SPICA Mid-infrared Instrument (SMI)

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SMI: SPICA Mid-infrared Instrument by Japanese Consortium

Three spectroscopic channels:

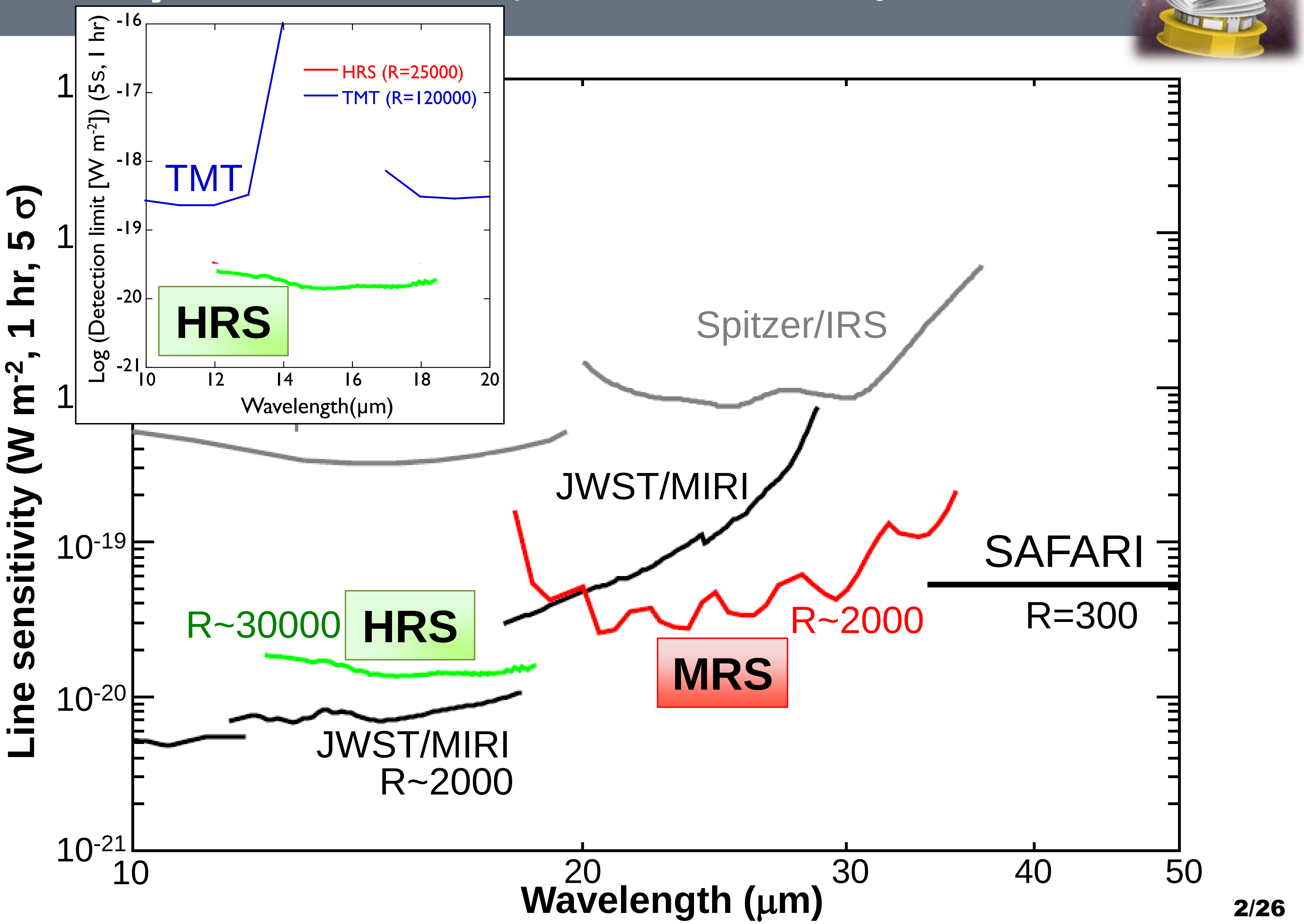
LRS: Multi-long-slit prism + Si:Sb w/ slit viewer
17 – 36 μm, R = 50 – 120, slit:10' long, 4 slits

MRS: Grating + Si:Sb w/ beam-steering mirror
18 – 36 μm, R = 1200 – 2300, slit: 1' long

HRS: Immersion grating + Si:As
12 – 18 μm, R = 28,000, slit: 4" long

AKARI Mid-IR all-sky map

Why we need SMI, besides JWST/MIRI ?

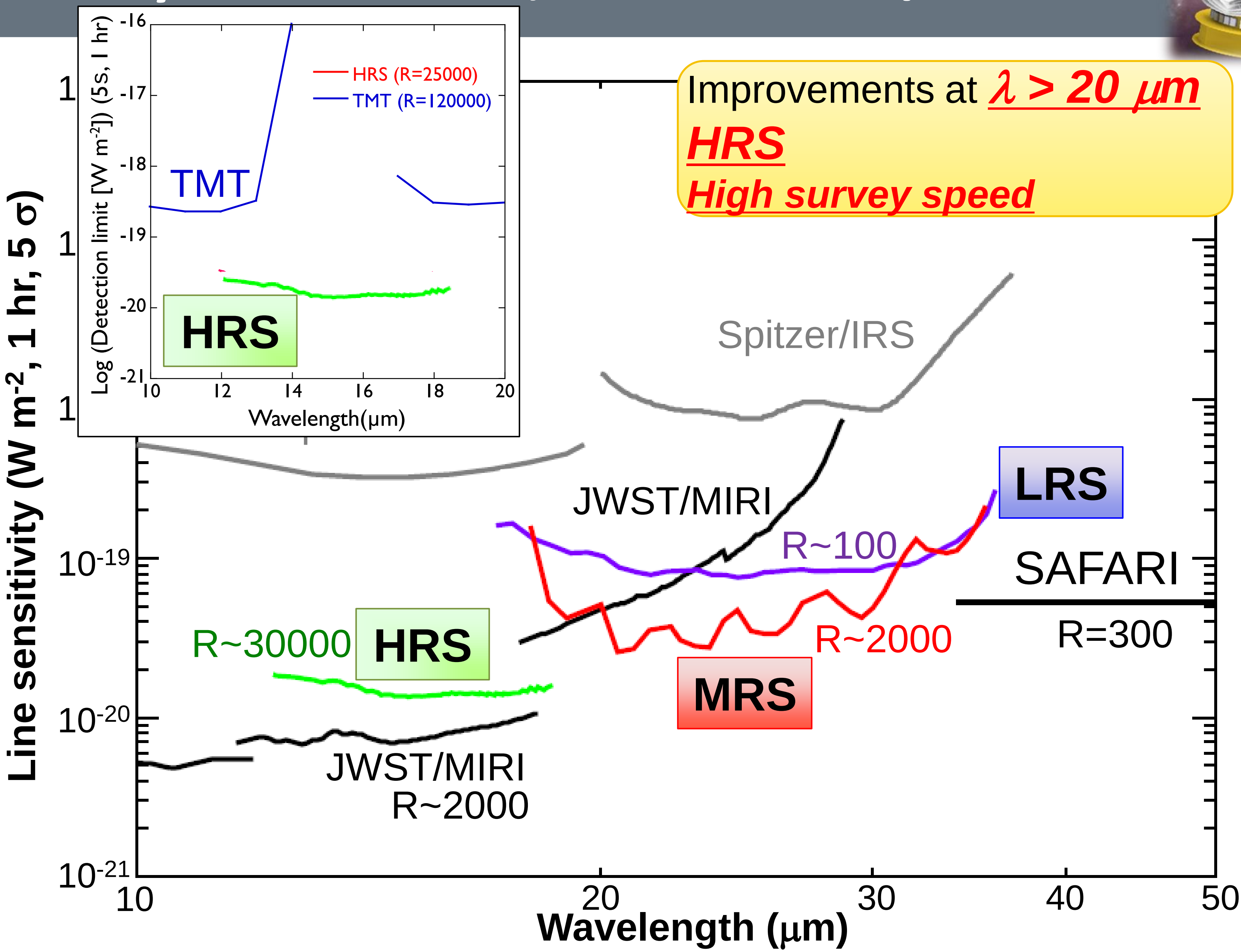


Why we need SMI, besides JWST/MIRI ?

Improvements at ***λ > 20 μm***

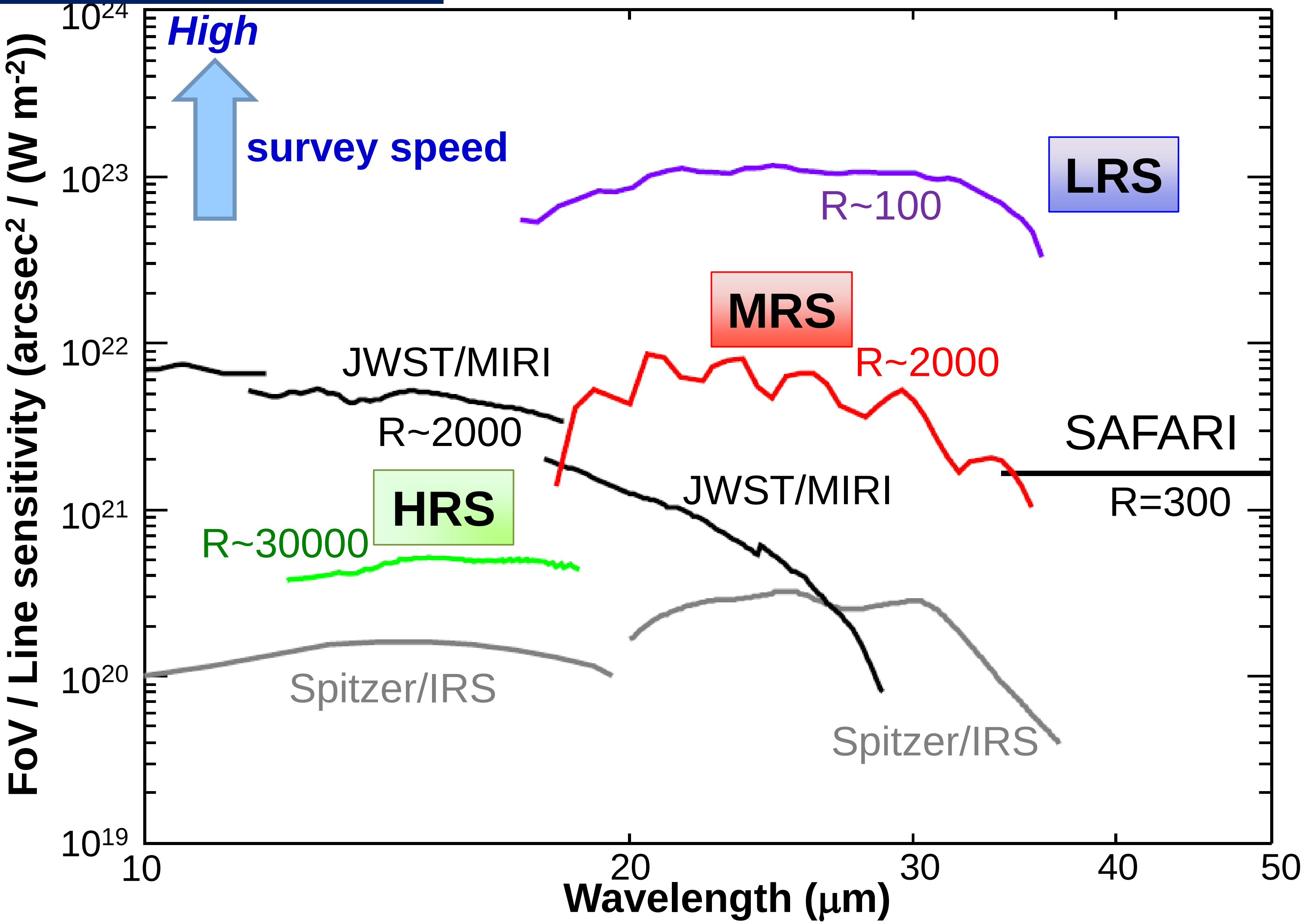
HRS

High survey speed

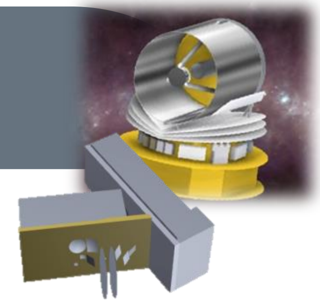


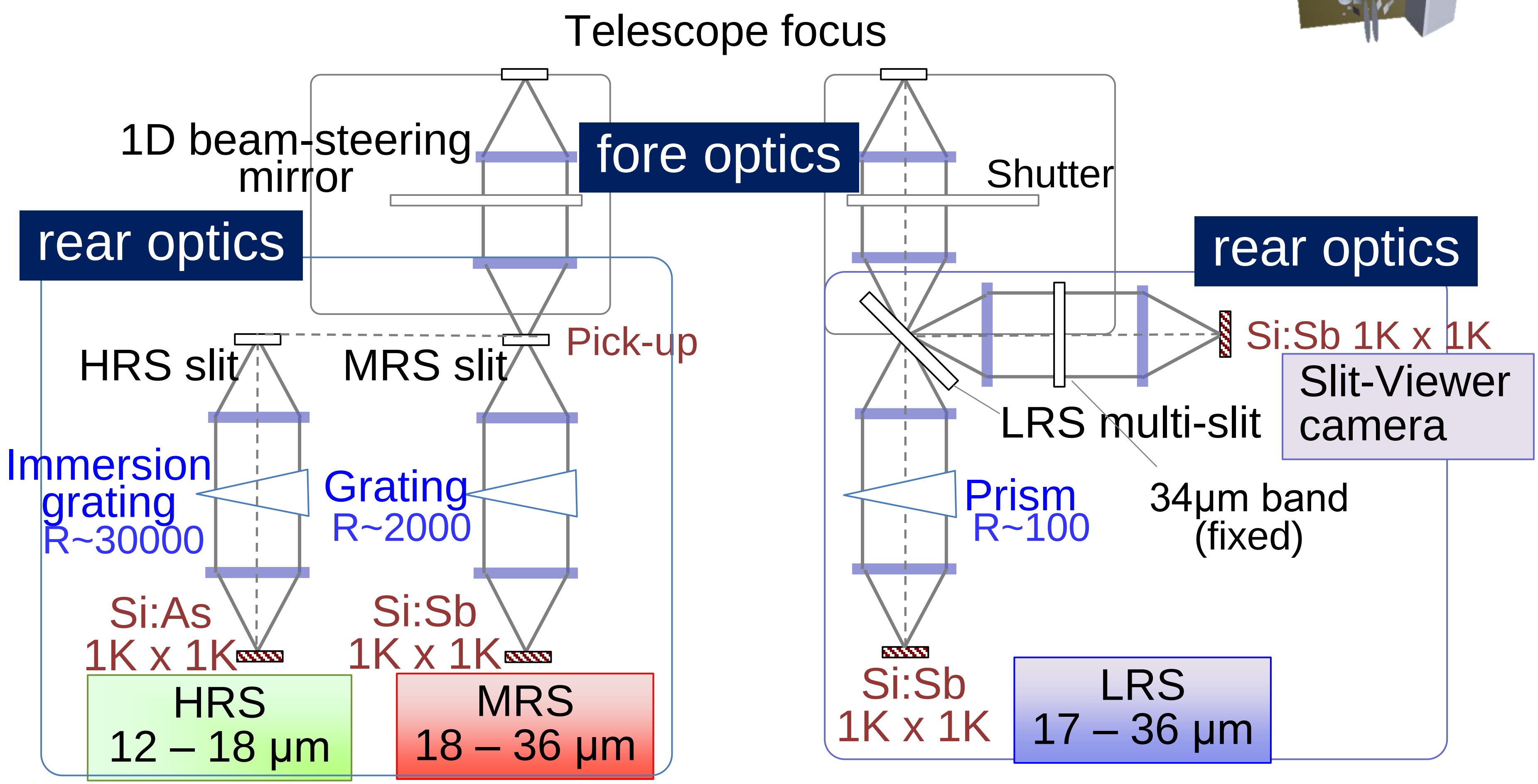
Why we need SMI, besides JWST/MIRI ?

FoV / (Line sensitivity)



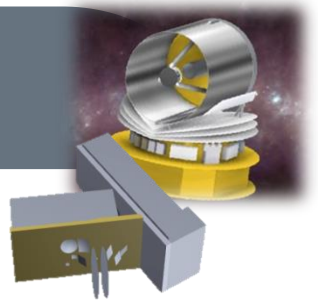
SMI block diagram





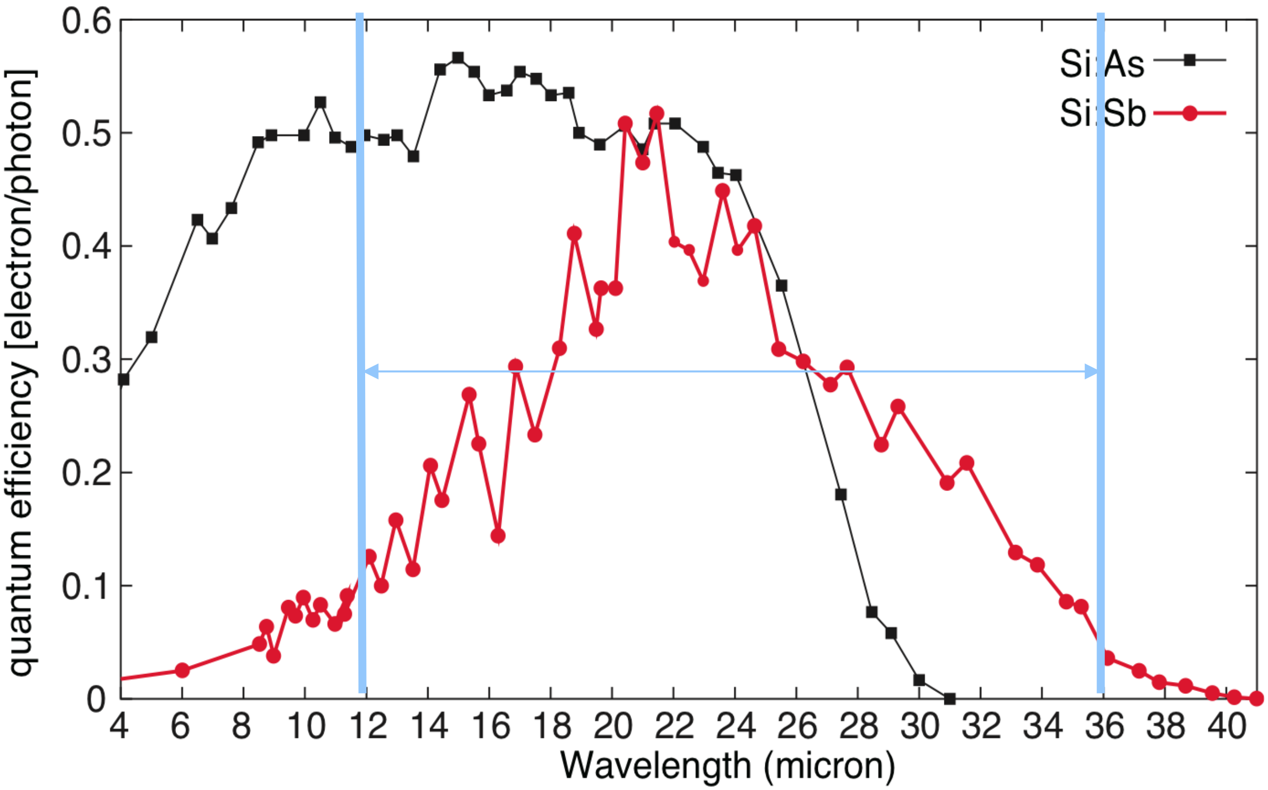
No moving parts except for a beam-steering mirror and shutter.

SMI: Detectors



Si:Sb: 1K x 1K, 2 arrays for LRS, 1 array for MRS

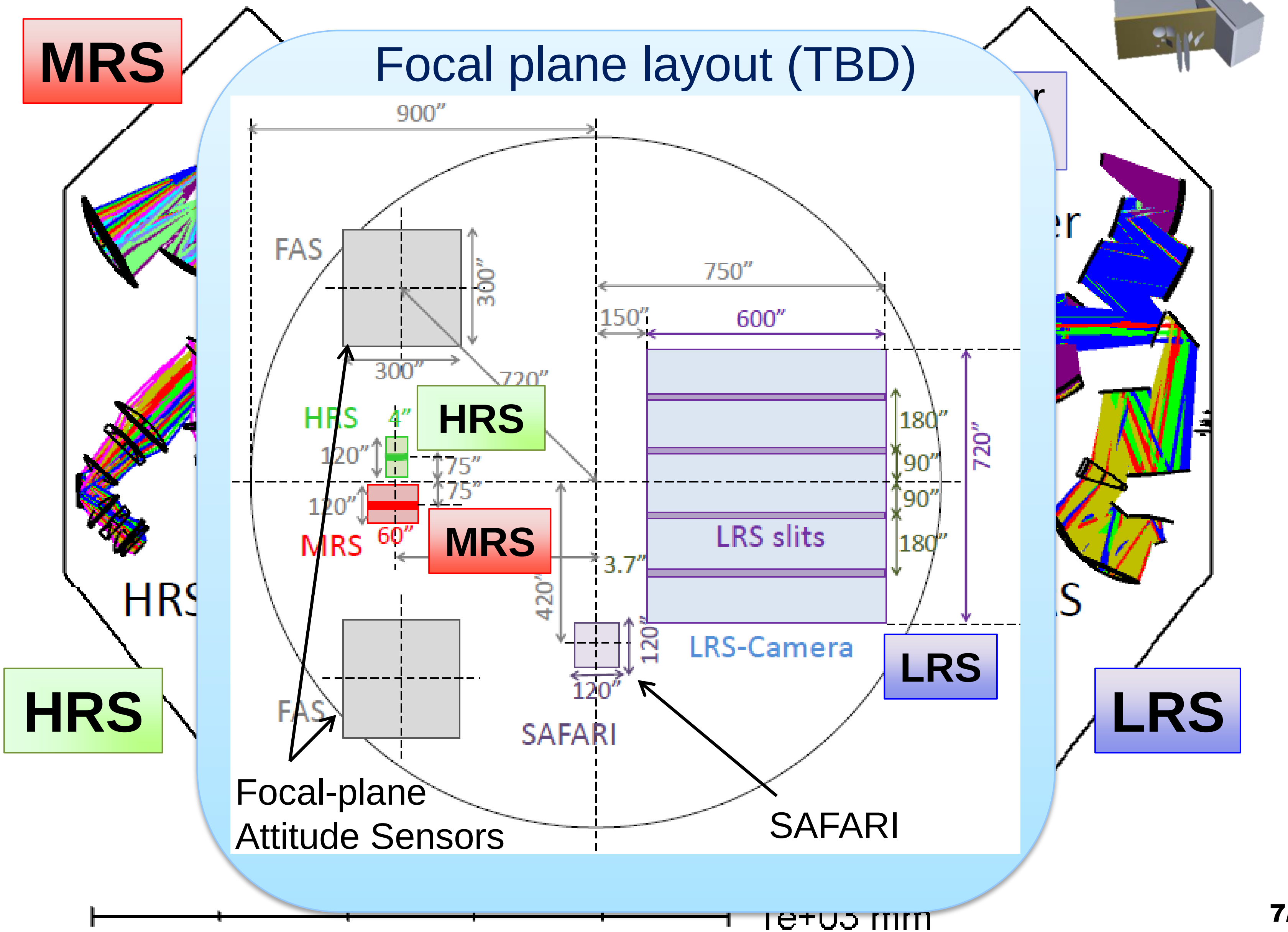
Si:As: 1K x 1K, 1 array for HRS



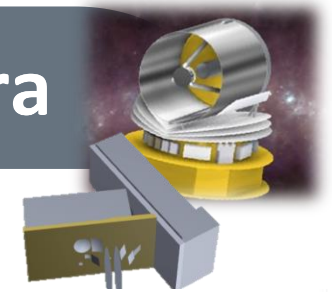
Si:Sb array: Spitzer/IRS 128 x 128, low QE at > 34 μm

SMI 1024 x 1024, improved QE (planned)

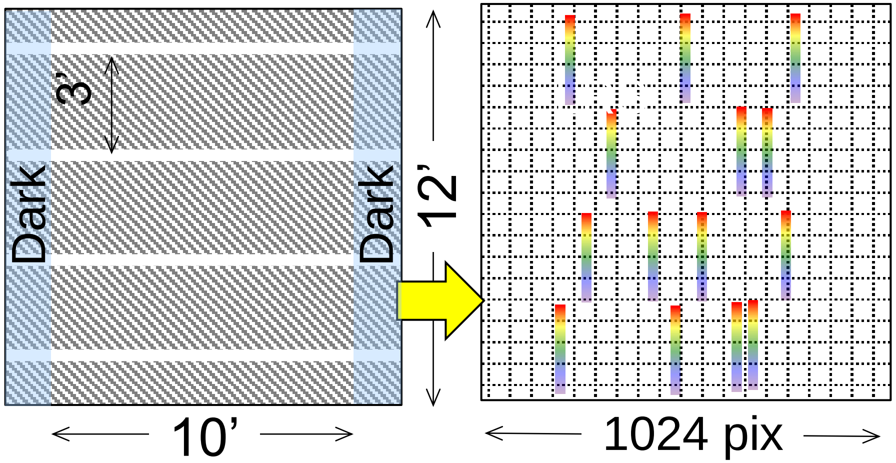
SMI: Optical layout

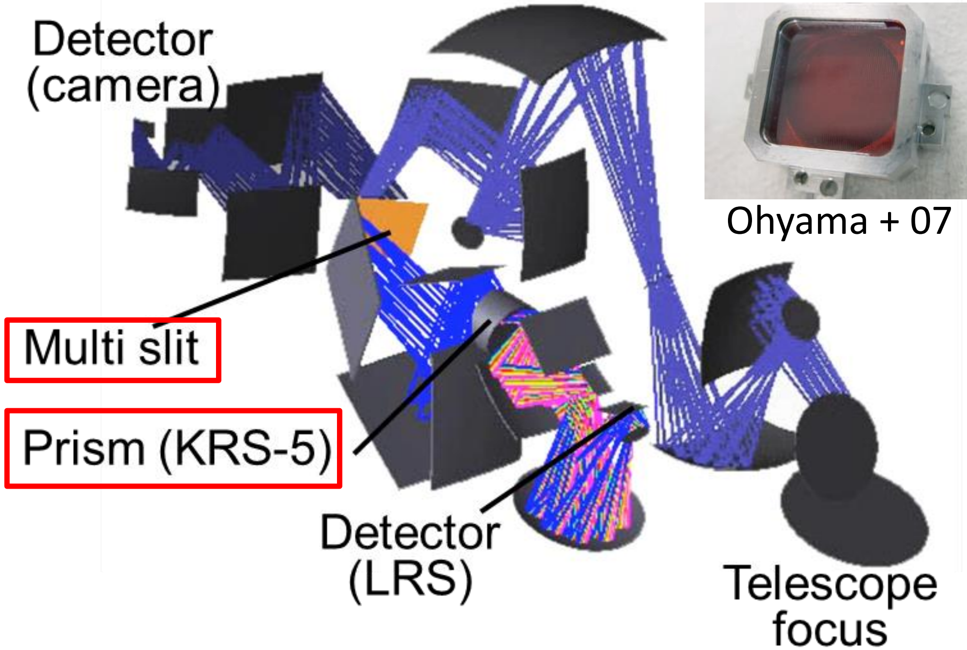


(1) Low-resolution spectrometer and camera



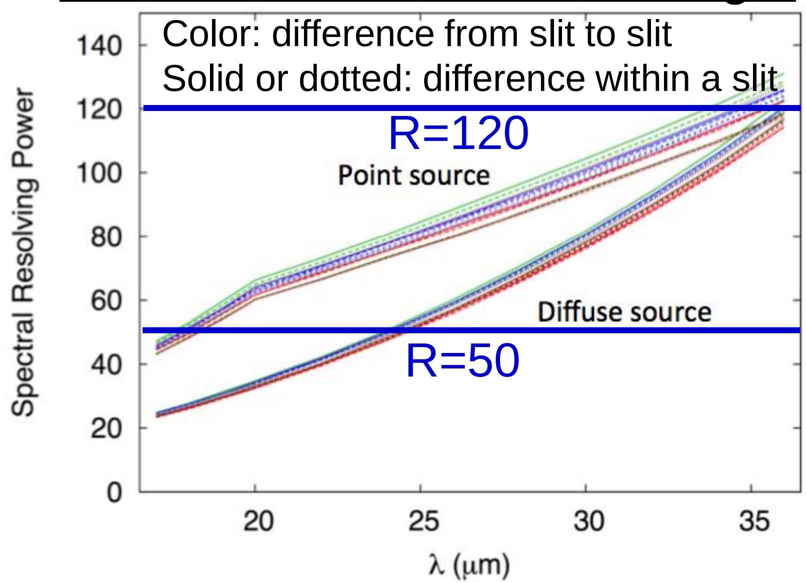
multi-slit format (4 long slits) **LRS** Detector: **Si:Sb**, 1K x 1K





Ohyama + 07

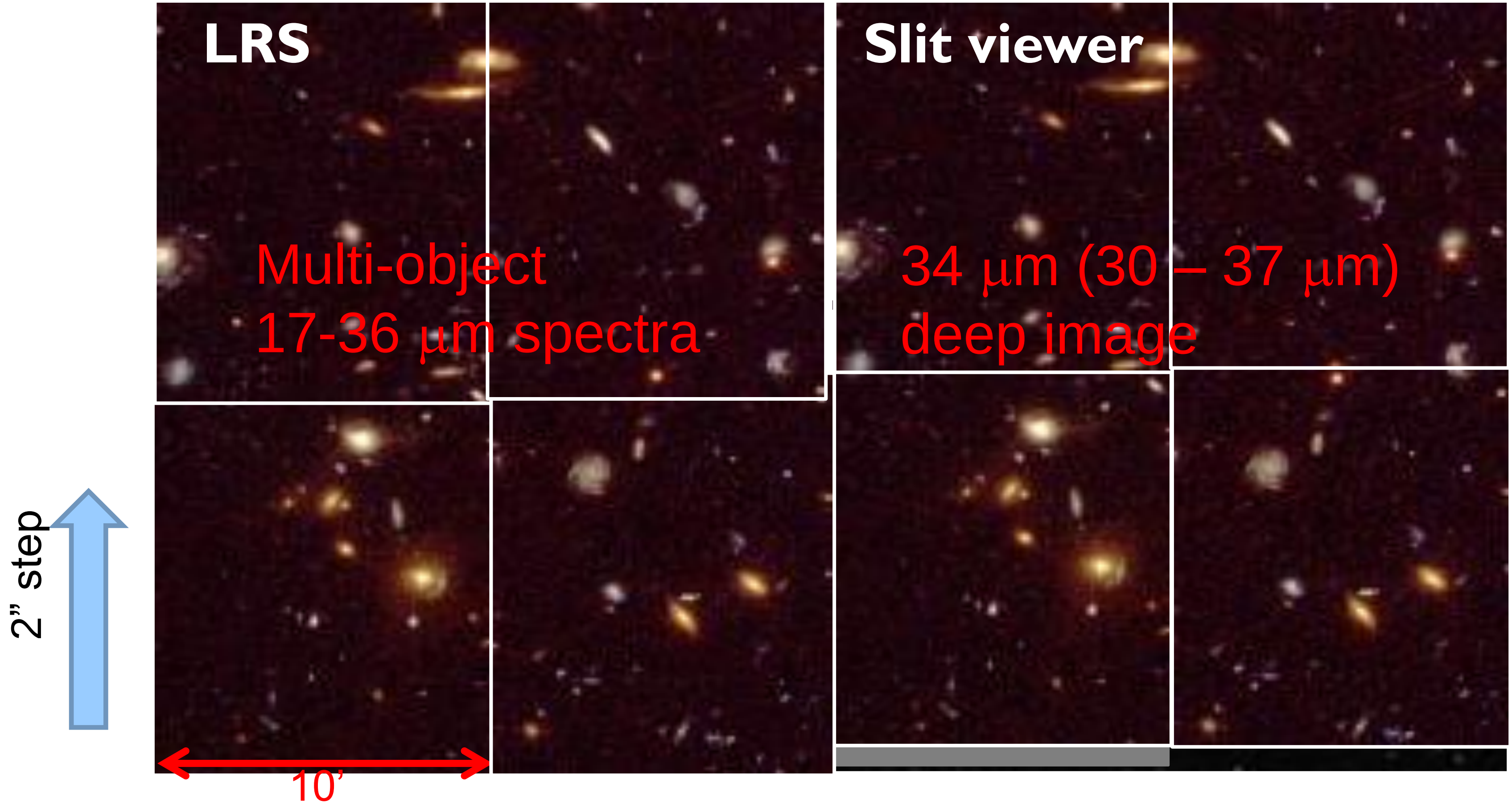
λ/Δλ as a function of wavelength



- Wide FoV (4 slits, slit length 10')
- high continuum sensitivity
  ~30 μJy (1hr, 5σ)
- 0.7"/pixel
- R = 50–120 spectral mapping
- 10'x10' slit viewer (34 μm, R = 5)
  sensitivity: ~10 μJy (1hr, 5σ)

17-36 μm spectroscopy & 34 μm imaging

Spatial scan with 90 steps (1 step length ~ 2" ~ 0.5 x slit width) produces a spectral map and a broad-band image of 10' x 12' area, ***simultaneously***.



30 – 40 μm: unexplored region between Spitzer 24 μm and Herschel 70 μm surveys.
SMI-LRS provides spectroscopic & photometric survey datasets at ~30 – 40 μm.

Cosmological survey with LRS

~2 hrs / field x 300 fields
1 field = 10’x12’
→ 10 deg^2 in ~600 hrs

SPICA/SMI-LRS

R = 50 – 120

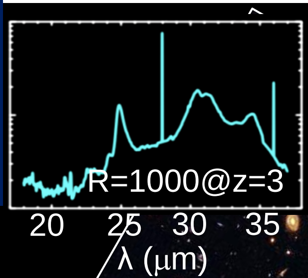
Multi slit
slit size: 10’x3.7”

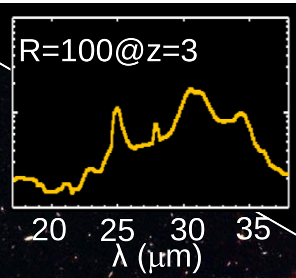
PAH galaxies at z > 1 (at z = 2 - 4)
43,000 spectra (14,000)

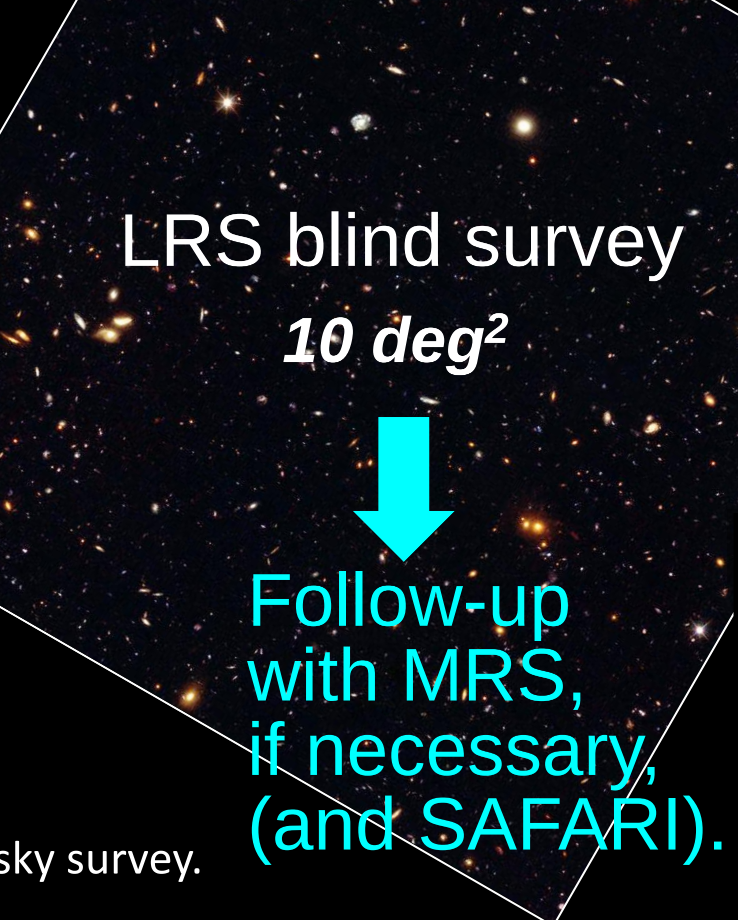
AGNs at z > 1
102,000 at 34 μm with slit viewer

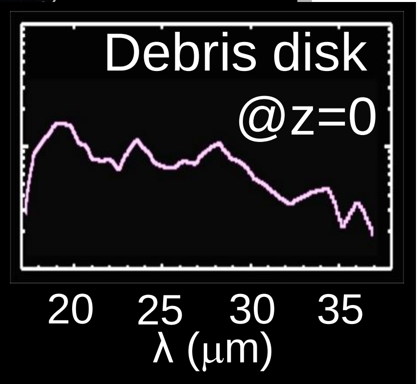
MS stars (F, G, K) (debris disks)
11,000 spectra (~1000 for >900 zodi.)

Based on AKARI mid-IR all-sky survey.





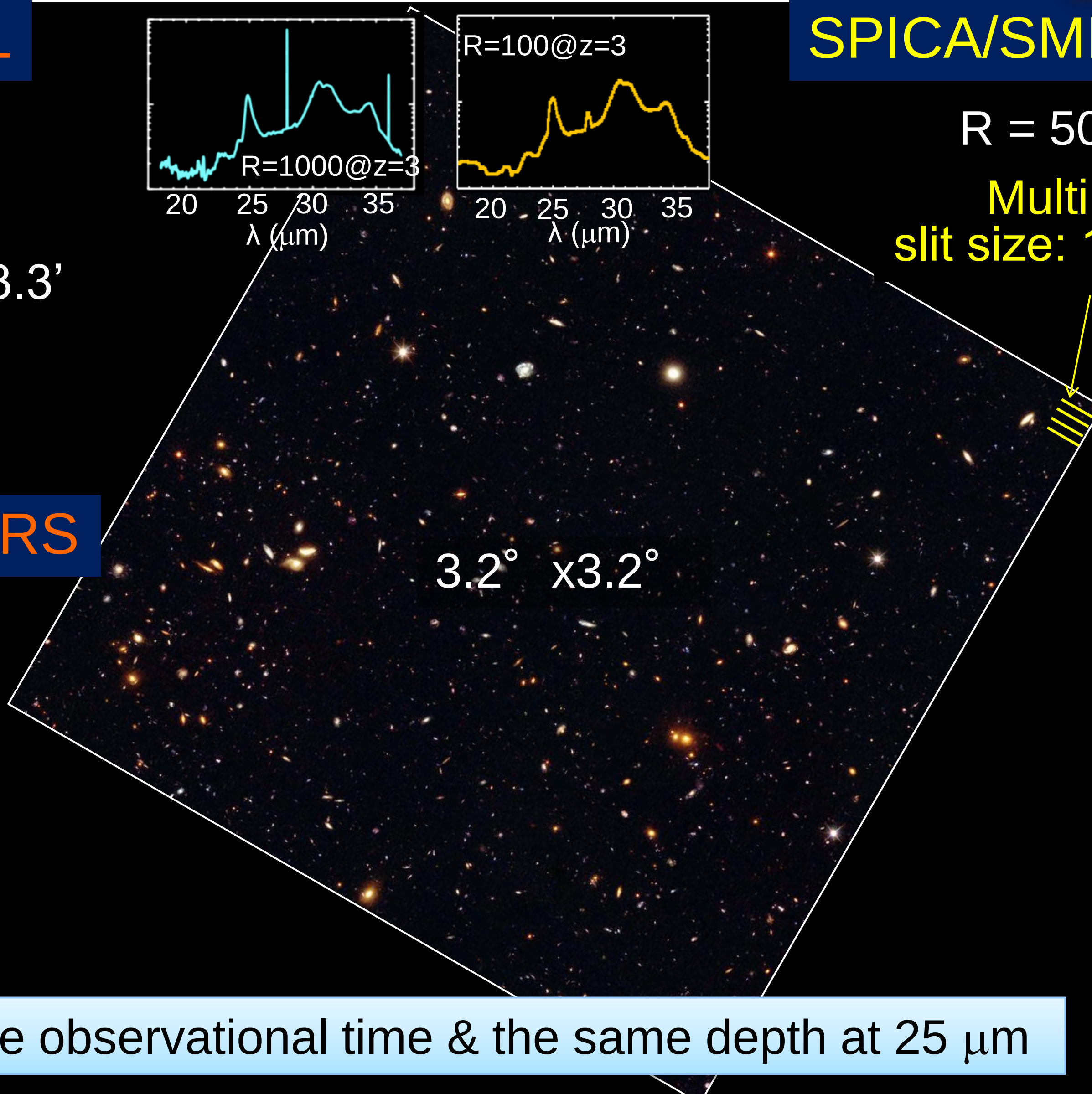




Comparison of spectral mapping efficiency at 25 μm

Spitzer / IRS-LL
R = 60 – 120
slit size: 168”x11”
3.3’x3.3’

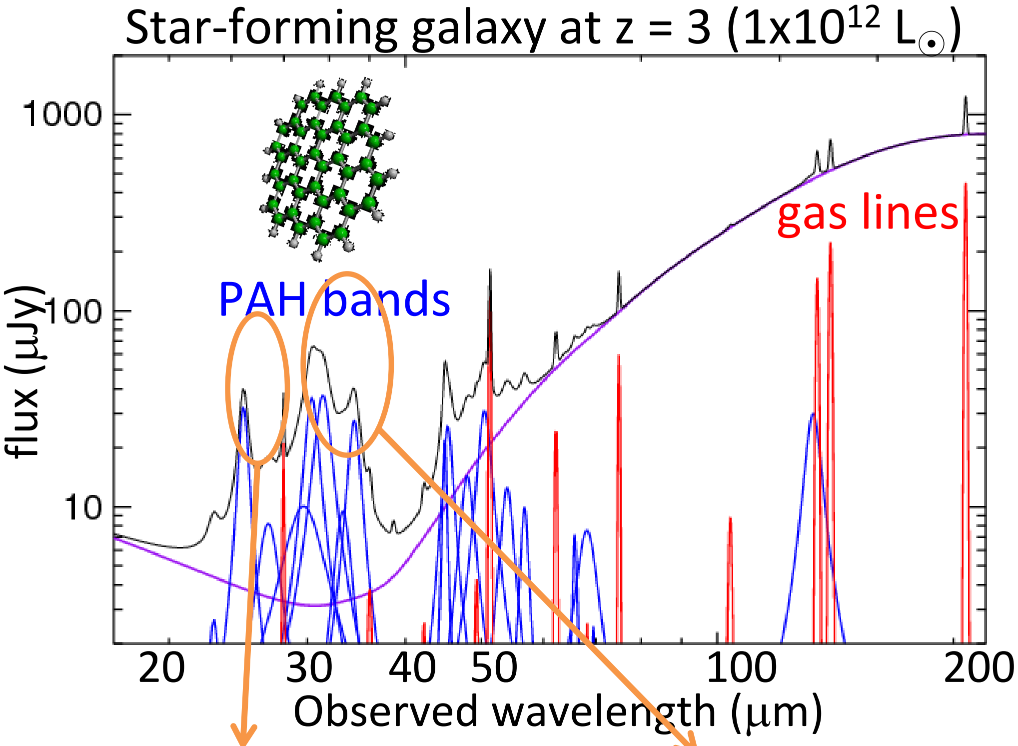
SPICA/SMI-LRS
R = 50 – 120
Multi slit
slit size: 10’x3.7”

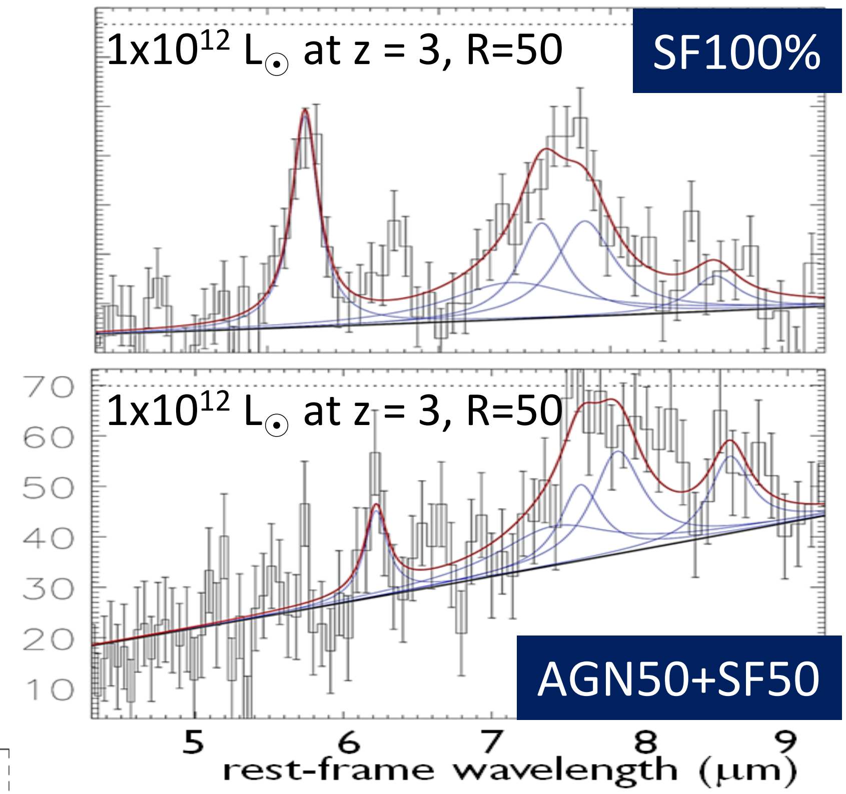


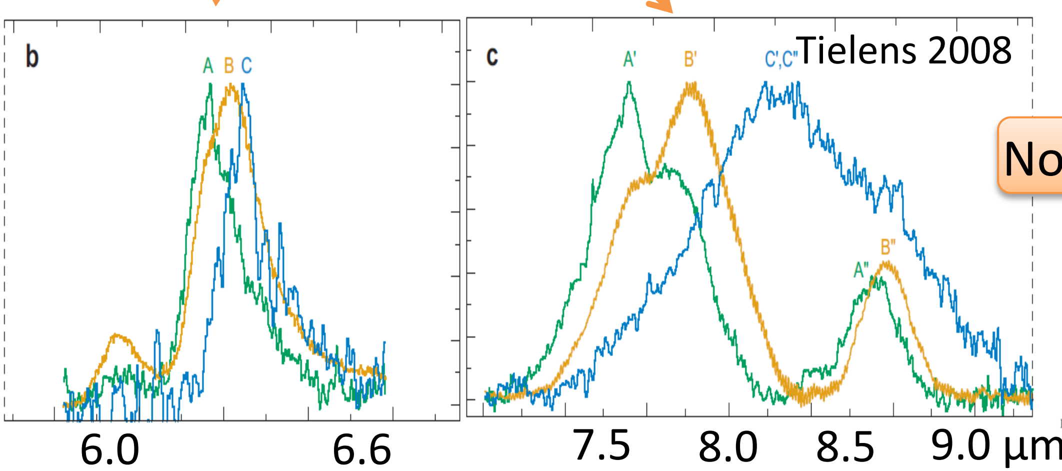
JWST / MIRI-MRS
R = 2000
slit size: 7.7”x7.7”
2’x2’

For the same observational time & the same depth at 25 μm

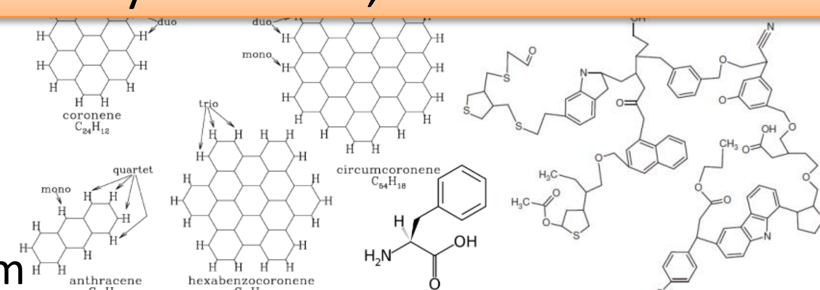
PAH band diagnostics for distant galaxies





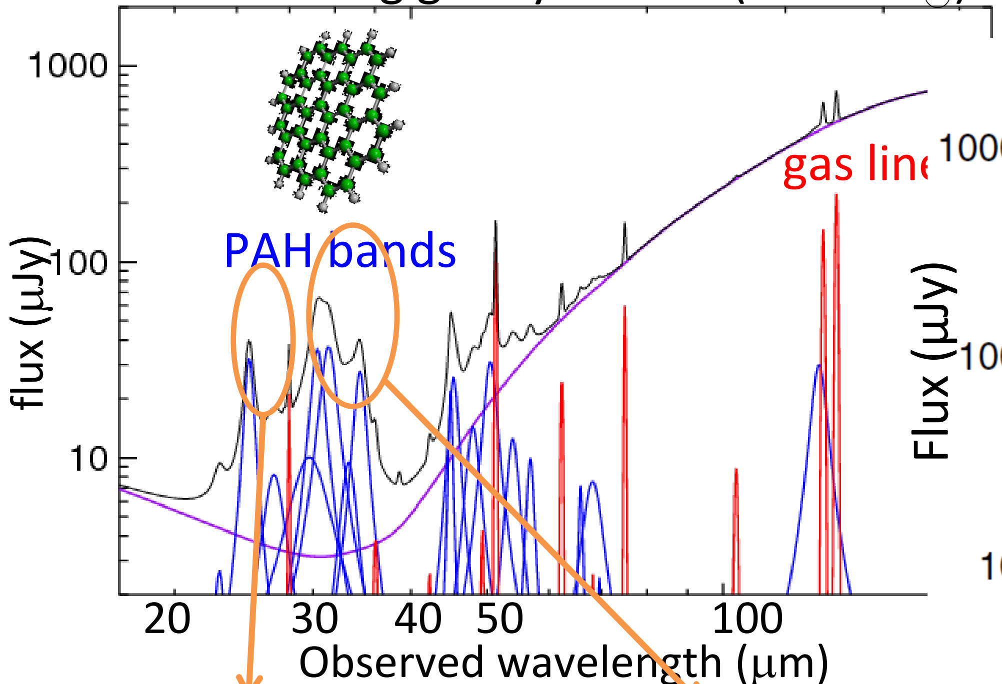


Not only detection, but characterization

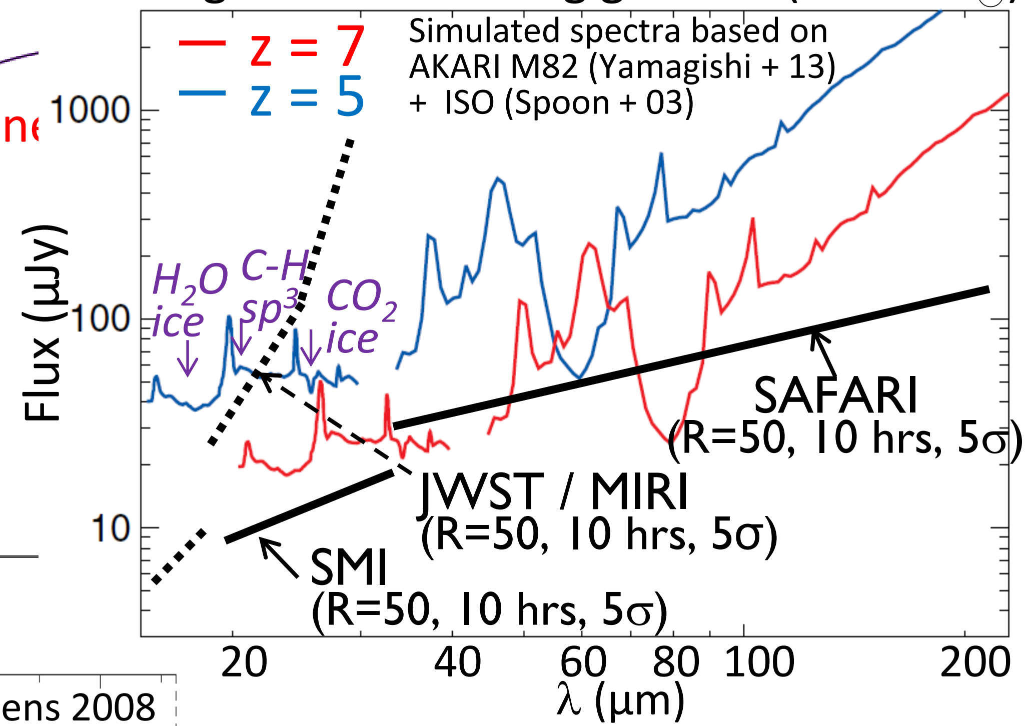


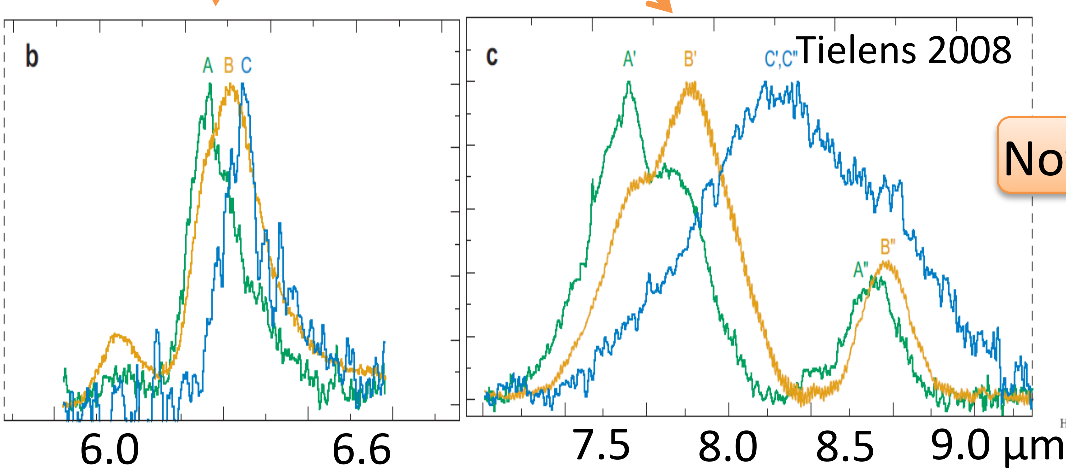
Organic matter & ice in the early Universe

Star-forming galaxy at z = 3 ($1x10^{12}$ $L_\odot$)

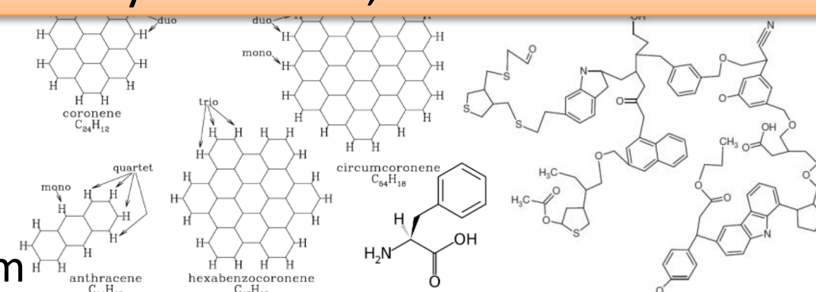


High-z star-forming galaxies ($2x10^{13}$ $L_\odot$)



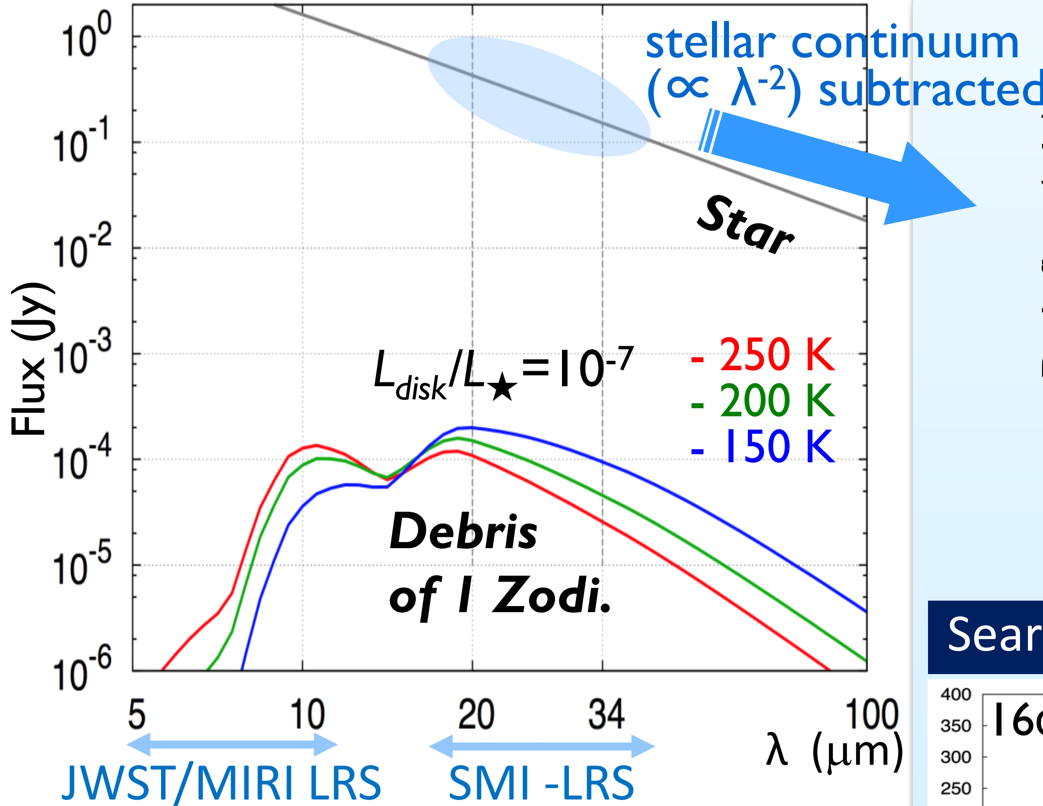


Not only detection, but characterization



Faint debris disks, vital debris disks

G2V at 10 pc; 6,000 K → 400 mJy at 20 μm

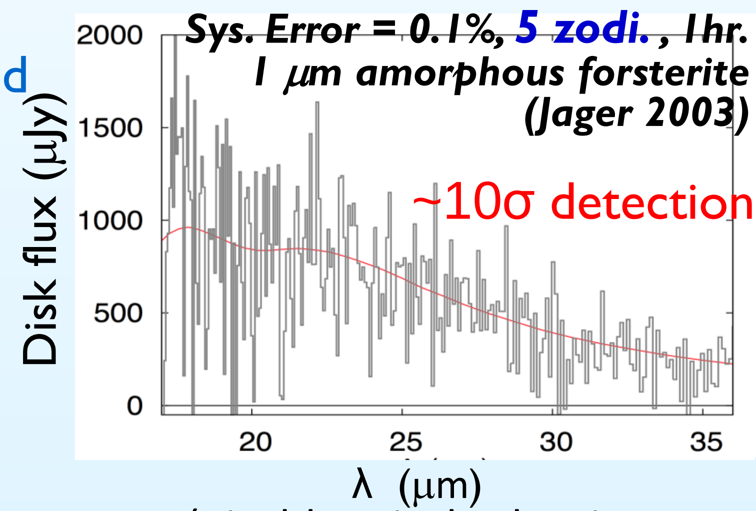


◆ For 200 K disks:

$F_{disk}/F_{\bigstar}$ at 20 μm = ~6 x $F_{disk}/F_{\bigstar}$ at 10 μm

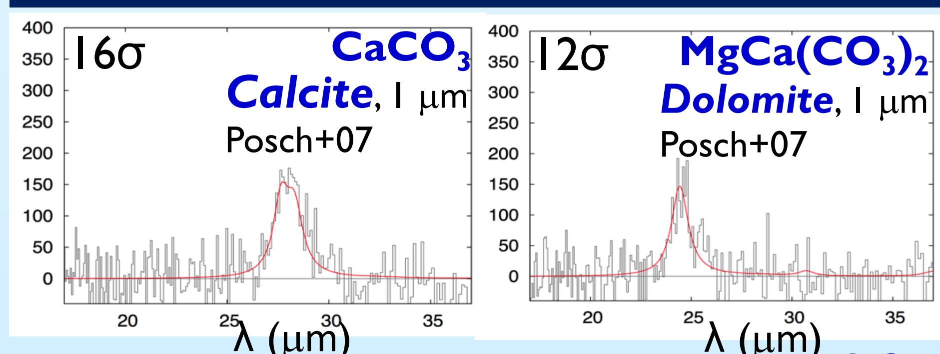
~36 times more photons needed at 10 μm.
(SPICA's advantage over JWST)

Challenges to Zodi analogs



(pixel-by-pixel cal. using our Zodi.)

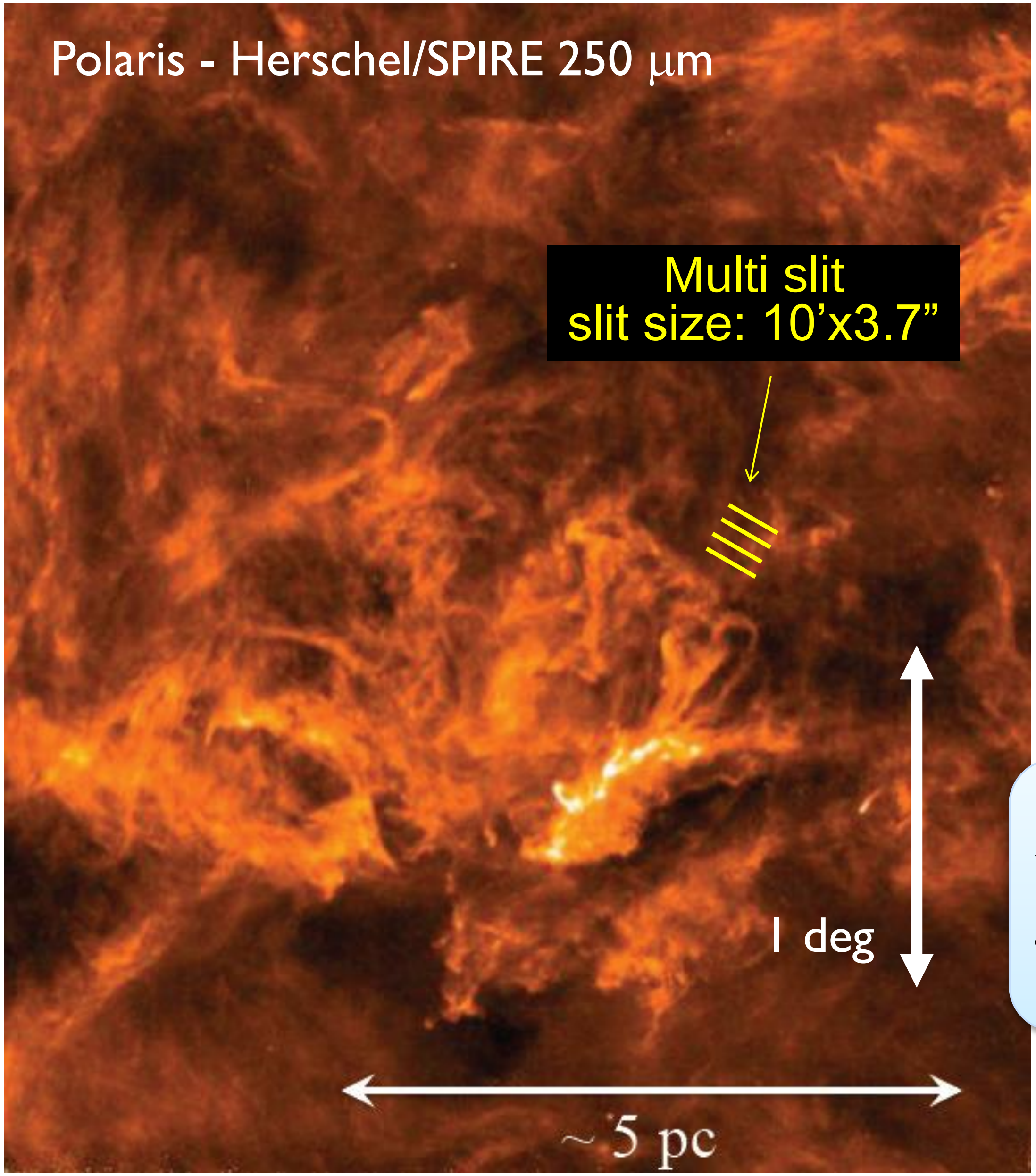
Search for vital minerals in a large sample

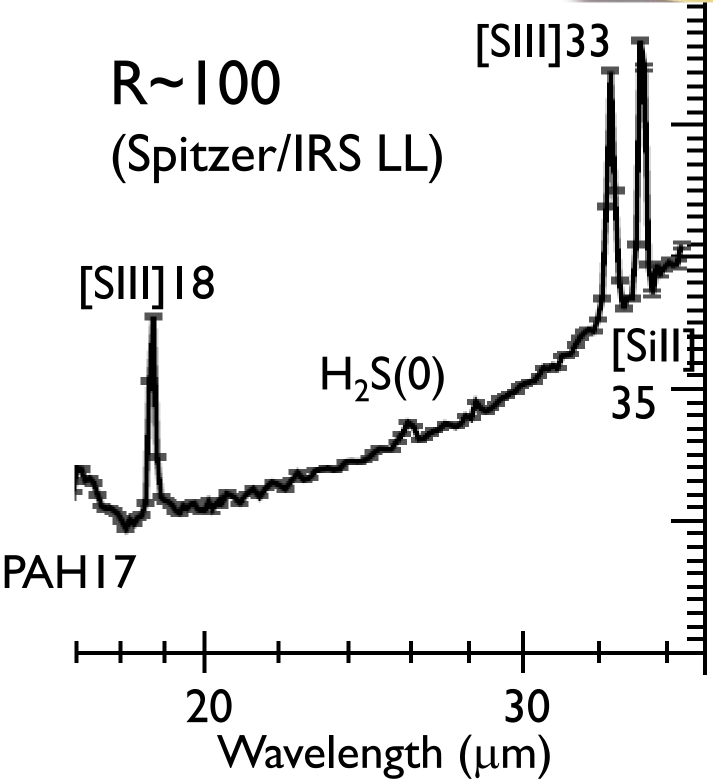


Low-T, link to water, atmosphere and ***life***.

e.g., Halevy et al. 2011

Spectral diagnosis of Galactic filaments

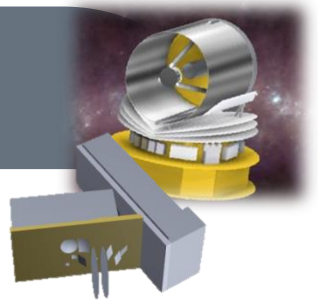




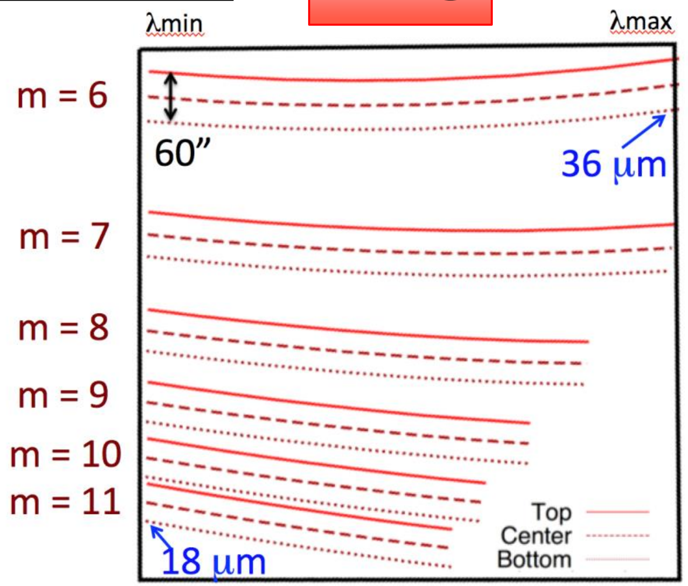
Fast spectral mapping of large areas with the tracers of PDRs, ionized gases, shocks. (thanks to pointing reconstruction with the slit viewer).

Miville-Deschenes + 10, Ward-Thompson + 10, Men'shchikov + 10, Andre + 10

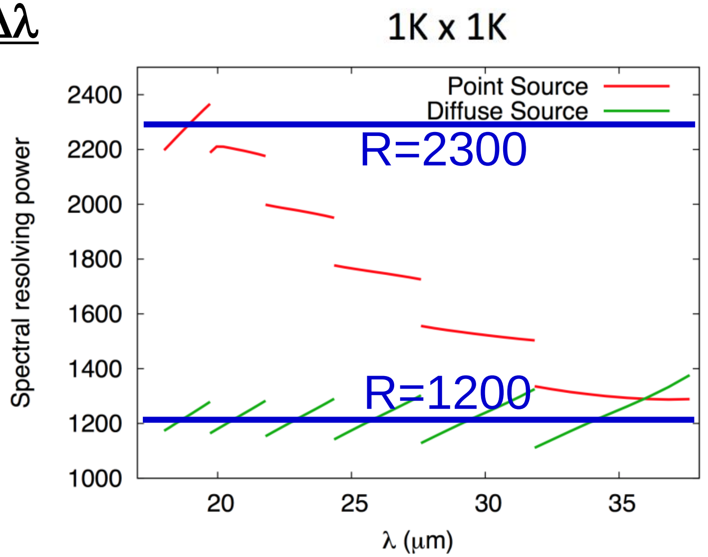
(2) Mid-resolution spectrometer



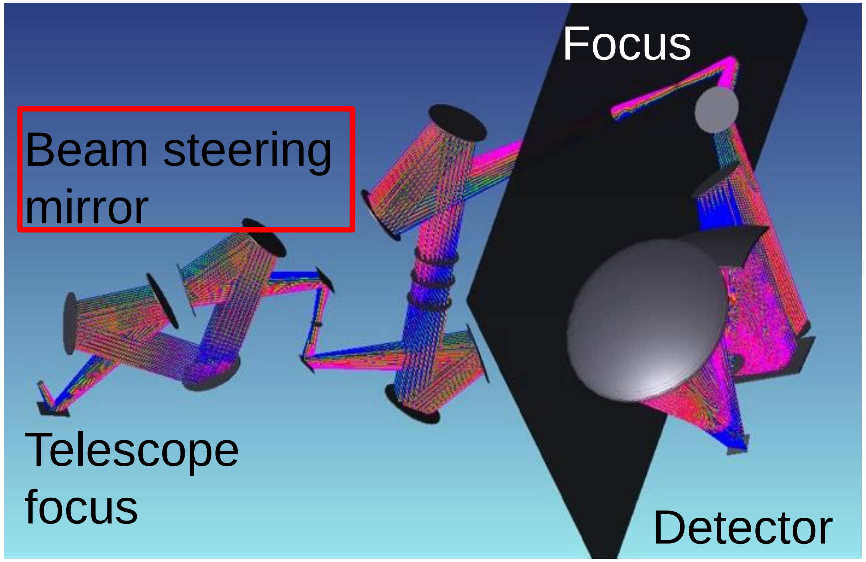
Echelle format **MRS**



λ/Δλ



Detector: 1 **Si:Sb**, 1K x 1K

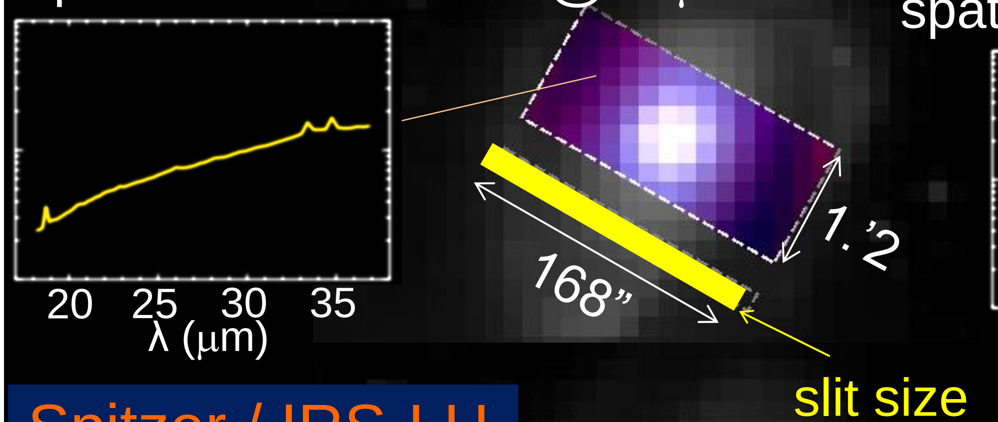


- wide FoV (slit length 60” + beam steering mirror)
- high line sensitivity ~4 x10^{-20} W/m^2 (1 hr, 5σ)
- good spectral resolution R = 1200 – 2300
- spectral mapping

Comparison of spectral mapping efficiency at 35 μm

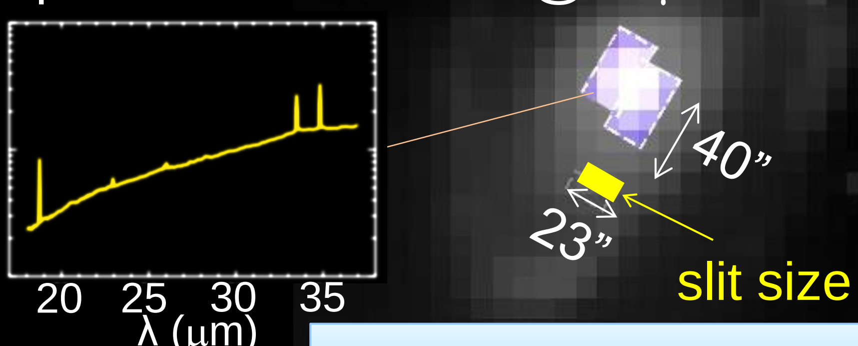
Spitzer / IRS-LL

slit size : 168” x 11”, R = 60 – 120
spatial resolution: 11” @35 μm



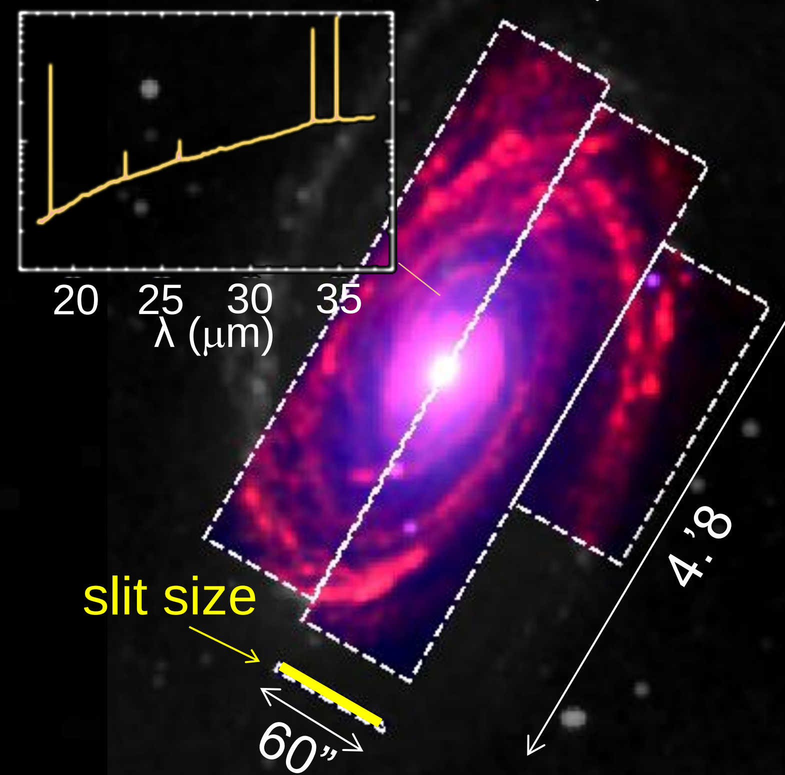
Spitzer / IRS-LH

slit size : 22” x 11”, R = 600
spatial resolution: 11” @35 μm



SPICA / SMI-MRS

slit size: 60” x 3.7”, R = 1200 – 2300
spatial resolution: 3.7” @35 μm



For the same observational time & the same depth at 35 μm

Major gas lines and dust bands for SMI & SAFARI

Atomic gas line	indicator	purpose
[NeII] 12.8 μm, [NeIII] 15.6 μm	SF	ionization temperature
[SIII] 18.7 μm	SF	n_e~10^4 cm^{-3}
[ArIII] 21.8 μm	SF	n_e~10^5 cm^{-3} (w JWST)
[FeIII] 22.9 μm	J-shock	temperature
[NeV] 24.3 μm	AGN	
[OIV] 25.9 μm	AGN	
[FeII] 26.0 μm	J-shock	
[SIII] 33.5 μm	SF	n_e~10^4 cm^{-3}
[SiII] 34.8 μm	J-shock/PDR	
[NeIII] 36.0 μm	SF	n_e~10^5 cm^{-3} (w JWST)
[OIII] 51.8 μm	SF	n_e~10^3 cm^{-3} metallicity
[NIII] 57.3 μm	SF	metallicity
[OI] 63.2 μm	PDR/C-shock	n_H
[OIII] 88.4 μm	SF	n_e~10^3 cm^{-3} metallicity
[NII] 121.7 μm	SF	n_e~10^2 cm^{-3}
[OI] 145.5 μm	PDR	n_H
[CII] 157.7 μm	PDR	N_H
[NII] 205.2 μm	SF	n_e~10^2 cm^{-3}

Molecular gas lines	indicator	purpose
H_2 12.3, 17.0, 28.2 μm	PDR/ C-shock	N_{H2} outflow
HD 19, 23, 28, 38, 56, 112 μm	MC/PDR	CO-dark gas tracer
OH 53, 84, 119, 163 μm	PDR/ C-shock	outflow
High-J CO	C-shock/AGN	
H_2O 17.8, 18.7,, μm	SF	

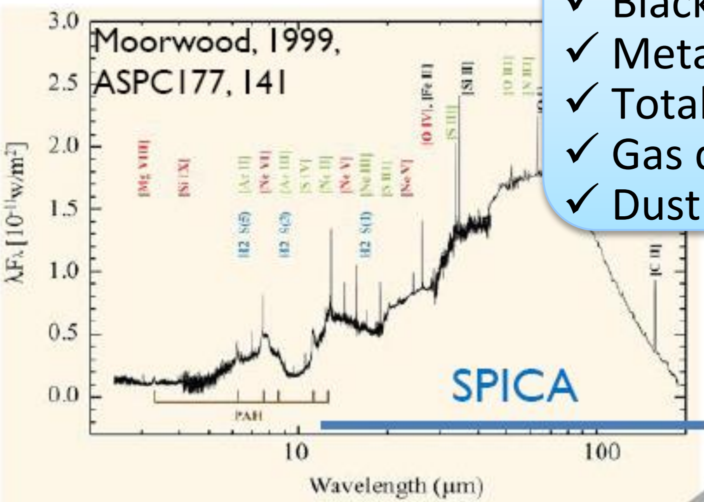
Dust band	indicator	purpose
H_2O ice 44, 62 μm	PDR/MC	crystallinity
Crystalline silicate 24 – 69 μm	PDR/MC/ CSM/SNR	mineralogy, crystallinity temperature
graphite 30 μm	PDR/XDR	crystallinity
PAH 12.7, 13.5, 14.2, 15.9, 17, 18.9 μm	PDR	
FeO 20 μm	SNR	
MgS 30 μm	CSM/SNR	
Carbonate 20-100 μm		

***Red*: covered by SMI**

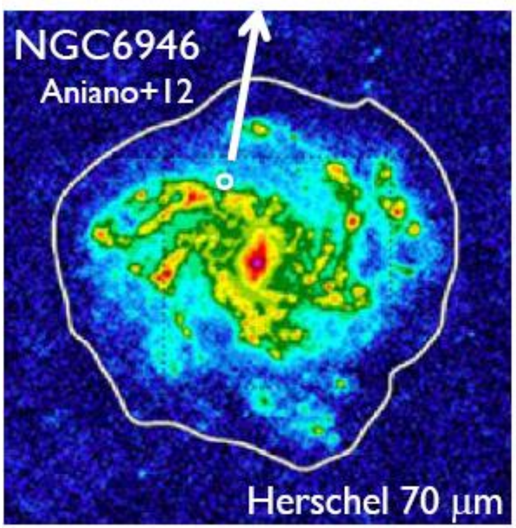
Full gas & dust spectral diagnostics is applied to studies of nearby Universe.

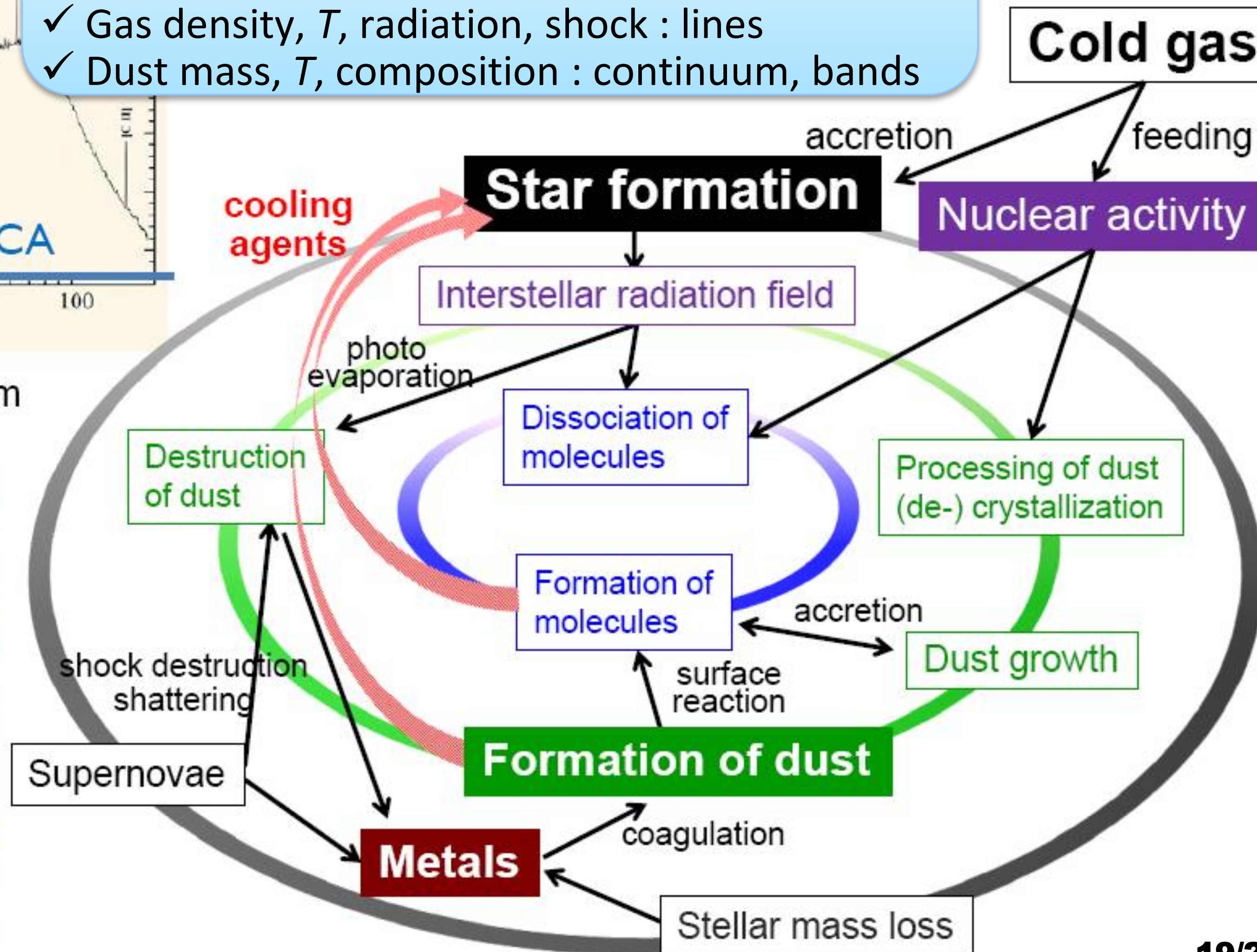
Revealing local relationship of SF activity with metal-dust enrichment and AGN through spectral mapping

- ✓ Star-formation rate : [OI]+[CII], [OIII], MIR-FIR
- ✓ Black hole accretion rate : [NeV], [OIV]
- ✓ Metallicity : [NIII]/[OIII], [NeII]/Huα
- ✓ Total gas mass: dark gas (HD, [CII]) + radio (HI, CO)
- ✓ Gas density, *T*, radiation, shock : lines
- ✓ Dust mass, *T*, composition : continuum, bands



MIR-FIR continuous spectrum per spatial bin



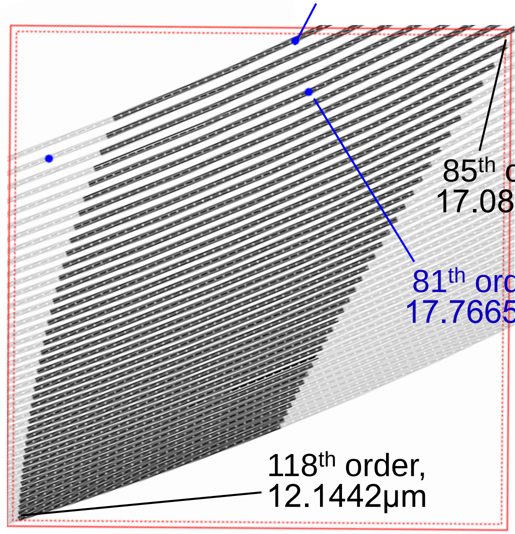


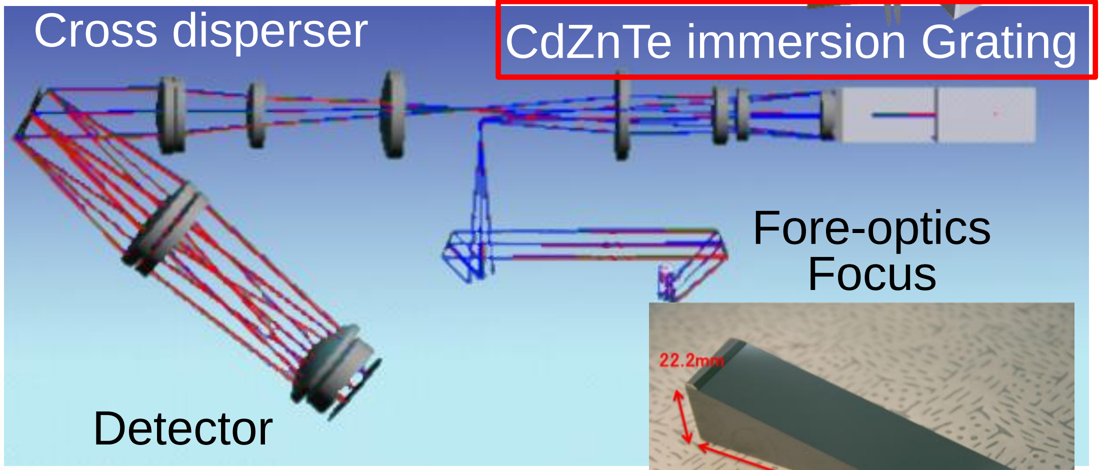
(3) High-resolution spectrometer

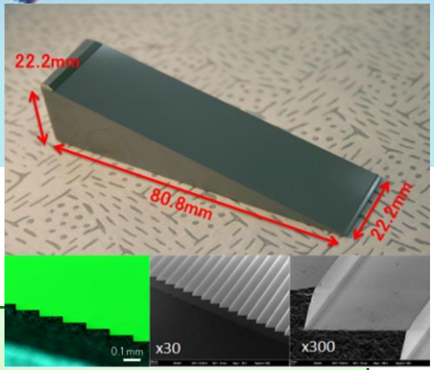
HRS

Detector: 1 Si:As 1K x 1K

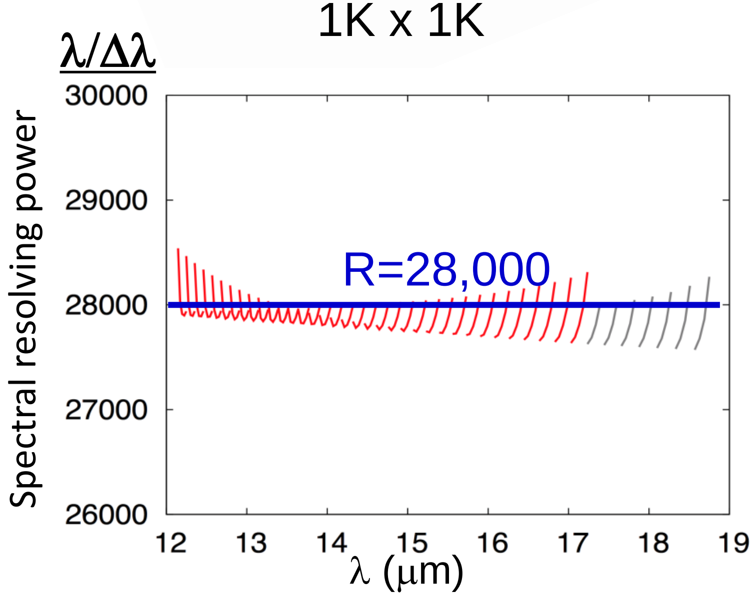
Echelle format







Ikeda et al. 2015
Applied Optics 54, 5193

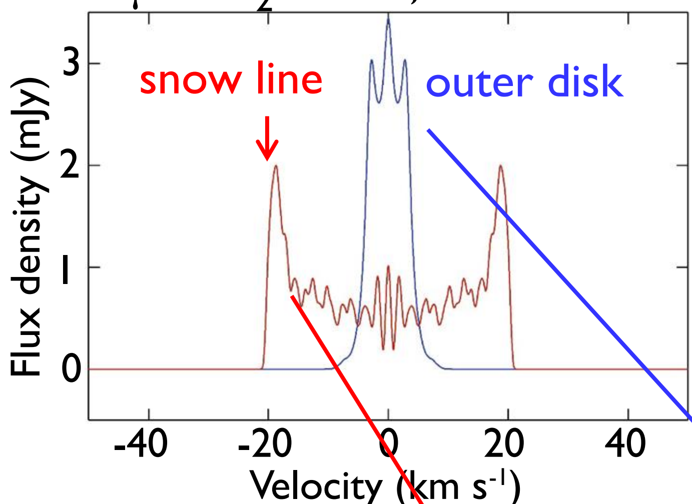


- slit length ~4”
- very high line sensitivity
  $\sim 1 \times 10^{-20}$ W/m^2 (1 hr, 5σ)
- high spectral resolution
  R = 28,000
- Continuous coverage from 12.1 to 17.3 μm, plus partial coverage up to 18.9 μm for H_2O 17.77 & 18.66 μm.

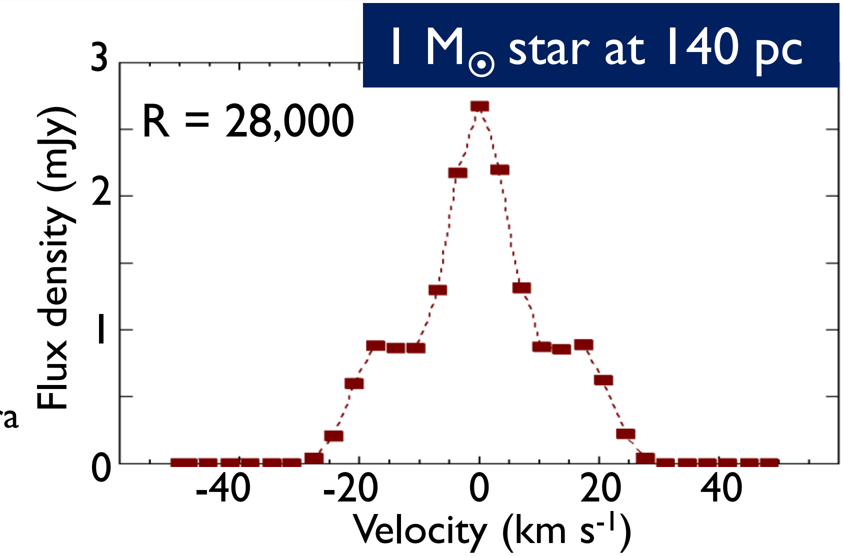
Snow line and its 3-D geometry

SMI-HRS can reveal snow line and its 3-D geometry by ***velocity-resolved*** spectroscopy of multiple H_2O lines with ***different*** Einstein A-coefficients.

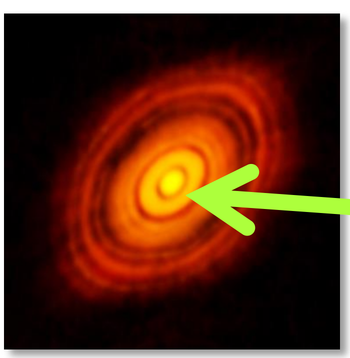
17.8 μm H_2O line, $A = 2.91 \times 10^{-3}\ s^{-1}$

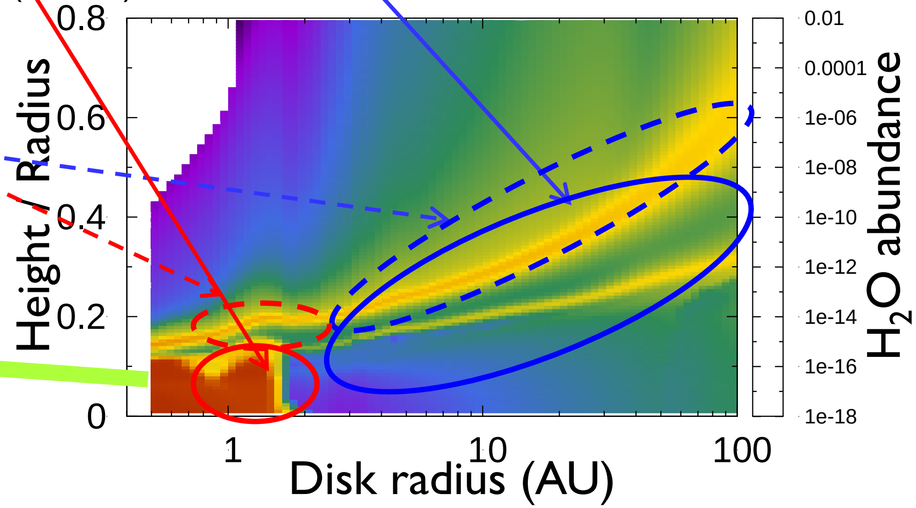


Base on disk models from Notsu, Nomura + 2016a, b



18.7 μm H_2O line
$A = 1.69 \times 10^{-2}\ s^{-1}$

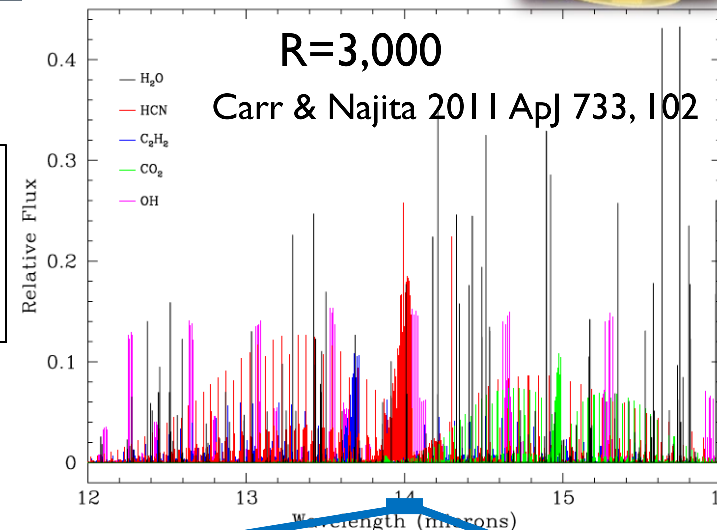




HRS can separate the snow line (red) from the contribution of the outer disk surface (blue).

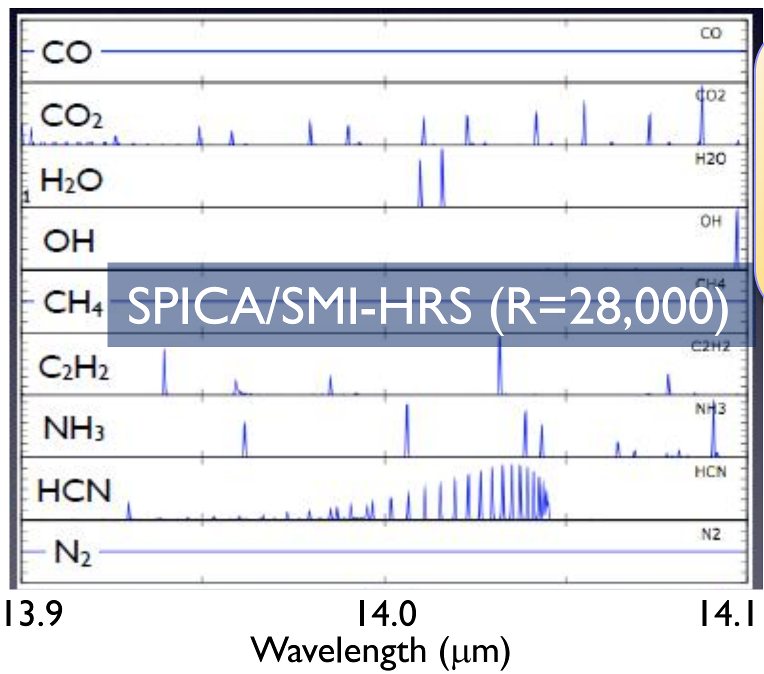
Chemistry in proto-planetary disks

- The HRS range of 12–18 μm contains numerous emission bands of major C-bearing molecules.



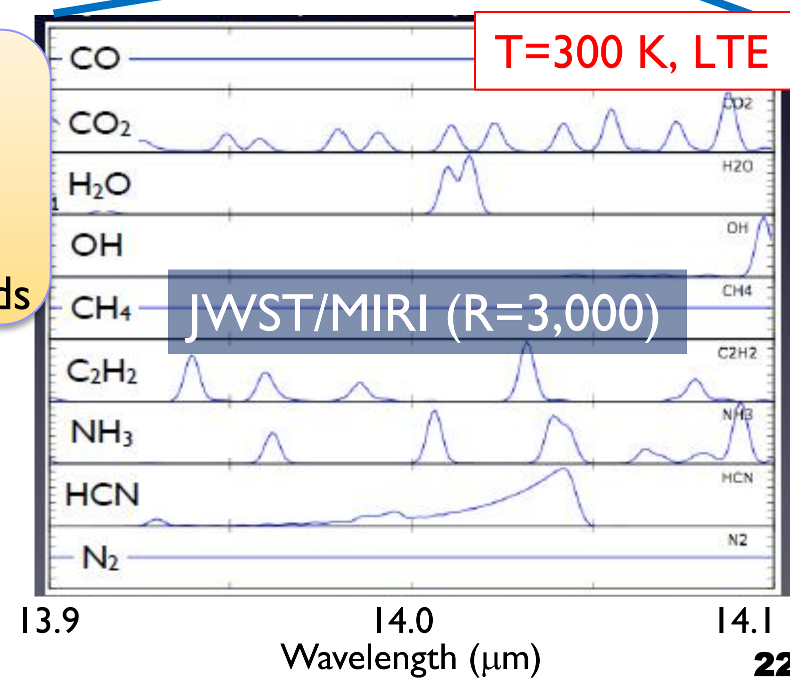
Velocity-resolved
H_2O, OH, HCN, CO_2, C_2H_2 lines
→ C/O ratio distribution at <~1–2 AU in disks

Characteristics of planetary atmosphere depend on the C/O ratio of the gas at a formation site.
→ CO_2 & H_2O in the atmosphere of exoplanets to be studied by JWST.



Not only de-blending, but also resolving molecular bands

By M. Takami



Current status of SPICA in Japan

Evaluations and Reviews

International Science Preview (Paris, July 2015)

Mission Definition Review (MDR) was held by ISAS's Space Science Advisory Committee (Sep - Nov 2015) → passed

New SPICA is now in phase A1 ("project preparation").

Science Council of Japan

In Master Plan for Big Project 2017, SPICA is recommended by Astronomy/Astrophysics Division as a highest-priority project.

SPICA Special Session in ASJ meeting

16 Mar 2016, >250 participants,

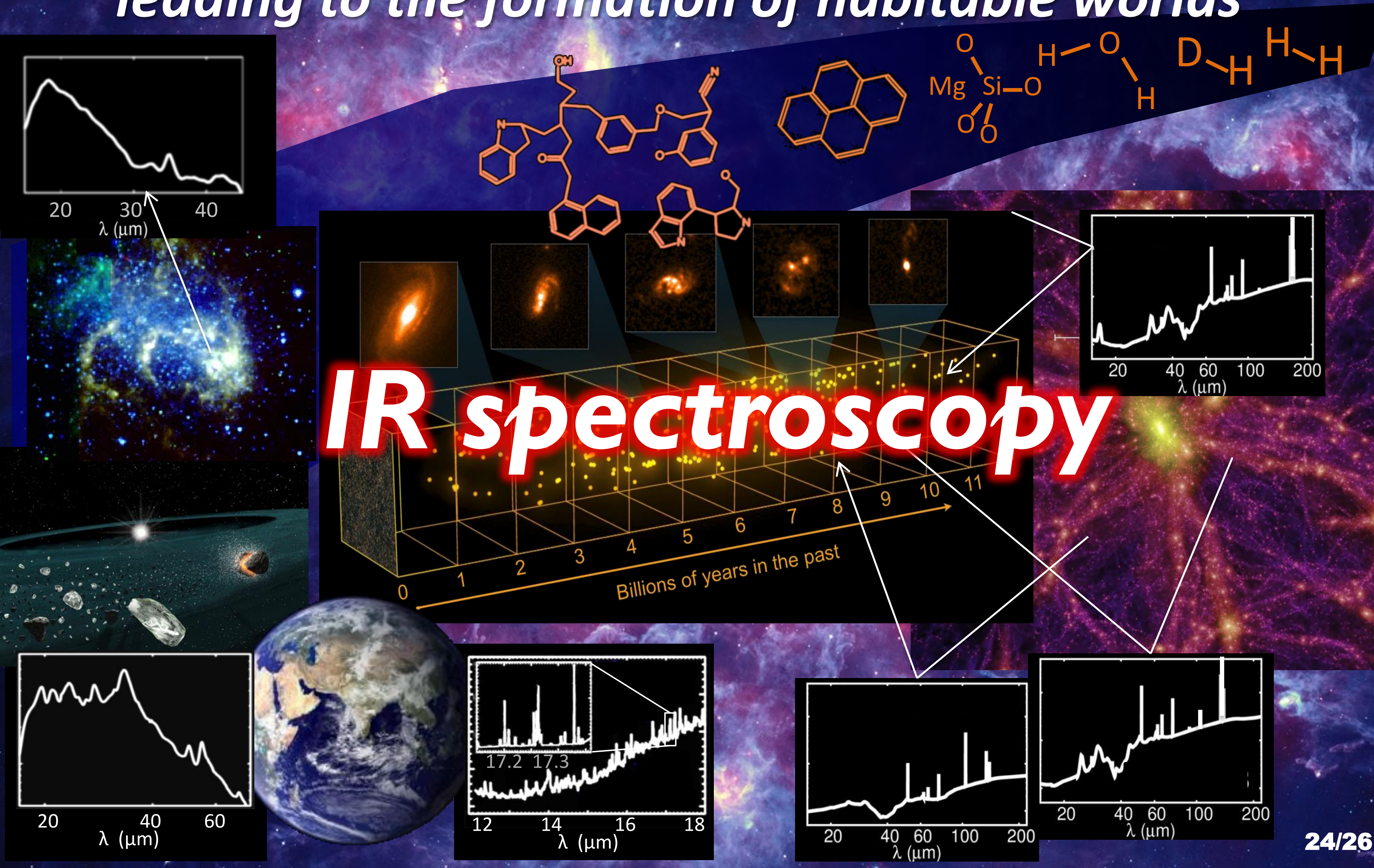
talks: H. Shibai, HK, P. Roelfsema, E. Egami, H. Nomura

SMI technical meeting

29 Mar 2016, 35 participants from the SMI university consortium

SPICA science program for JAXA MDR

“Enrichment of the Universe with metal and dust leading to the formation of habitable worlds”

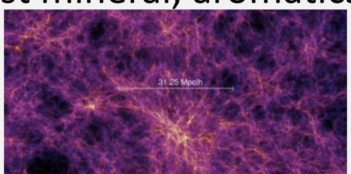


Roles of SMI in the SPICA science program

Enrichment of the Universe with metal and dust leading to the formation of habitable worlds

Metal and dust enrichment through galaxy evolution

Beyond the peak, first mineral, aromatics



The peak of the cosmic star formation history and beyond

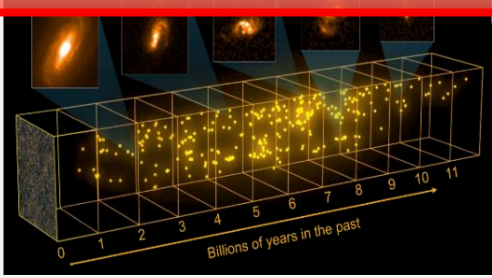
AGN Outflows with HRS

Cosmological surveys with LRS

Over the peak of the cosmic star-formation history

+ follow-up with MRS

Interplay with dust-obscured AGNs



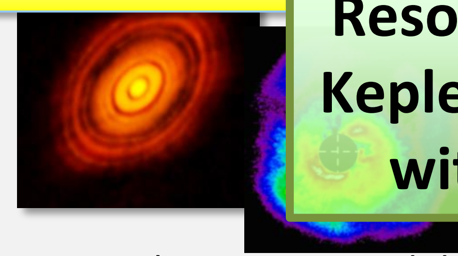
Nearby galaxies, including high-z analogs

Spatially-resolved, high-z analogs or relics

Spectral mapping with MRS

Planetary formation to habitable systems

Gas dissipation in proto-planetary disks



Resolving gas Kepler motion with HRS

Tracing the gas, ice, and dust evolution

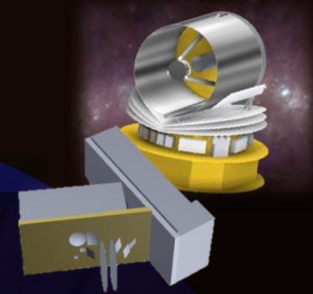
Debris disks to solar system

Changes of mineral and ice properties in disks

Mineralogy with LRS

+ follow-up with MRS

Summary



- ✓ **SMI has three spectroscopic channels:**

(1) LRS (17–36 μm, R~100) w/ slit-viewer camera (34 μm)

10'-long, 4 slits. Spitzer/IRS-LL-like with higher mapping speed.

High-speed dust-band mapping

(2) MRS (18–36 μm, R~2000)

1'-long with beam-steering mirror. IRS-LH-like with better mapping.

High-sensitivity multi-purpose spectral mapping

(3) HRS (12–18 μm, R~30000).

4"-long with beam-steering mirror. Unique (↔ JWST/MIRI R~2000)

High-resolution molecular-gas spectroscopy

AKARI Mid-IR all-sky map