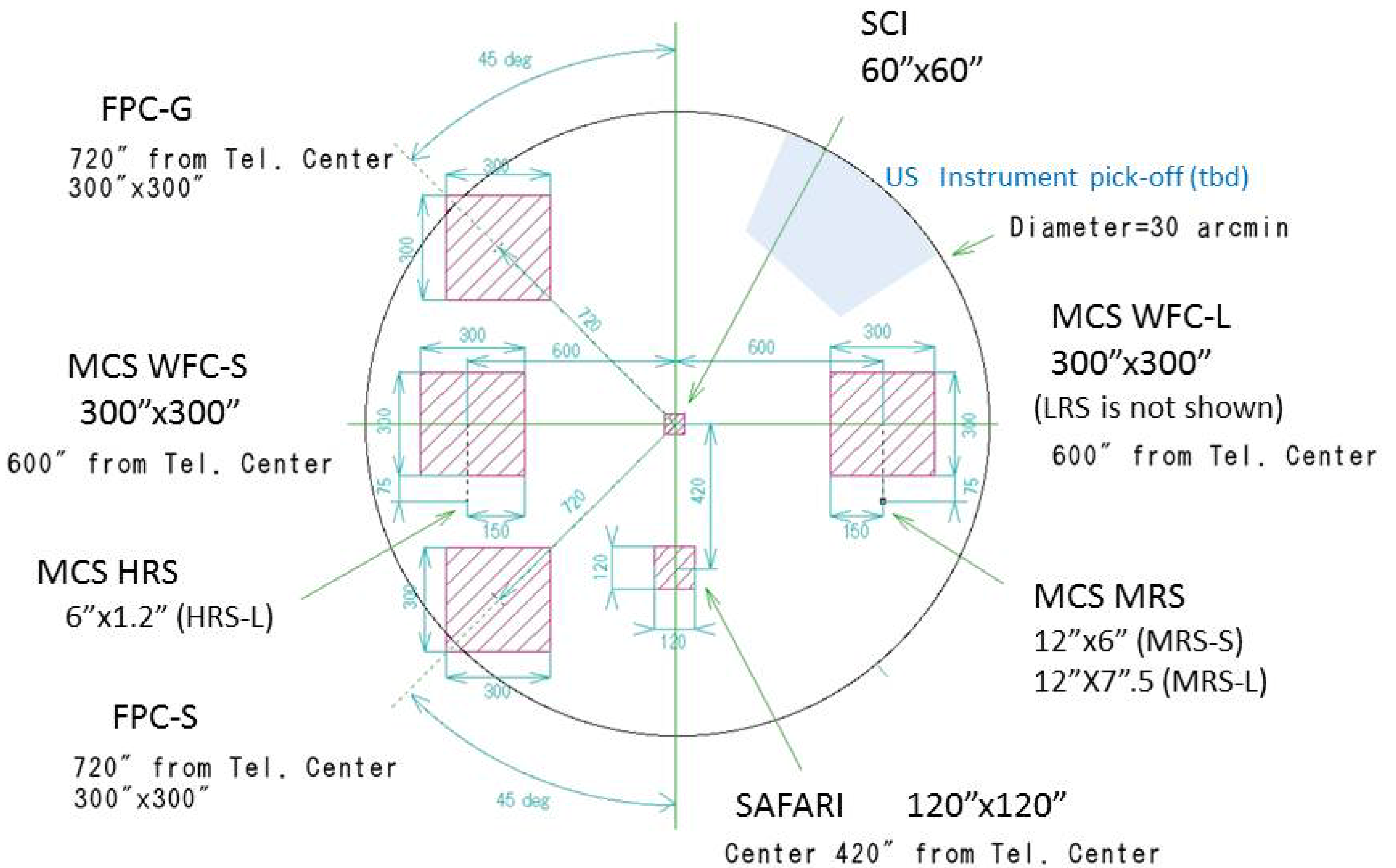


FPIA: Focal Plane Instrument Assembly





Focal Plane map



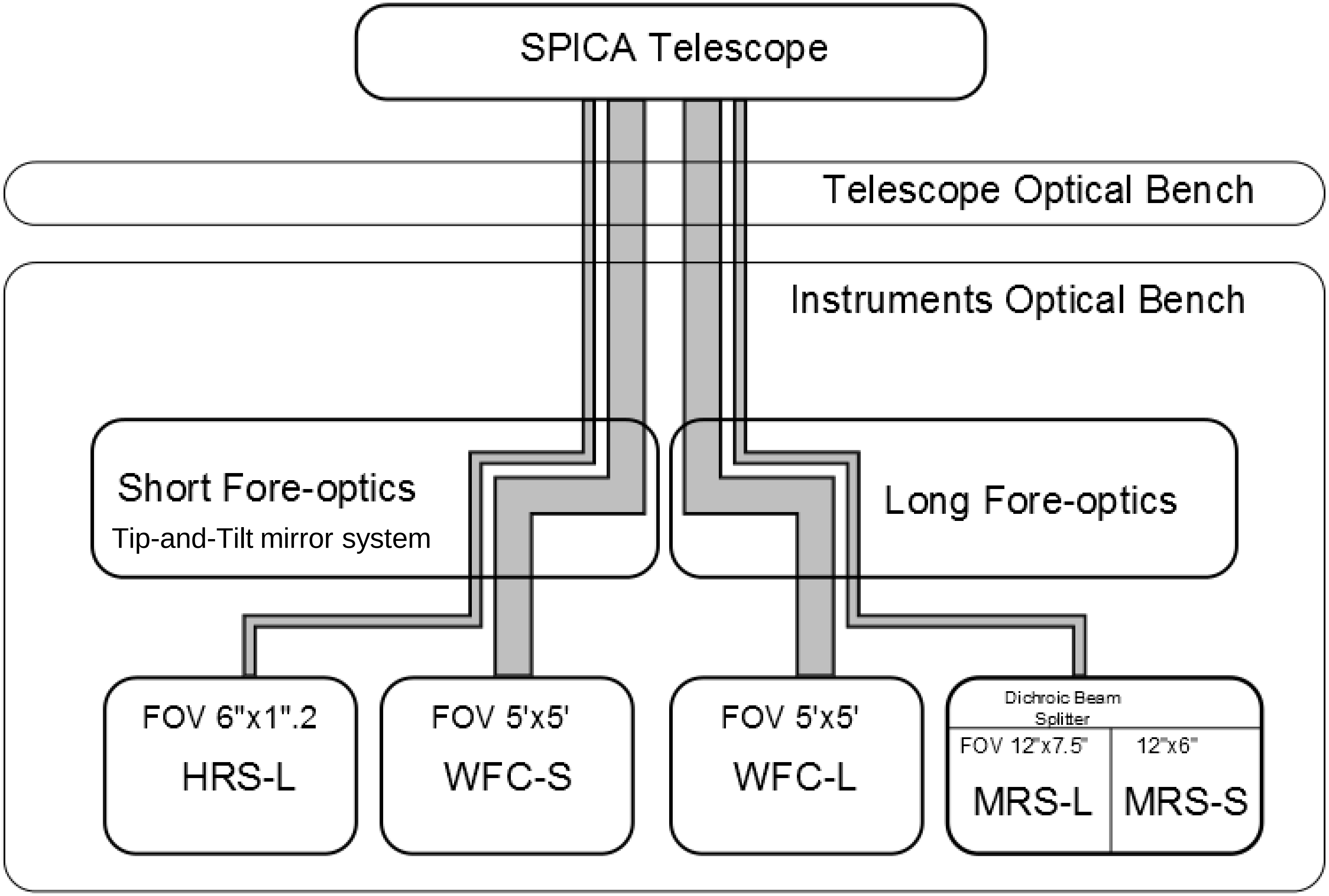
Instrument description

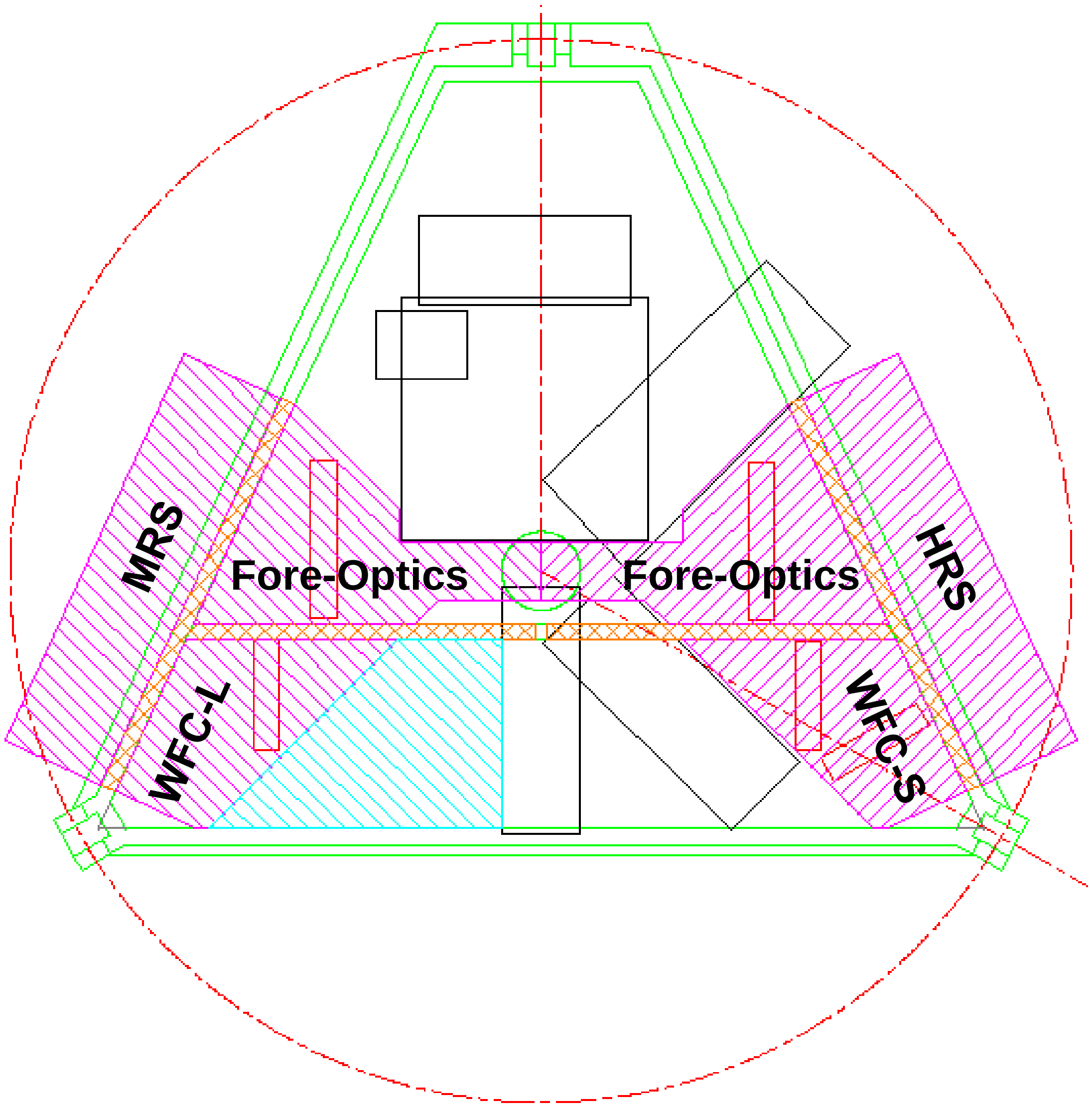
MCS consists of the following camera and spectrographs

- WFC: wide field camera
- MRS: medium resolution spectrograph
- HRS: high resolution spectrograph

Each of them shares their fore-optics.

Design: Optical architecture




MRS
Fore-Optics
Fore-Optics
HRS
WFC-L
WFC-S

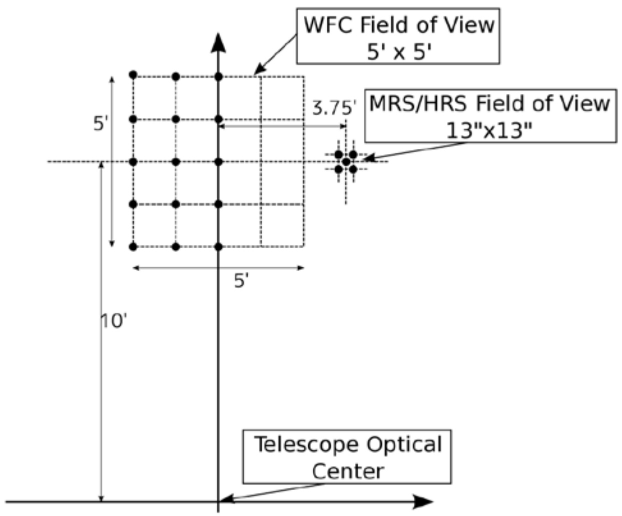
Fore-Optcs

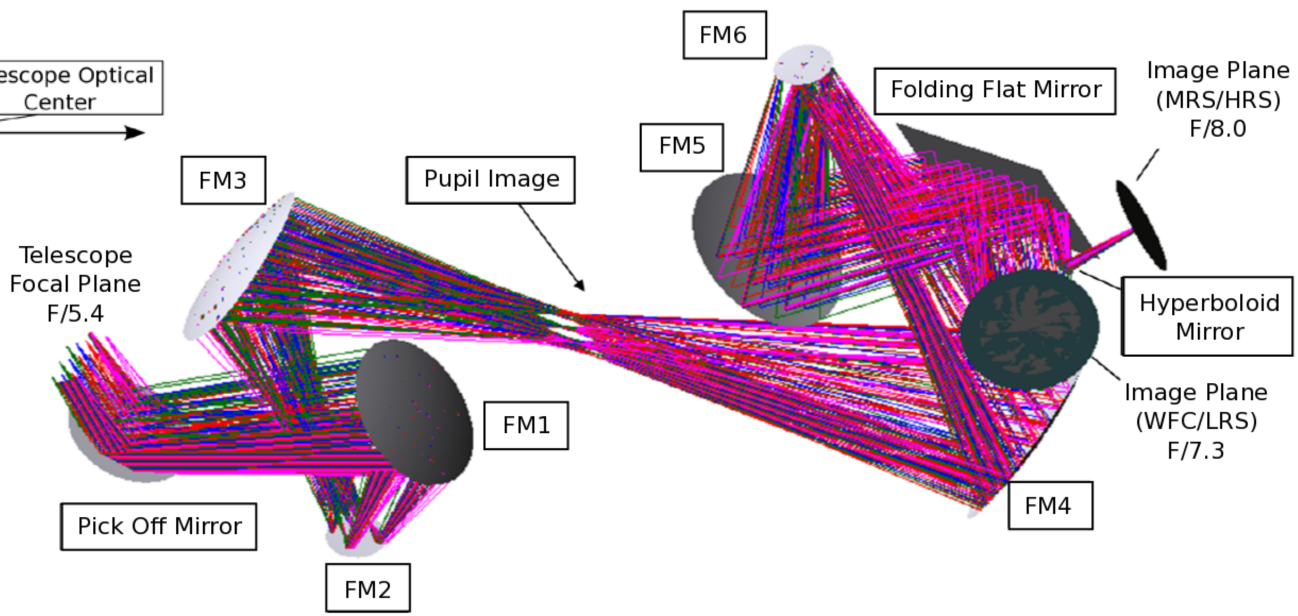
Relay optics with Collimator + Camera

Free-surface mirror

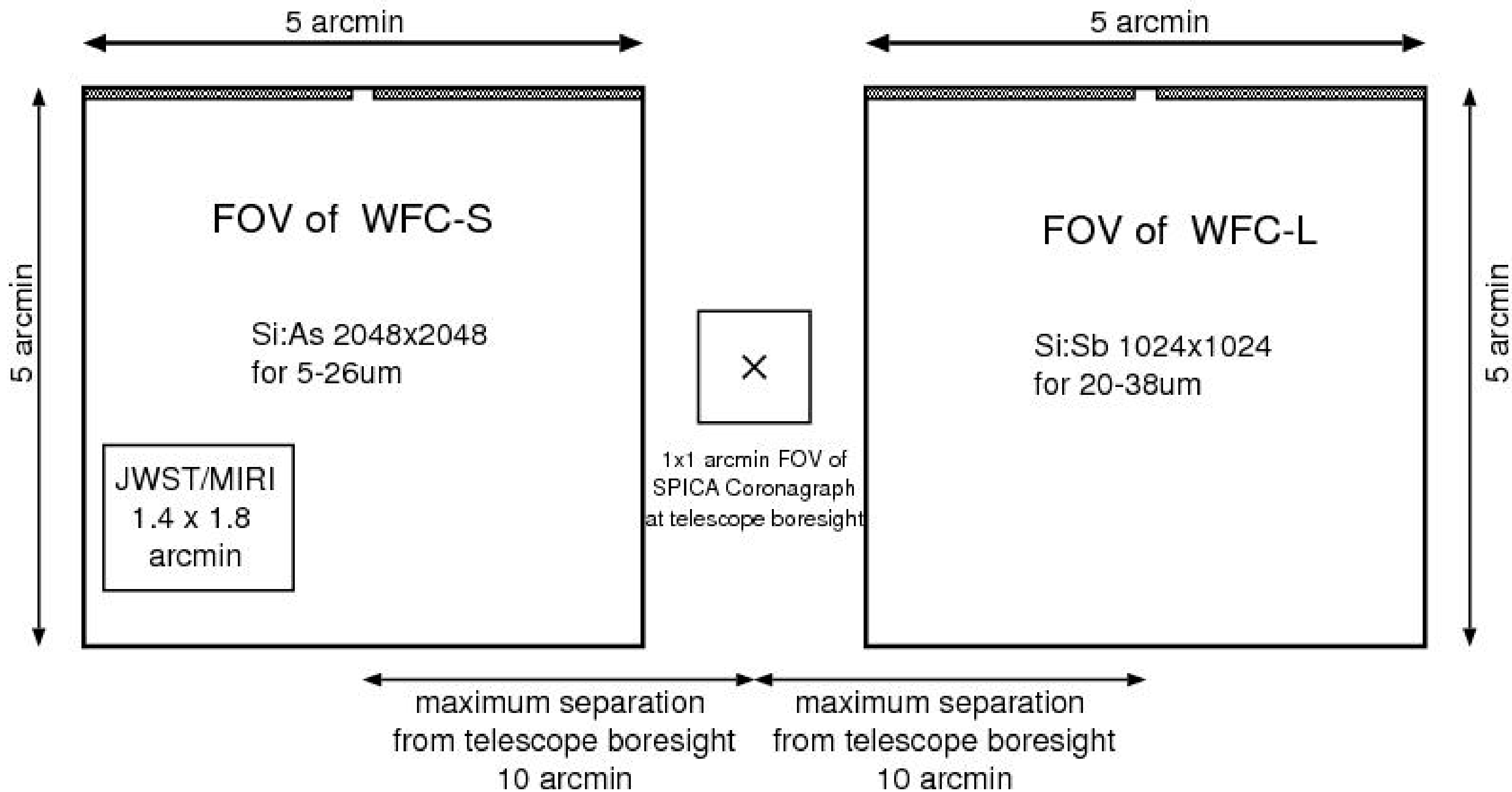
Wide FOV including WFC+(MRS/HRS)

Compensate telescope aberrations





Wide-Field Camera (WFC)



- Much larger FoV than JWST/MIRI
- PSF Nyquist sampling at λ= 5 or 10 μm (at 7 μm for JWST/MIRI)

WFC-S

FOV: 5' x 5'

Diffraction limited image

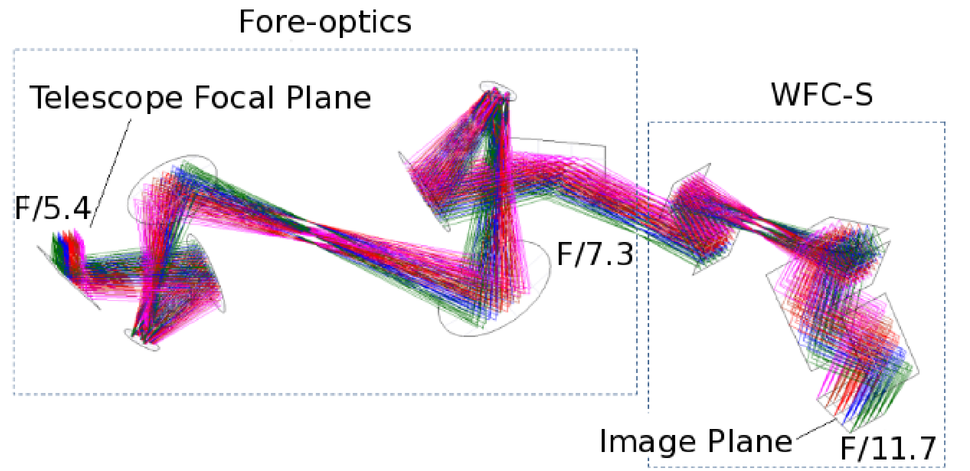
Zodiacal light limit noise

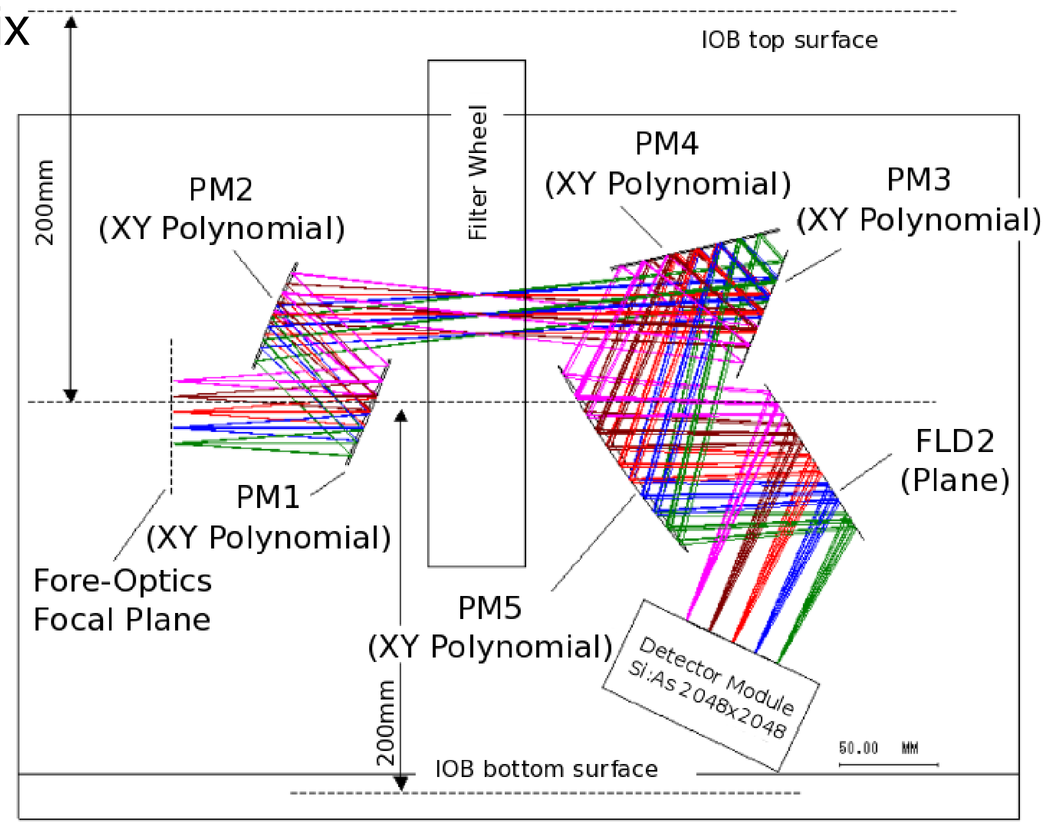
5 -- 25μm

Si:As 2048x2048   0."146 fov/pix

Band –pass filters

Grisms for low-resolution spectroscopy





WFC-L

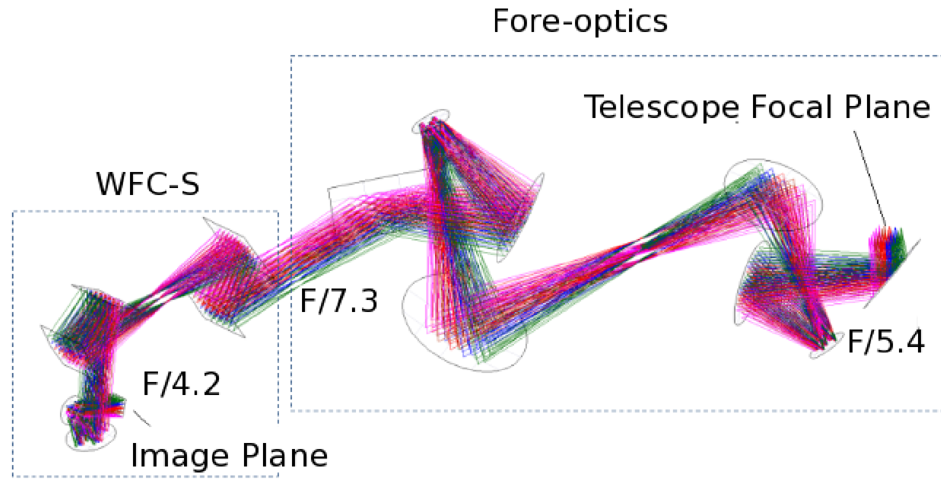
FOV: 5’ x 5’ x 2 field

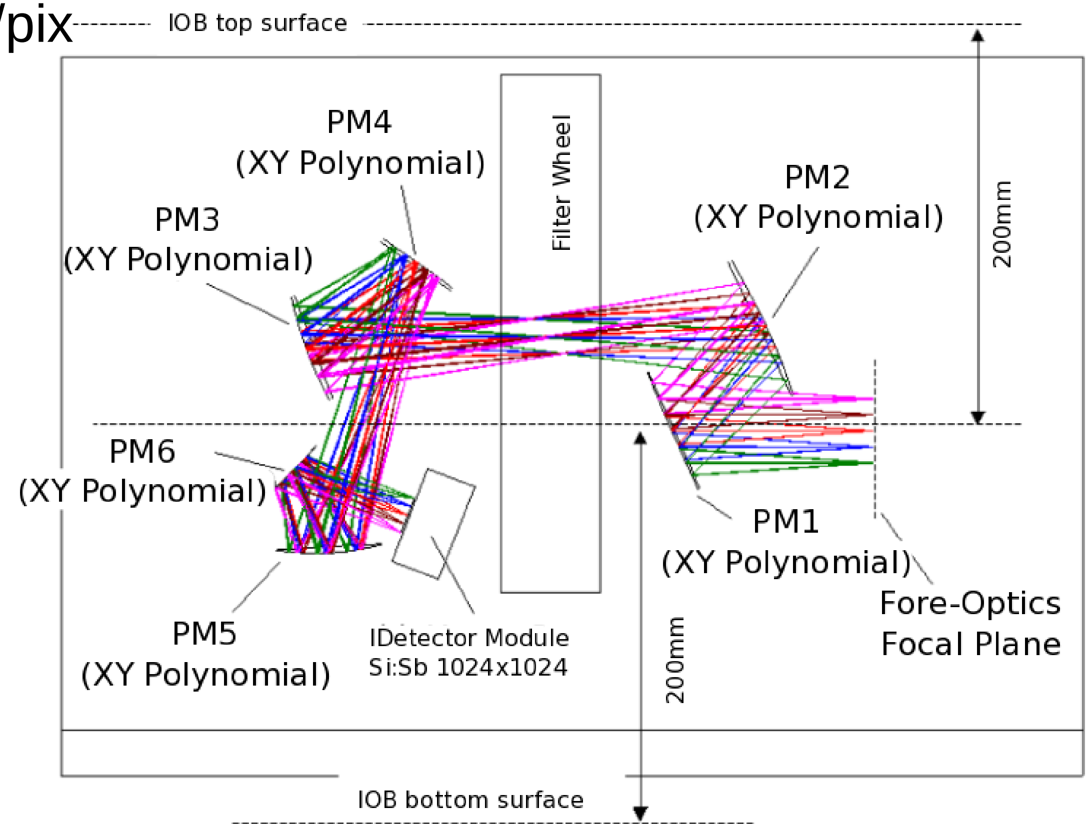
Diffraction limited image

Zodiacal light limit noise

20 -- 38μm

Si:Sb 1024x1024 0.”293 fov/pix





Band-pass filters

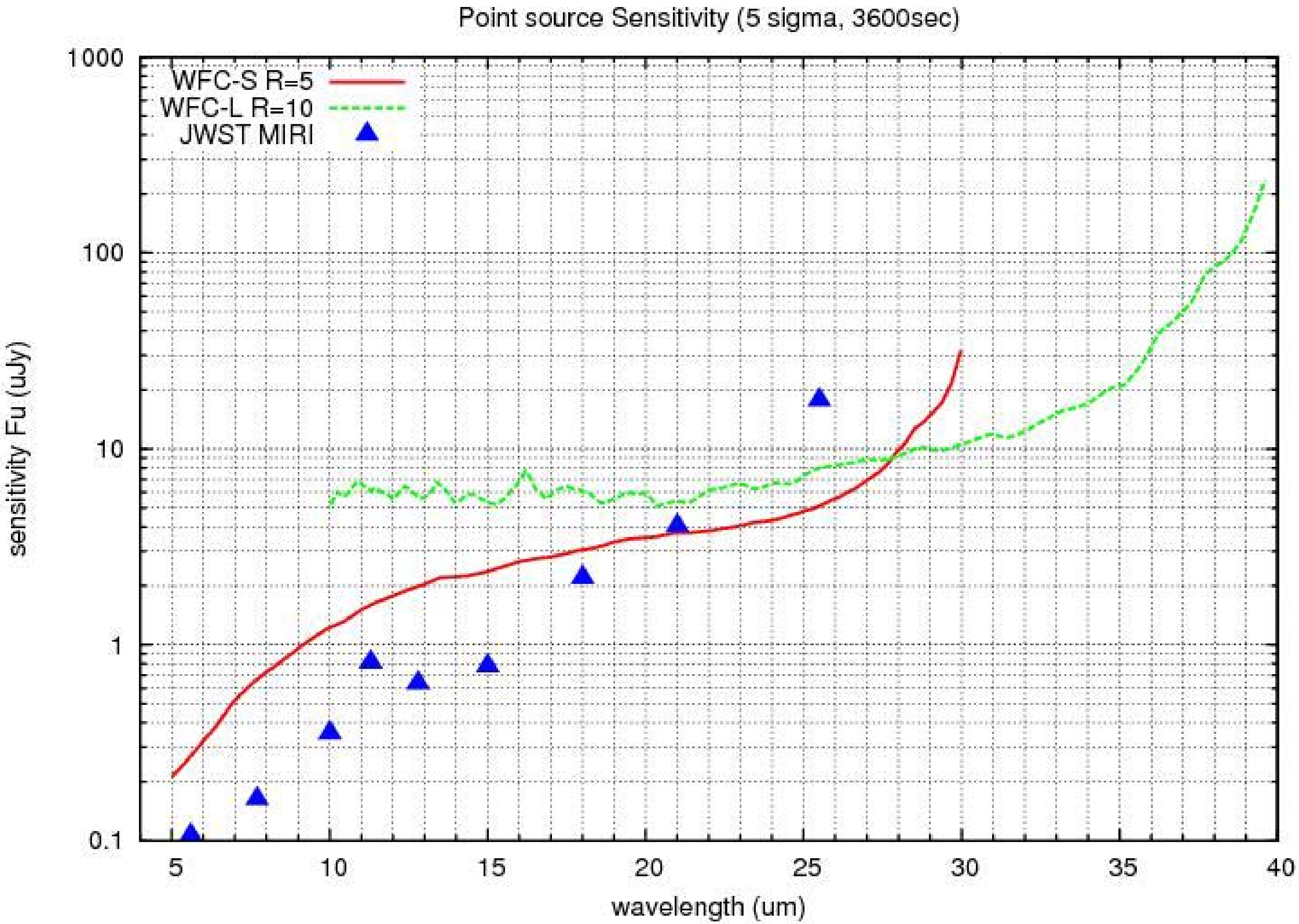
Grisms for low-resolution spectroscopy

WFC expected performance

For both WFC-S (Si:As 2k x 2x)/WFC-L(Si:Sb 1k x 1k)

Frame integration:617.3 s Background (Zodiacal light) 261K BB18MJy/str at 25μm.

Total integration time:3600s   Aperture photometry within the first diffraction null ring

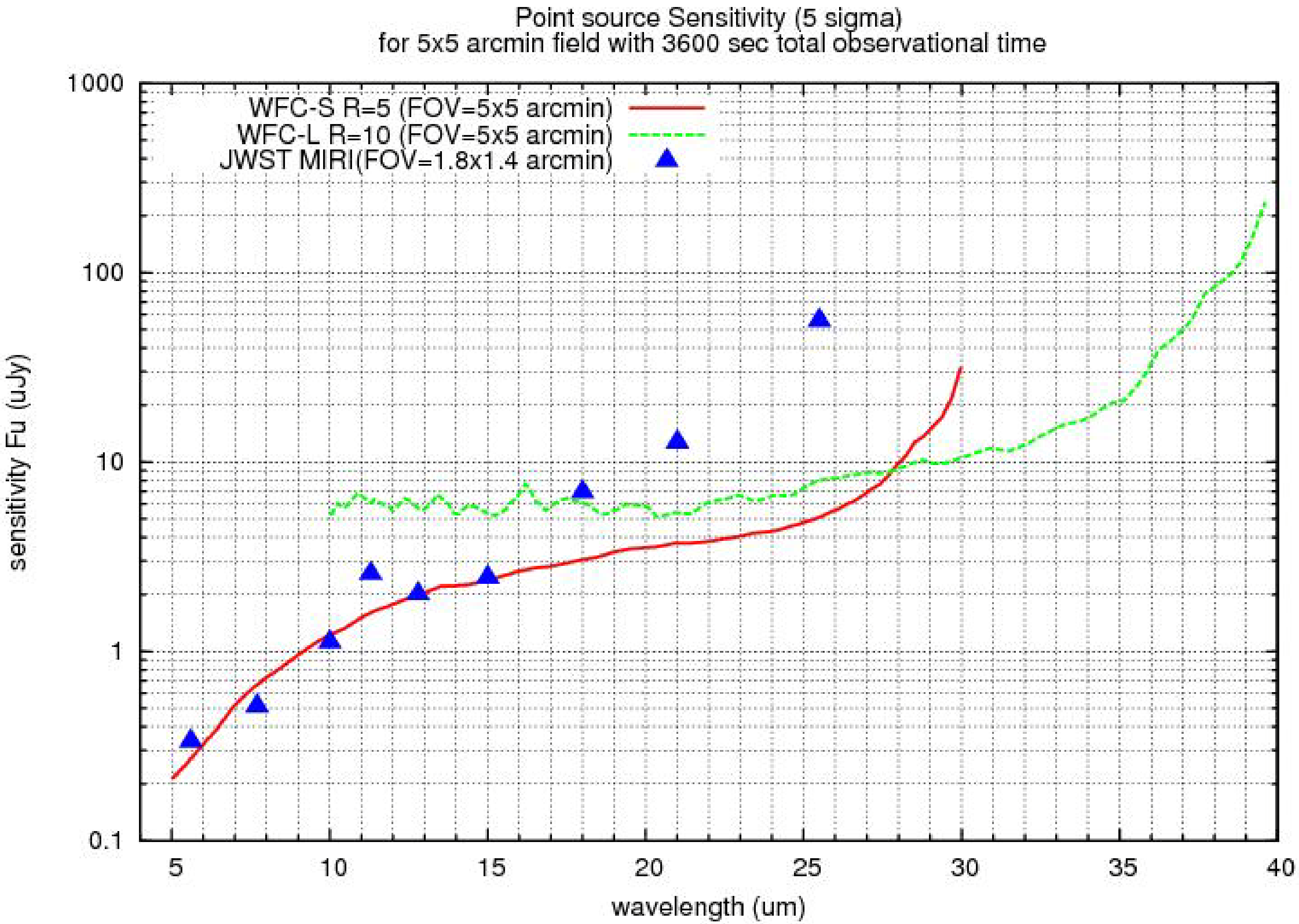


WFC expected survey performance (5’x5’)

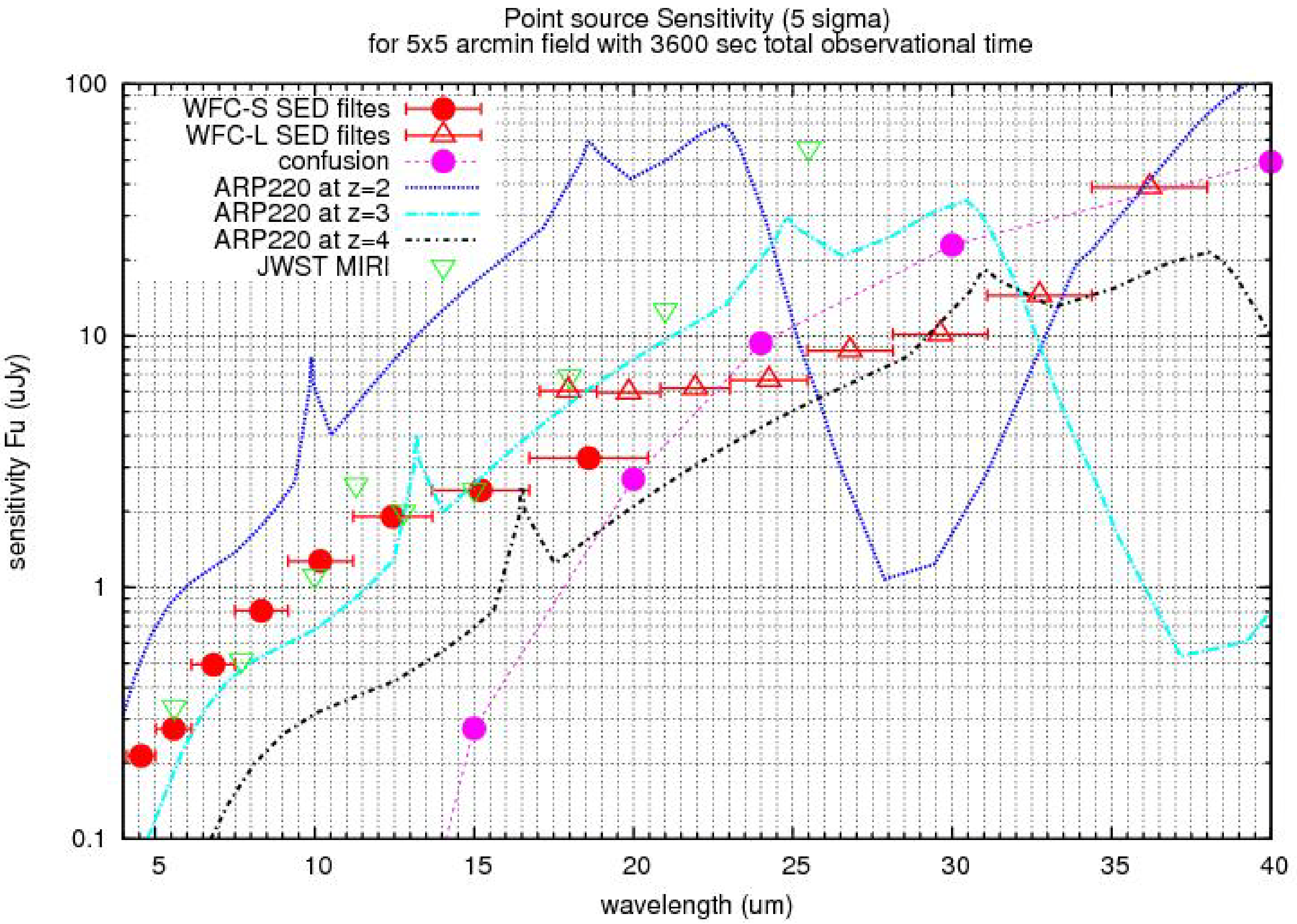
For both WFC-S (Si:As 2k x 2x)/WFC-L(Si:Sb 1k x 1k)

Frame integration:617.3 s Background (Zodiacal light) 261K BB18MJy/str at 25μm.

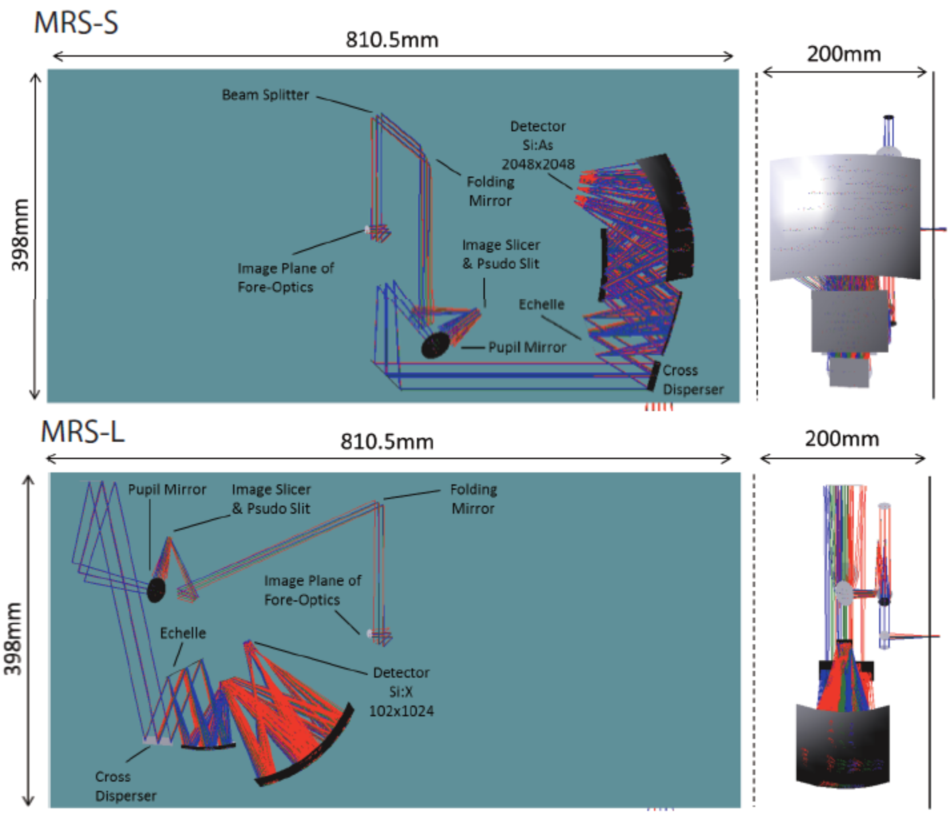
Total integration time:3600s   Aperture photometry within the first diffraction null ring



WFC for cosmological survey (1x1 deg in 1400 hrs)



Medium Resolution Spectrograph (MRS)

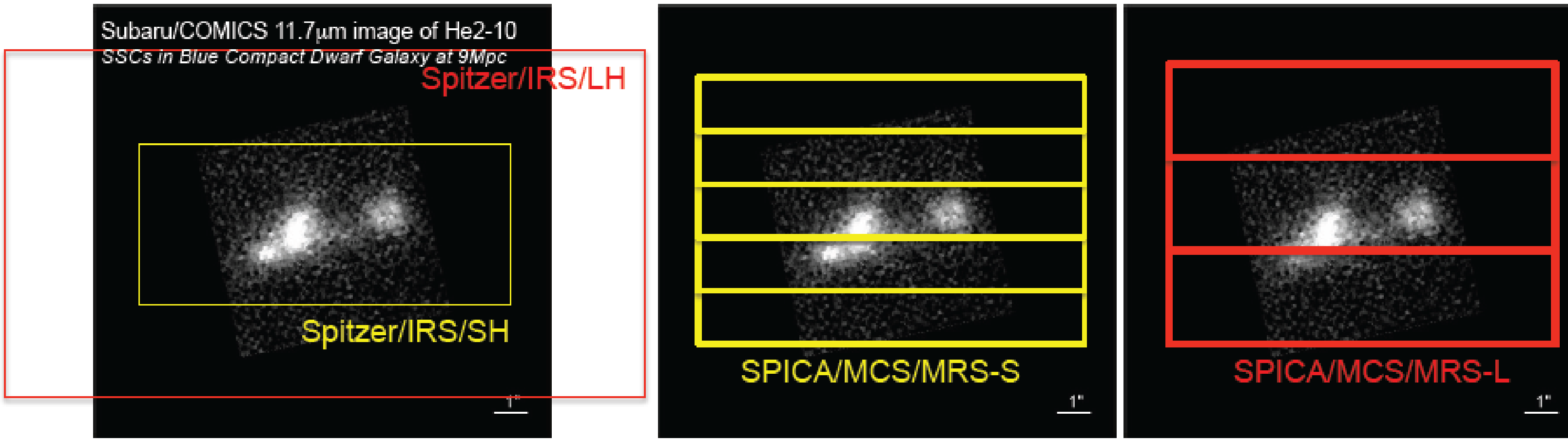


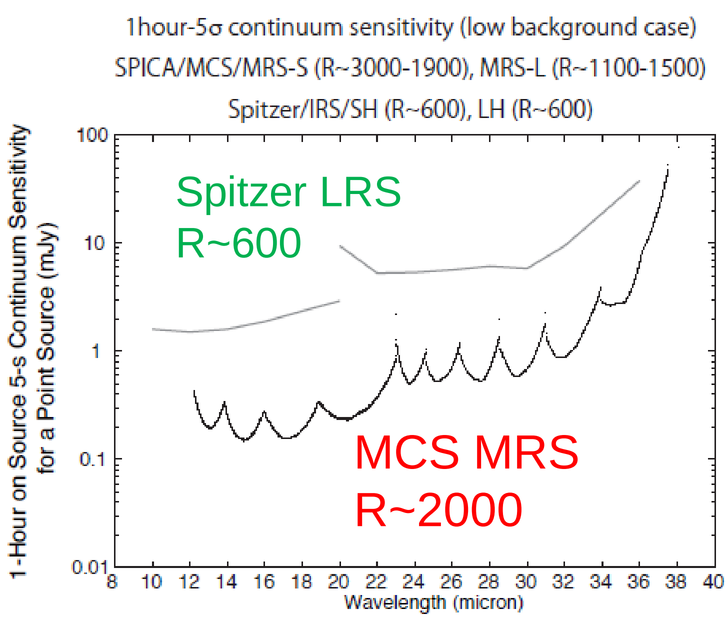
MRS-S 12.2 – 23.0 μm
R 1900 – 3000
Si:As 2k x 2k
pixel scale 0”.403

MRS-L 23.0 – 37.5 μm
R 1100 – 1500
Si:Sb 1k x 1k
pixel scale 0”.485

Image Slicer (slit length x width x slices)
MRS-S; 12” x 1”.2 x 5
MRS-L; 12” x 2”.5 x 3
sharing the same FOV,

MCS- Medium Resolution Spectrometer (MRS)





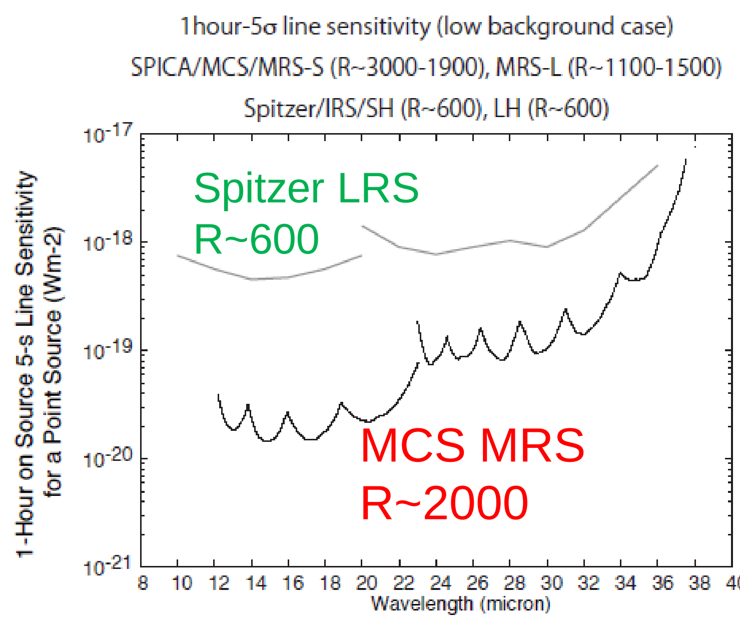


Table 1. Spectral Format of MRS-S and MRS-L on the detector arrays

MRS-S				MRS-L			
Echelle Order	λ_{min}^{m} (μm)	λ_{b}^{m} (μm)	λ_{max}^{m} (μm)	Echelle Order	λ_{min}^{m} (μm)	λ_{b}^{m} (μm)	λ_{max}^{m} (μm)
m=5	18.85	20.74	23.04	m=10	33.95	35.65	37.53
m=6	15.95	17.28	18.85	m=11	31.00	32.41	33.95
m=7	13.83	14.81	15.95	m=12	28.52	29.71	31.00
m=8	12.20	12.96	13.83	m=13	26.41	27.42	28.52
--	--	--	--	m=14	24.59	25.46	26.41
--	--	--	--	m=15	23.00	23.77	24.59

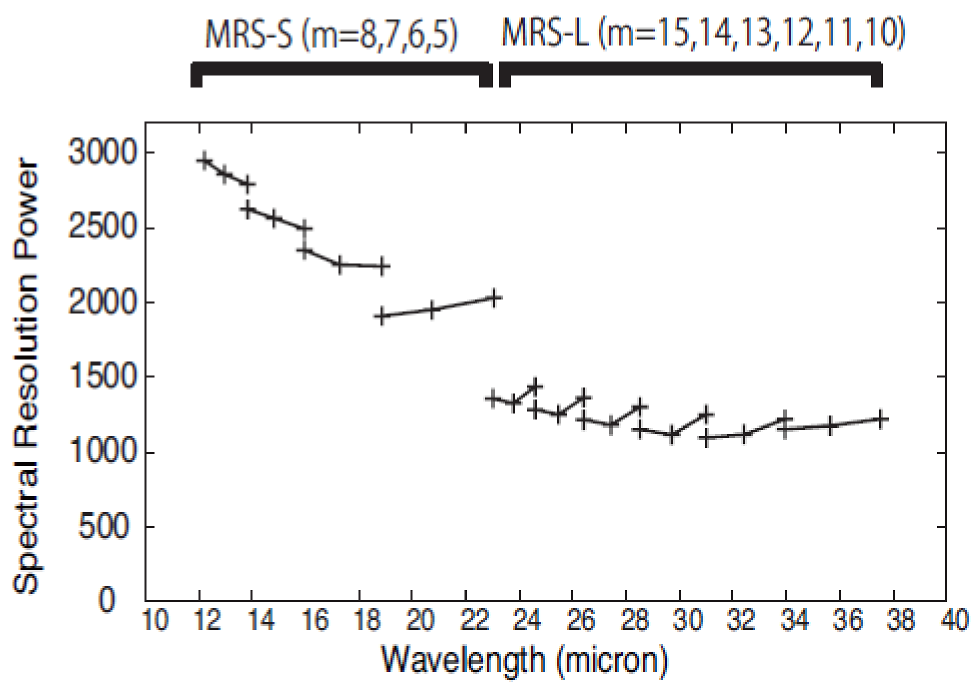


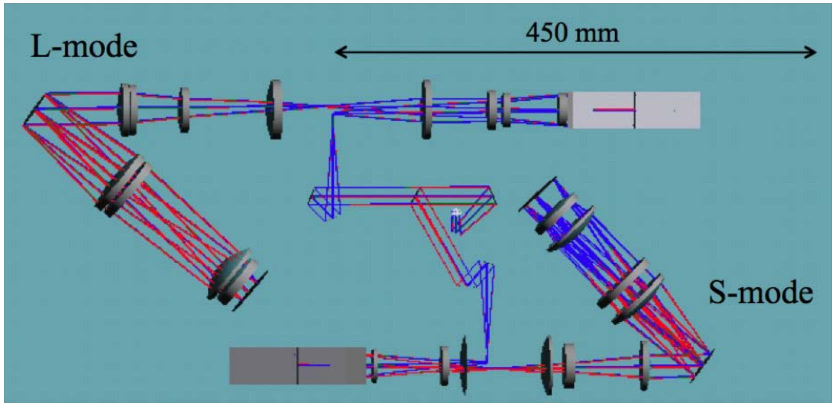
Figure 2. Spectral resolution powers of MRS-S and MRS-L for a point source

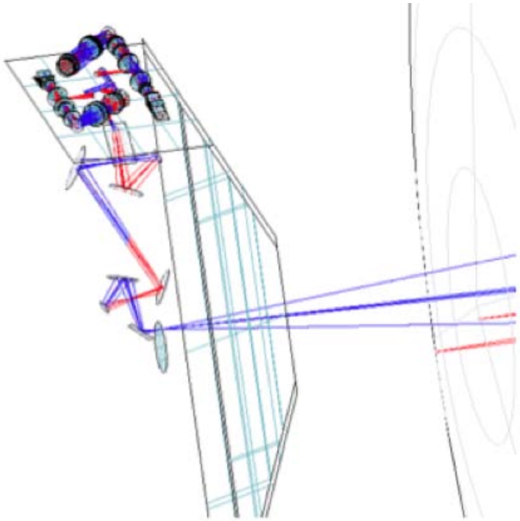
High Resolution Spectrometer (HRS)

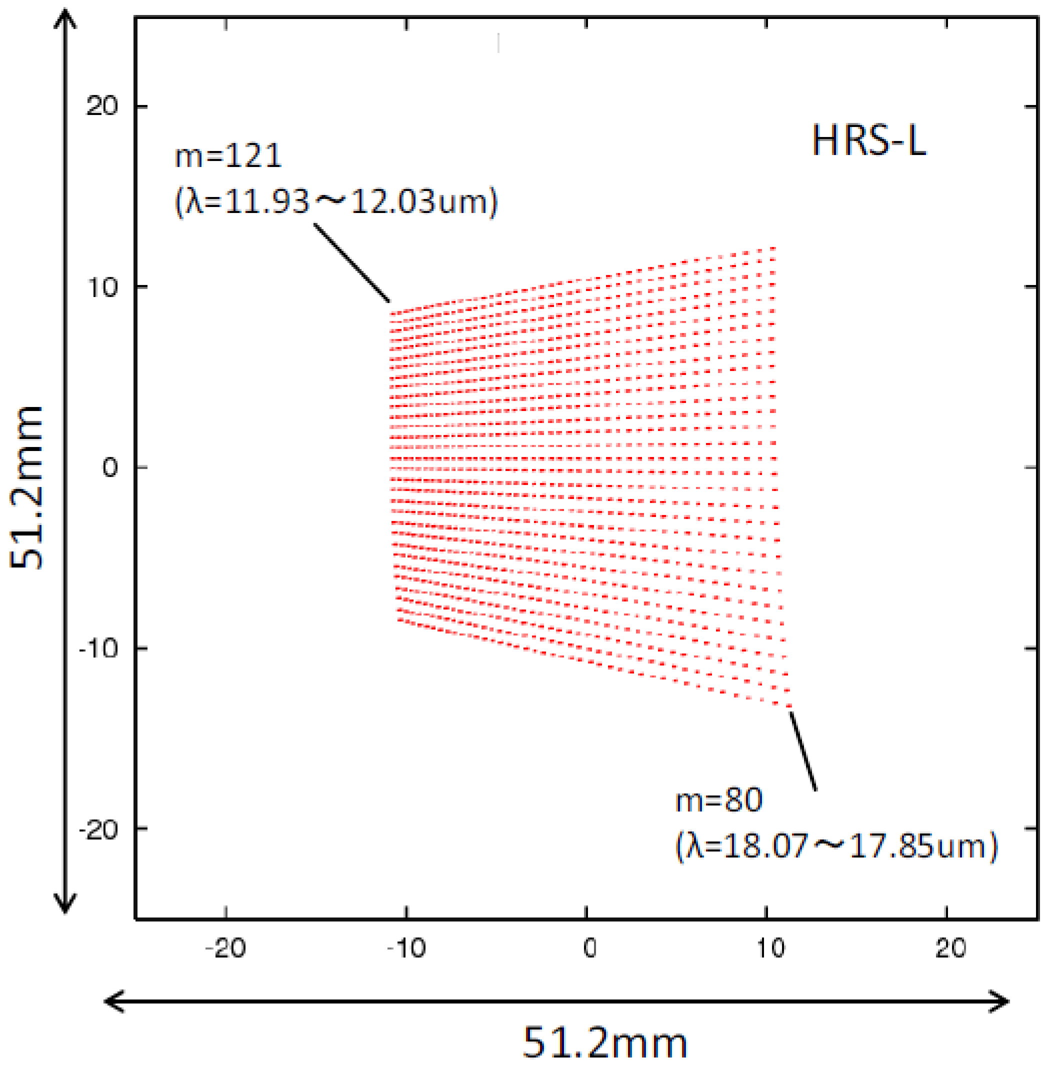
- Specifications of HRS

	HRS-L	HRS-S
Array format	Si:As (2k x 2k)	Si:As (2k x 2k)
Wavelength coverage	12-18 μm	4-8 μm
Spectral resolution (R=λ/Δλ)	20,000-30,000	withdraw
Pixel scale	0.48“/pix	0.288“/pix
Slit length x width	6.0” x 1.2”	3.5” x 0.72”
Main disperser	CdTe or CdZnTe immersion grating	ZnSe immersion grating

- Optical layout






HRS-L
m=121
(λ=11.93～12.03um)
m=80
(λ=18.07～17.85um)
20
10
0
-10
-20
-20
-10
0
10
20
51.2mm
51.2mm

HRS expected performance

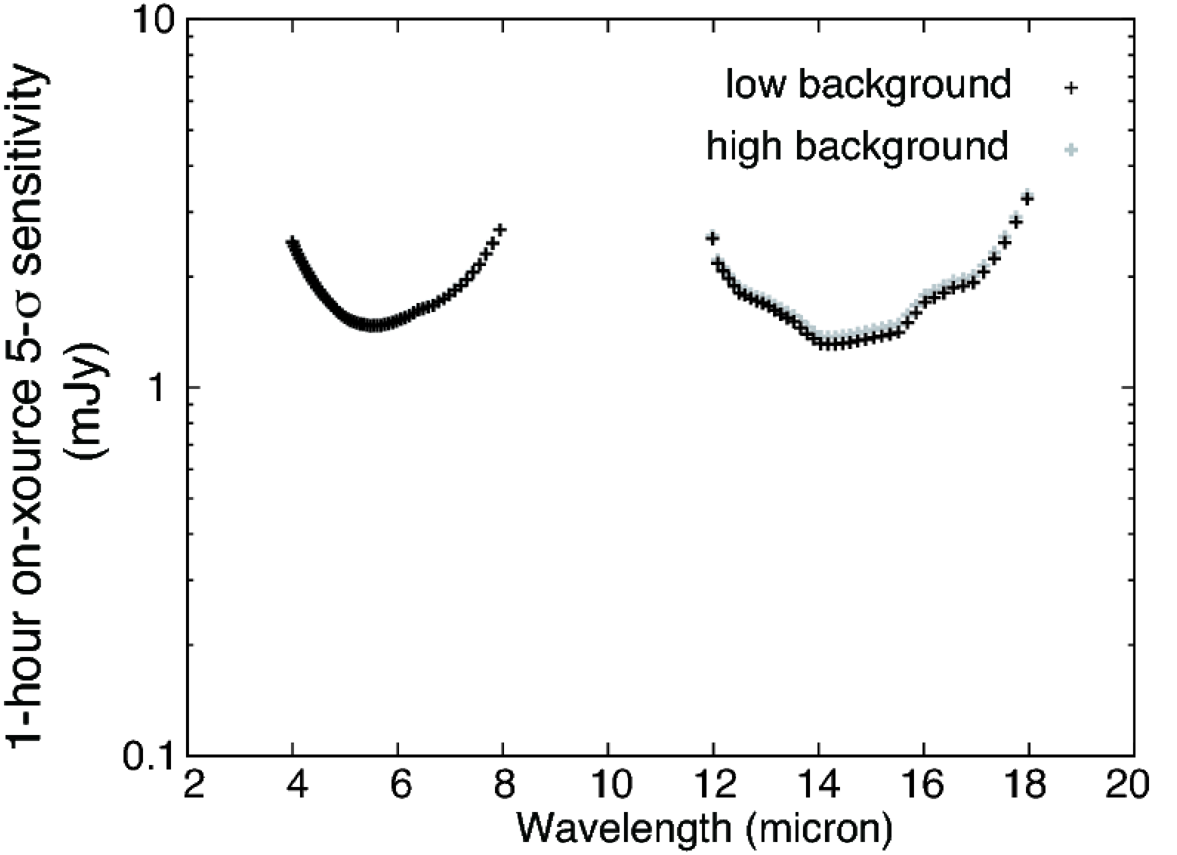
Pixel scale, wavelength band width : value in the optical design

Fowler-16 sampling – Read noise: 5 electron/pix/read-out

Frame integration time: 300s

High Background : BB T=268.5K normalized to 80 MJy/sr at 25μm

Low Background : BB T=274.0K normalized to 15 MJy/sr

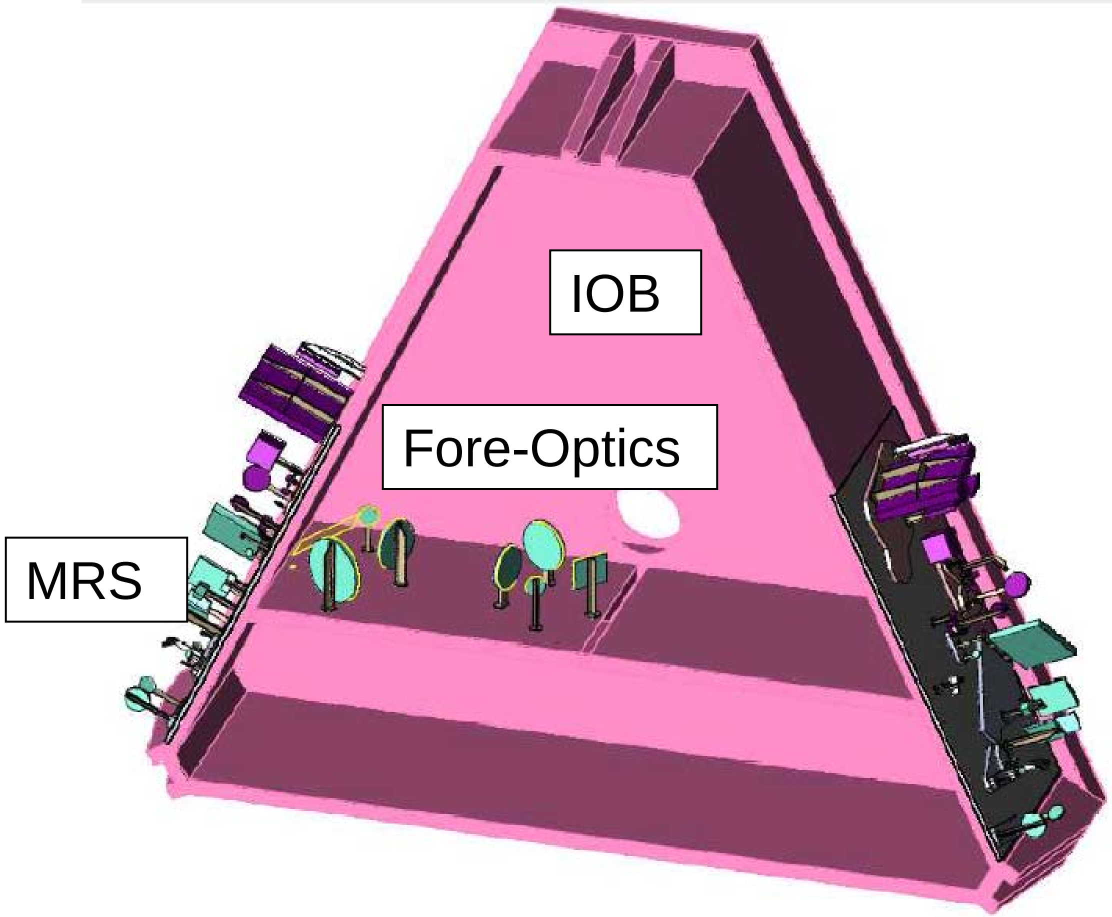


Technical details

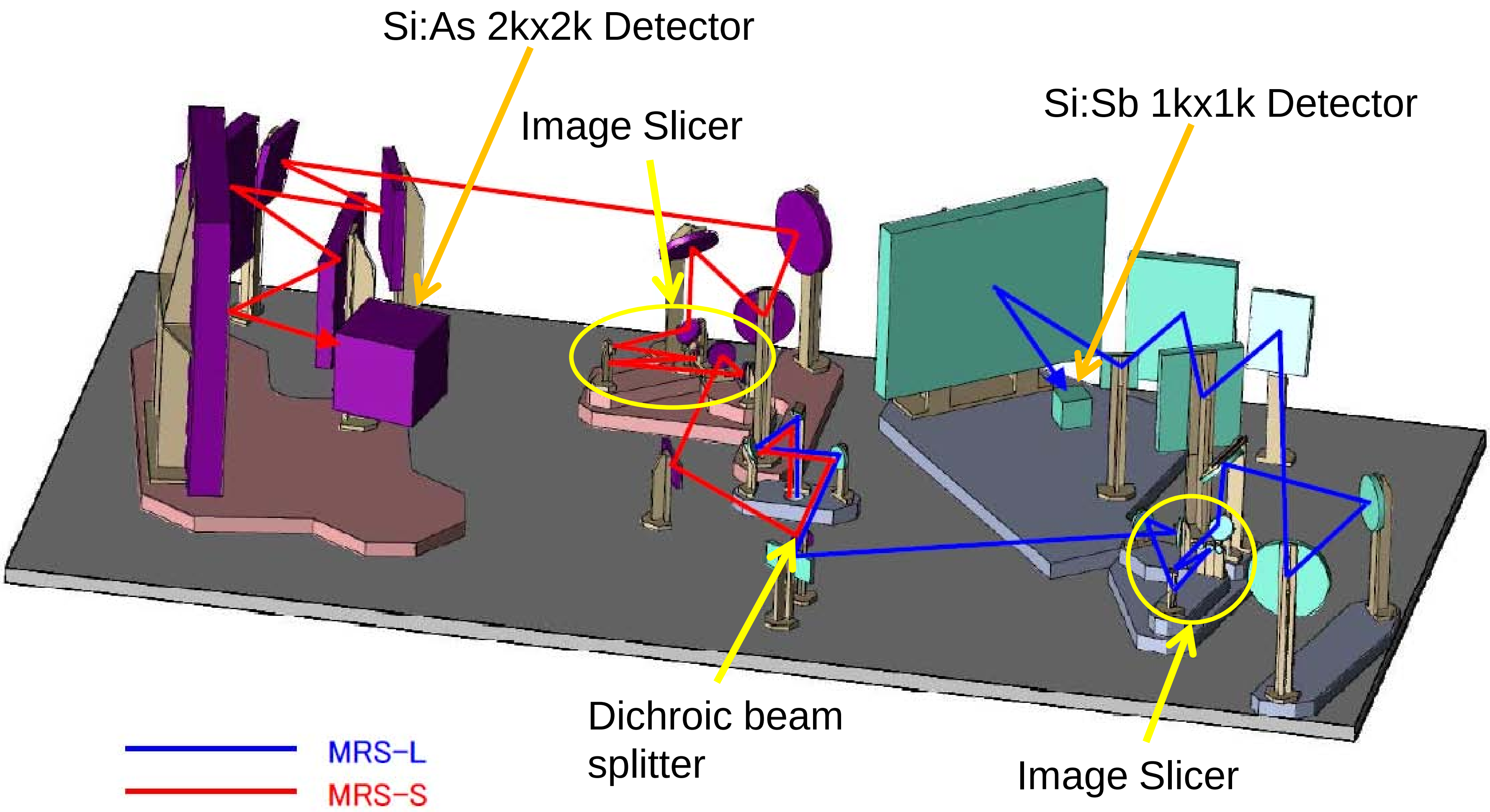
- Structure model
- Attitude stability problem

Structure model

Instrument Optical Bench and Support mount



Structure design of MRS

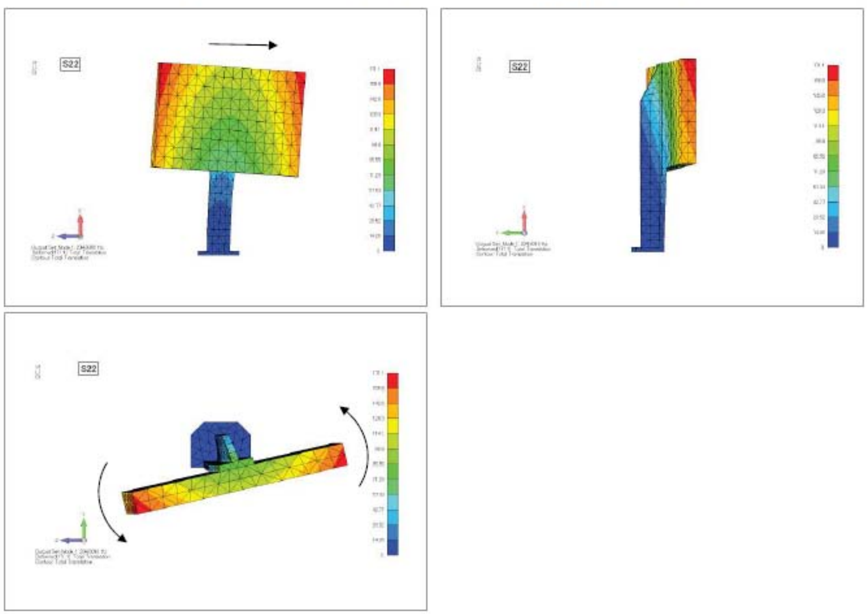


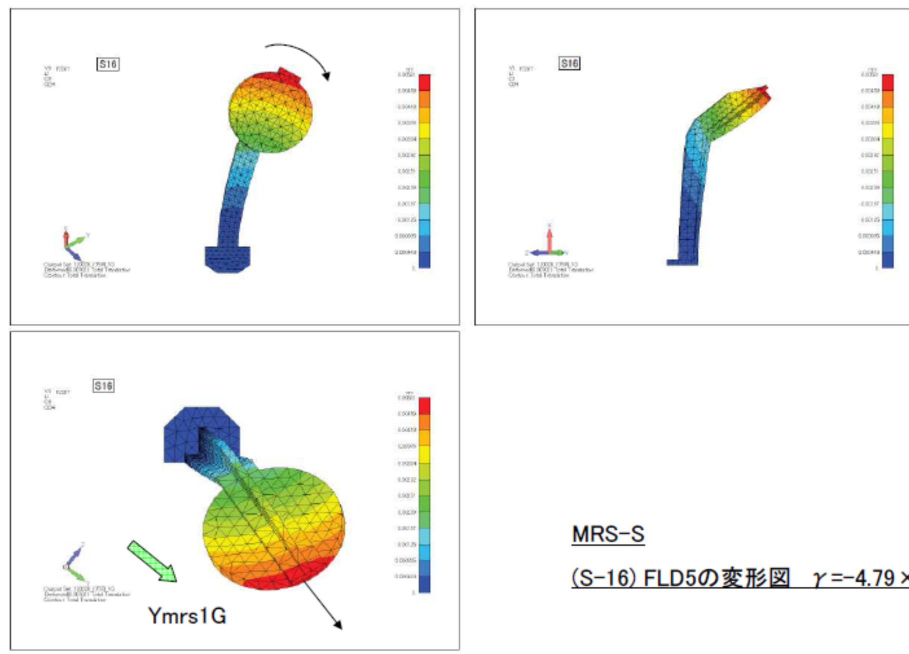
Mirror support

Natural frequency : High enough

Flexure under 1G : correspond few pix.

S-22 Camera Unit2の第2ミラーの一次固有モード(205Hz)





MRS-S

(S-16) FLD5の変形図　$\gamma = -4.79 \times 10^{-3}$deg

SPICA pointing accuracy

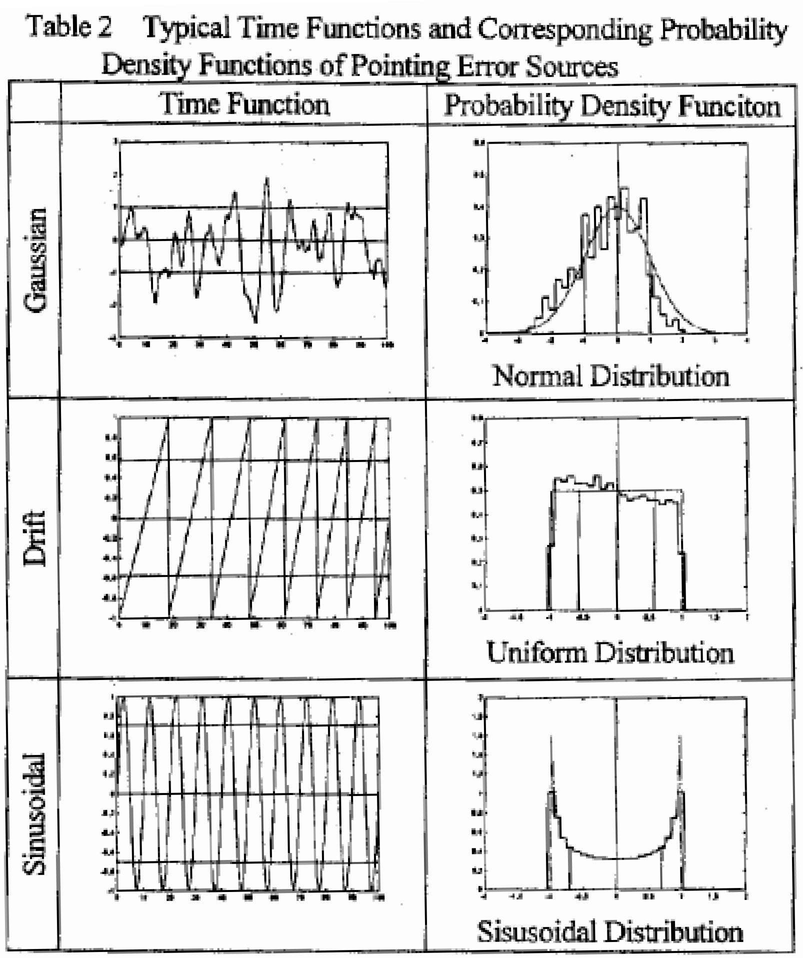


Table 2 Typical Time Functions and Corresponding Probability Density Functions of Pointing Error Sources

	Time Function	Probability Density Funciton
Gaussian		Normal Distribution
Drift		Uniform Distribution
Sinusoidal		Sisusoidal Distribution

At medium frequency (about 0.01 Hz), pointing stability may not good enough.
0.01Hz = 100sec < Exposure time 600sec

around 0.01Hz, 0-p fluctuation may be about 0.5 arcsec

Tip-and-Tilt system for short wavelength channel

0.5arcsec 0-peack pointing fluctuation

Imaging at 10μm :

- Gaussian : SN down to 83%
- Linear sinusoidal : down to 72%
- Circular rotation : down to 62%

Spectroscopy : Most sensitive - HRS-L at 18μm

- Gaussian: down to 97%
- Sinusoidal : down to 88%

Worst case is 70% degradation (2 times obs. time)

In order to recover the image quality at the shortest wavelength, we have decide to use Tip-and-Tilt mirror system in fore-optics.