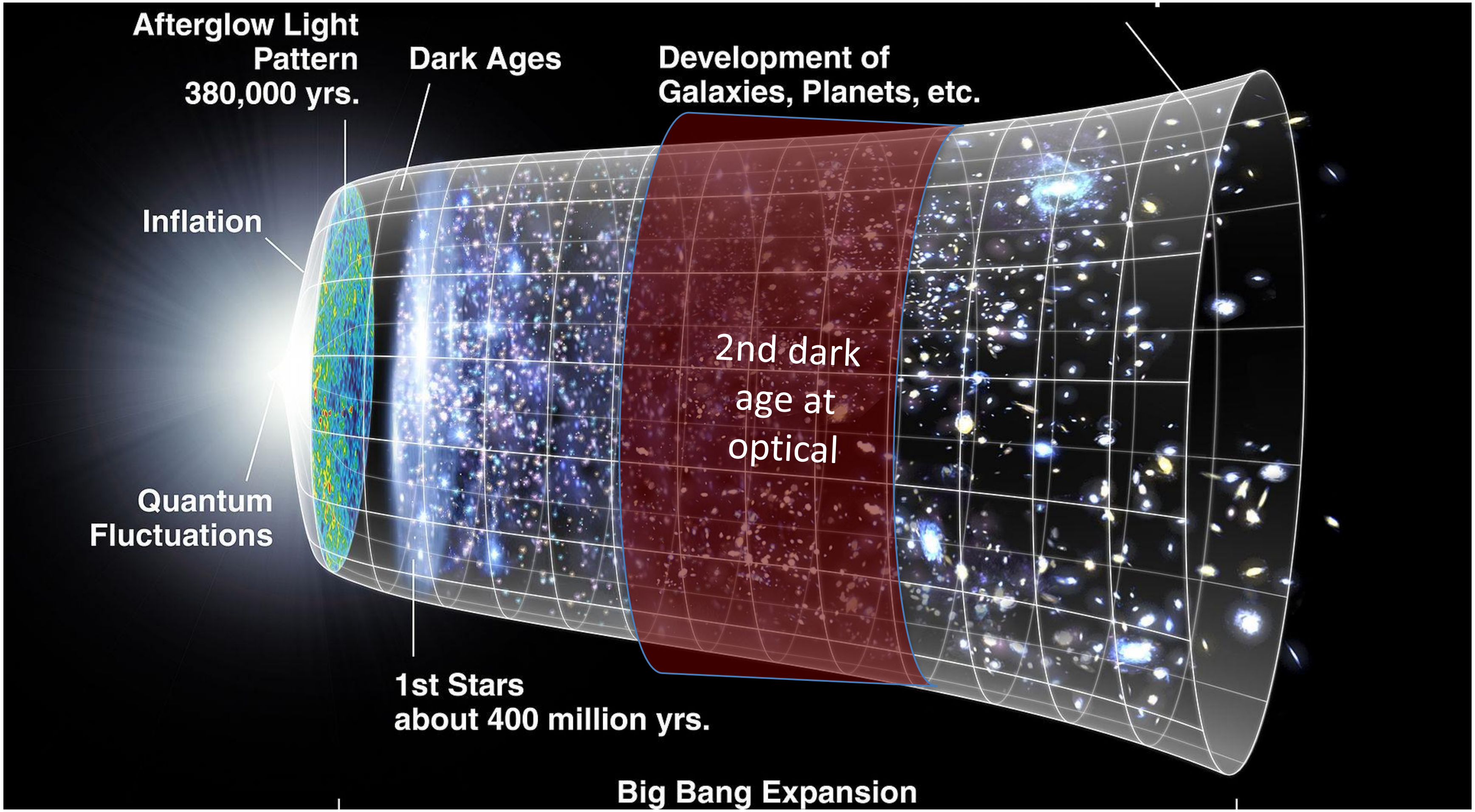
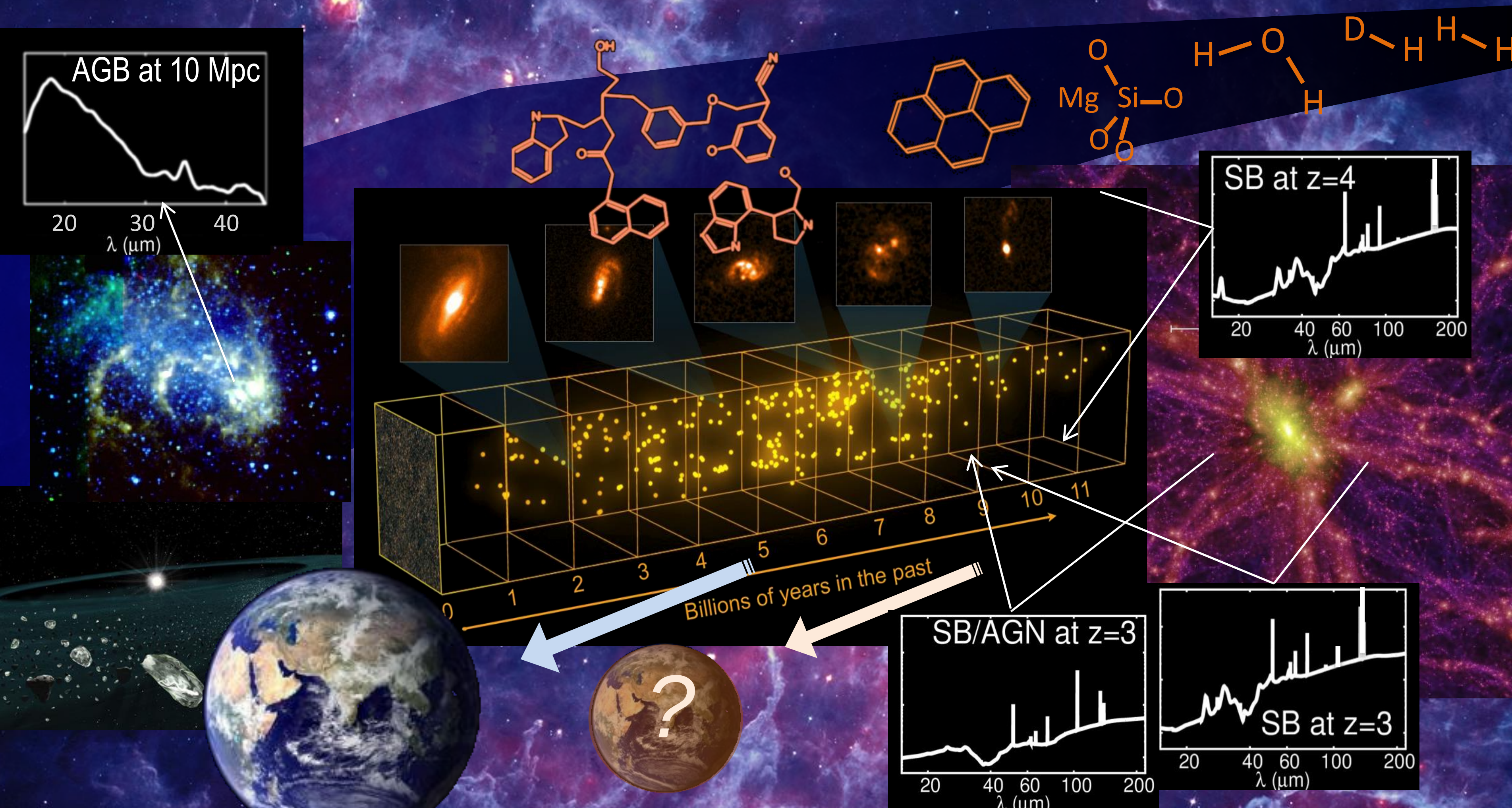
SPICA: Large Infrared Telescope in Space

(Japan-Europe Project)

Hiroshi Shibai (Osaka U, ISAS/JAXA)



When and How did our Universe Became Material-Rich and Even Habitable?



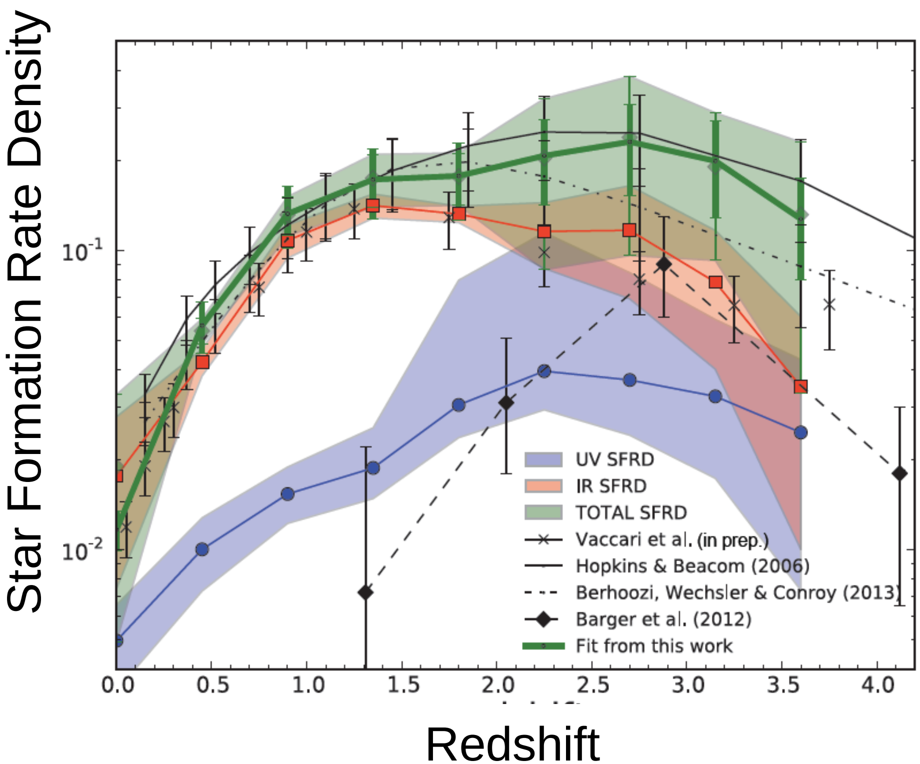
◆Present:
various targets to probe H_2, H_2O, mineral & planet-forming environments.

◆ 5-10 billion years ago:
metal enrichment through galaxy evolution.

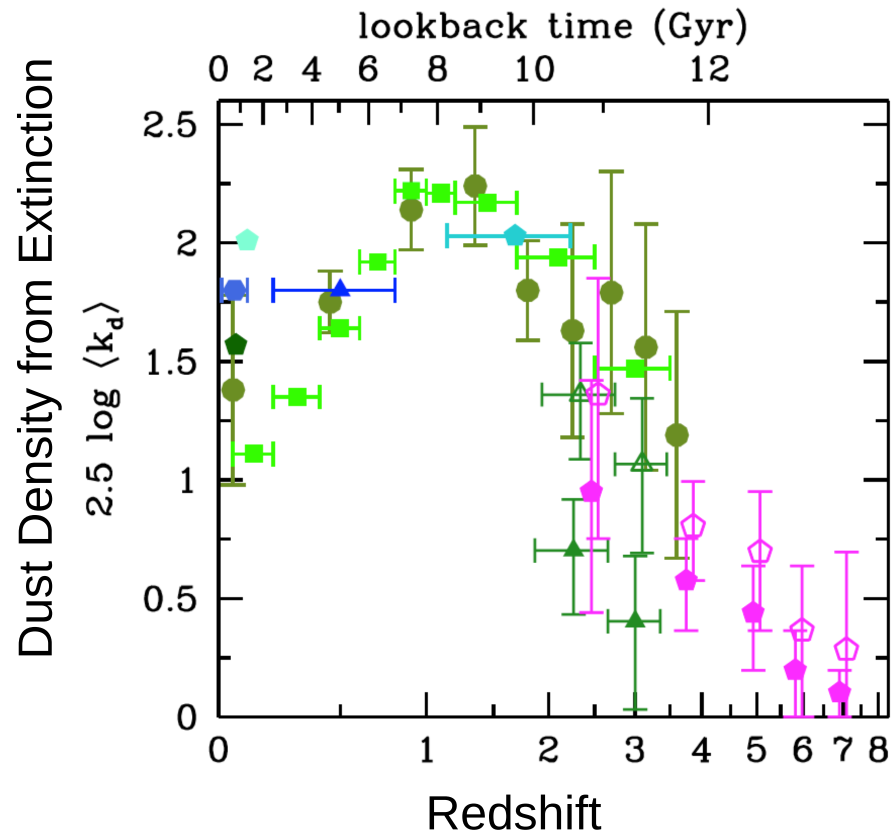
◆ >12 billion years ago:
first formation of minera
& organic matters.

Galaxy Growth Age of the Universe

Burgarella et al. 2013, A&A, 554, 70



Madau & Dickinson 2014



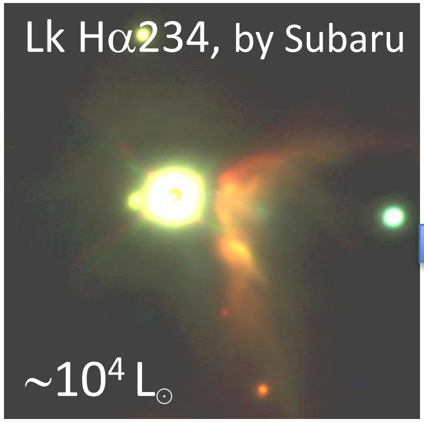
Peaking at z=1-3

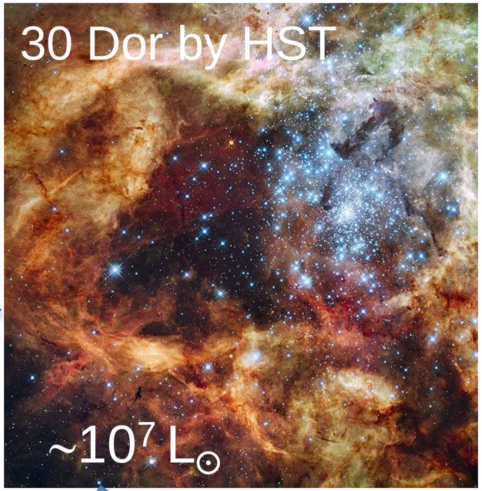
Star Formation? SMBH?

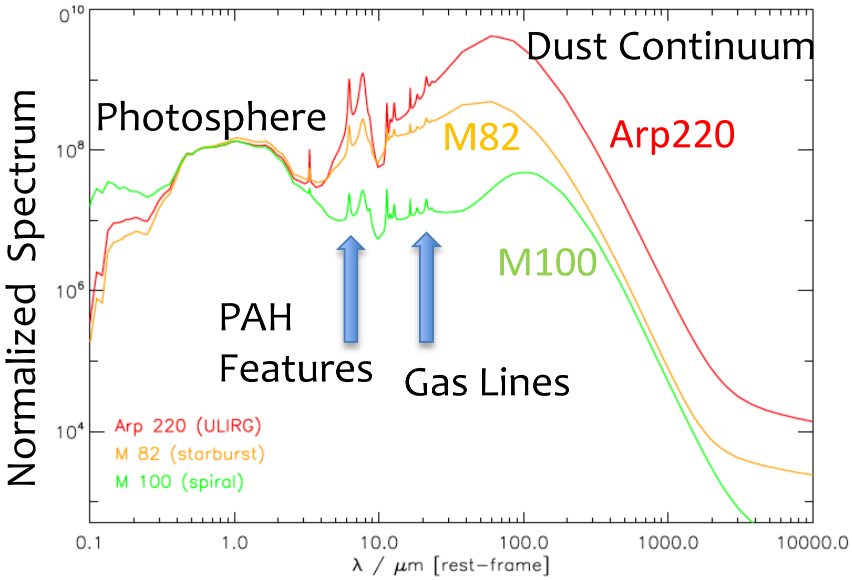
Peaking at z=1-3

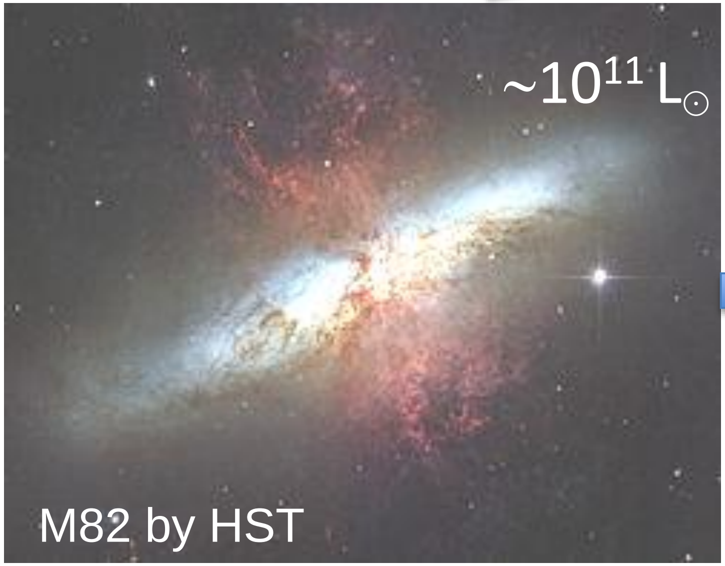
Core Regions of Galaxy Growth Obscured by Dust Grain!!

Star Forming Regions of Various Scales

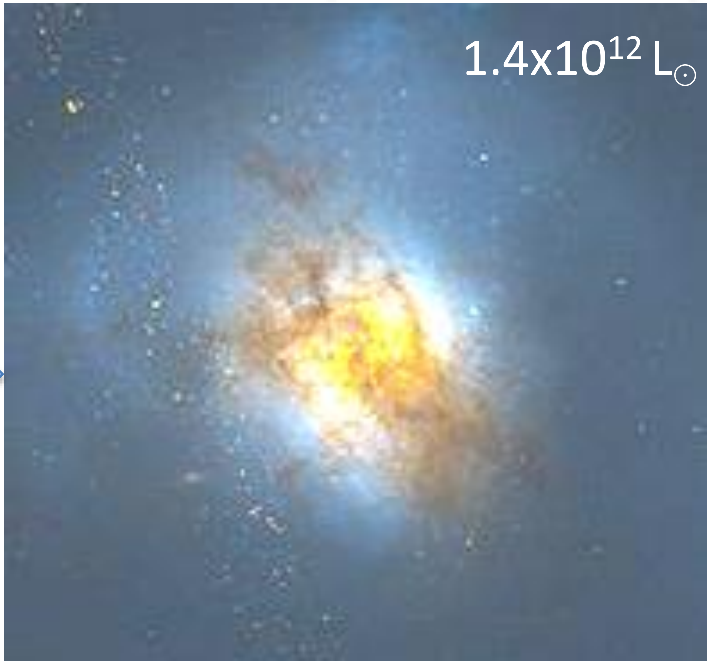




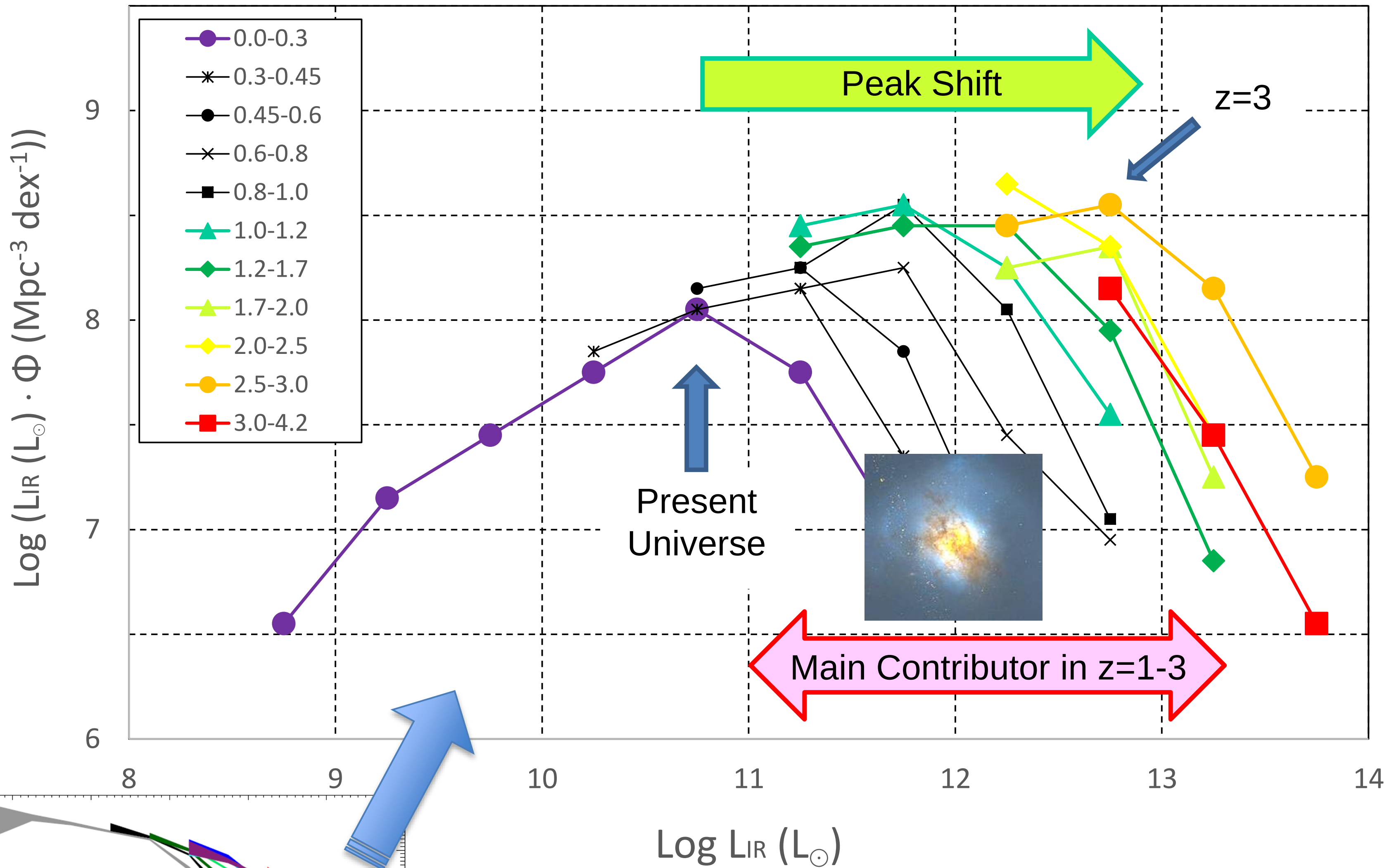


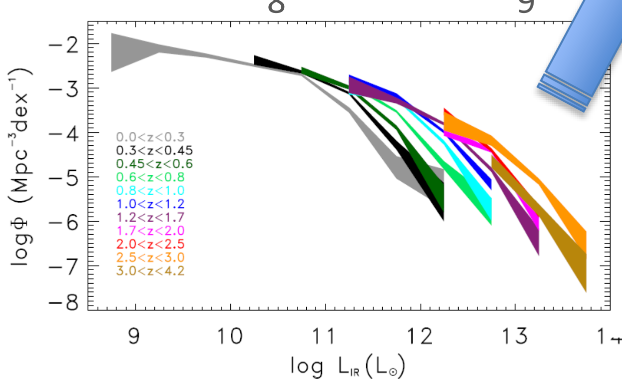


10 kpc



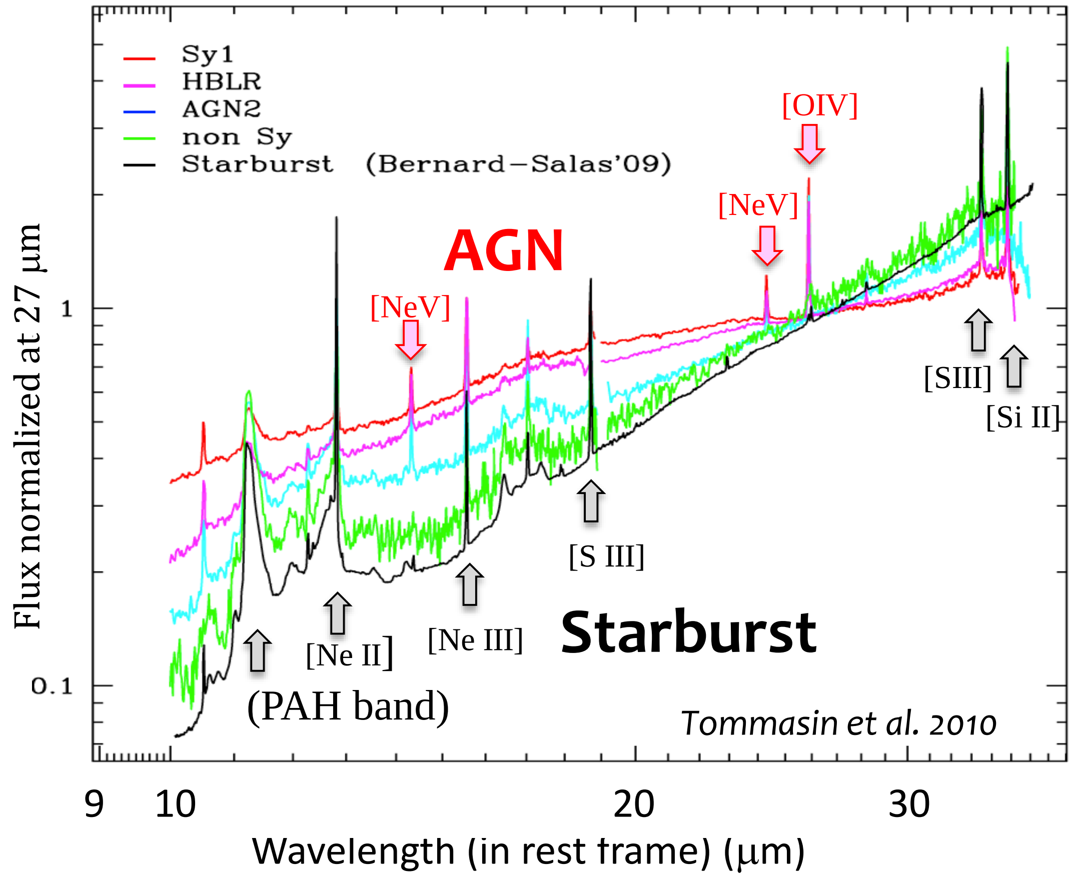
Luminosity Evolution of Main Contributor in Each Epoch





Luminosity Function at Each Epoch Obtained with Herschel
Gruppino et al. (2013)

Gas Lines and PAH bands as a diagnostic tool of SF Activity



[Ne V], [O IV] are robust tracer of AGN; hard radiation field.

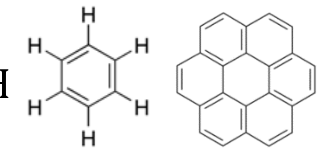
[Ne II] [S III] , [O III], [N III], etc.: tracer of gas density, temperature, metallicity of SF galaxies.

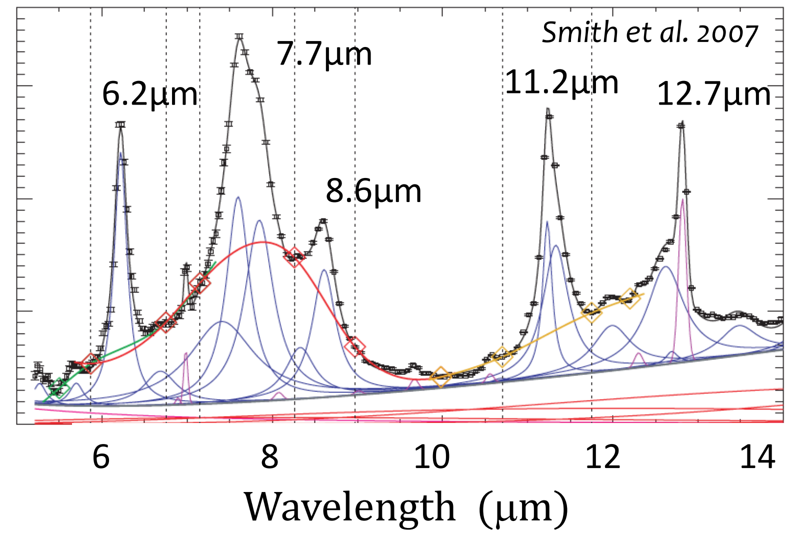
Merit of Gas Lines:

simple excitation physics → reliable estimate of physical conditions of SF activity.

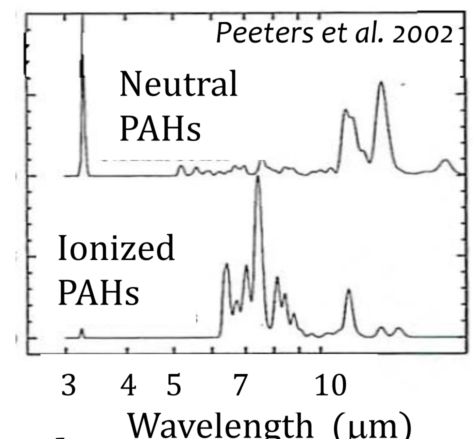
PAH (polycyclic aromatic hydrocarbons)

Broad emission features originated from C-C and C-H bonds





Relative Strength of PAH bands is an indicator of SF activity strength.



Merit of PAH bands:

stronger than gas lines

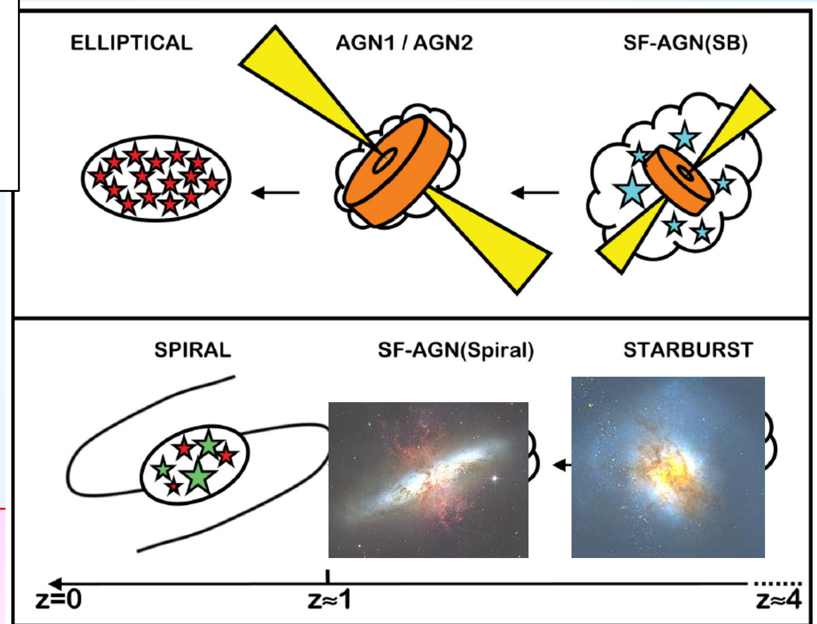
Interplay of Galaxies/AGNs, Stars, and Materials

How Galaxies made Stars/Planets and Materials During Their Growth in z=1-3? (Mass-Production Factory)

Did AGN accelerate or decelerate production?

Did Heavy Elements accelerate production? How much?

Galaxy Evolution



Element/ Material Production

H, He from IGM

O C N
Fe Si Mg

Silicate
Ice,,,,,

PAH

CO
H_2O
etc,

Interstellar Clouds

Trigger

Cooling by Heavy Elements

Life?

Stars/Planets

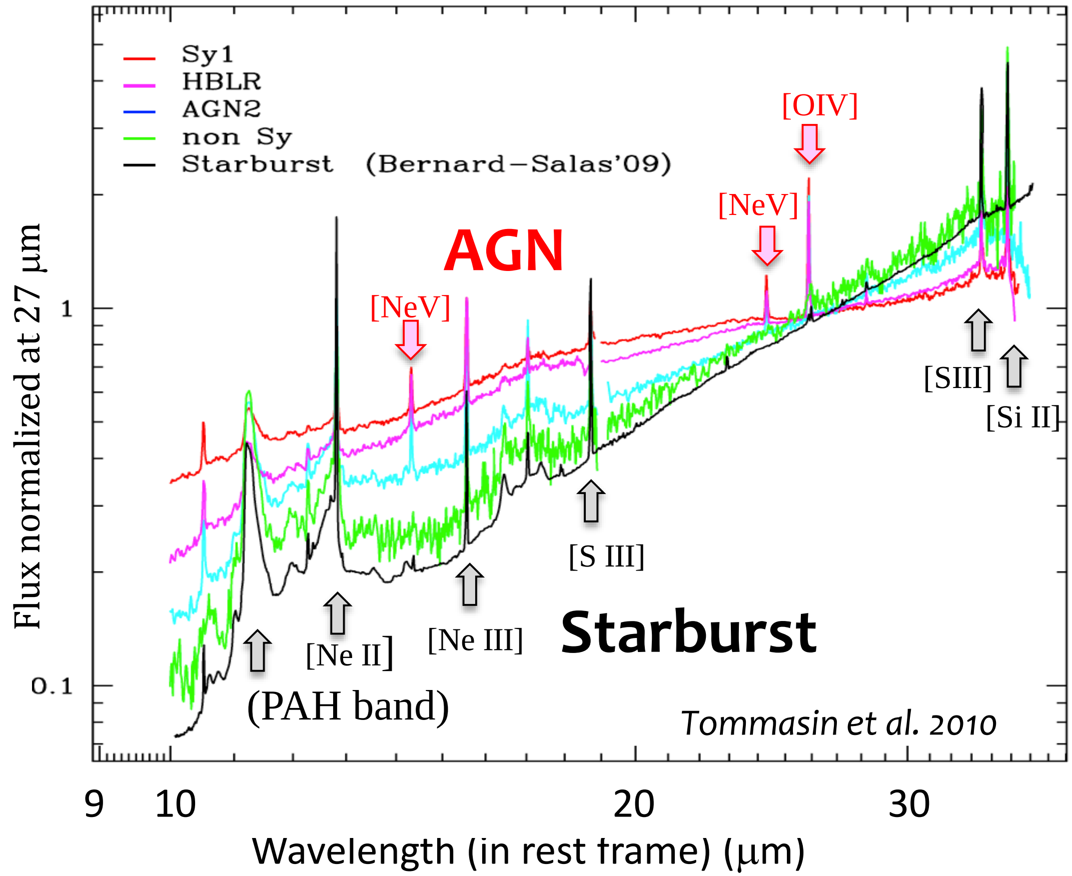
AGB
SNe

Supply of Heavy Elements

Supply of Solid Materials

Star/Planet Formation

Gas Lines and PAH bands as a diagnostic tool of SF Activity



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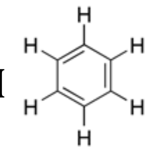

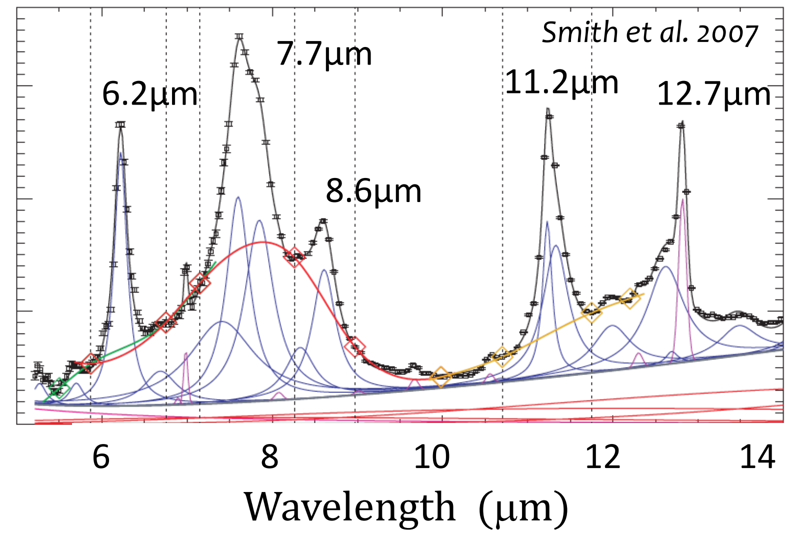

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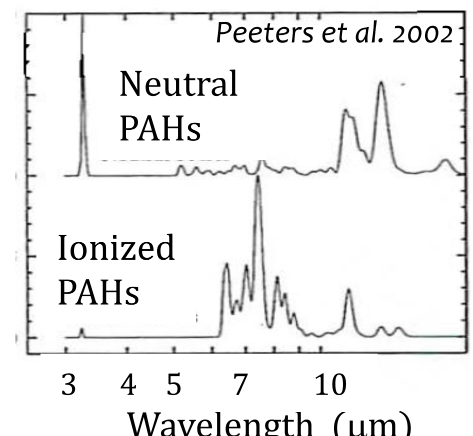


Merit of PAH bands:

stronger than gas lines

New SPICA (Current Baseline Plan)

Method for Primary Science:

Gas and PAH Diagnoses of Typical Galaxies in z=0-4
covering 20-210 μm (Extendable beyond both ends)

Telescope:

Diameter: 2.5 m (Outer Diameter of the Primary Mirror)
Temperature: below 8 K
<- Based on the Reference Design Made by ESA and JAXA

Organization:

SPICA Consortium is the whole team including
SAFARI/SRON as the PI proposer to ESA
FIR: SAFARI/Grating <- US Scientist
SPICA-J as the PI proposer to JAXA
MIR: SMI
<- MIR Transit Spectroscopy of Exoplanet Atmosphere

Schedule (Expected):

2015 Reviews for Approval by JAXA
2016 Submission to ESA M-Class
2025FY Launch -> Five year operation

New SAFARI concept with grating

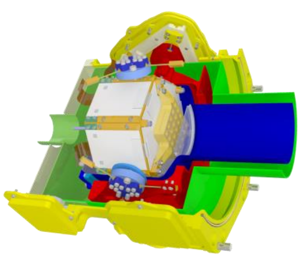
Likely to be achievable with SAFARI consortium

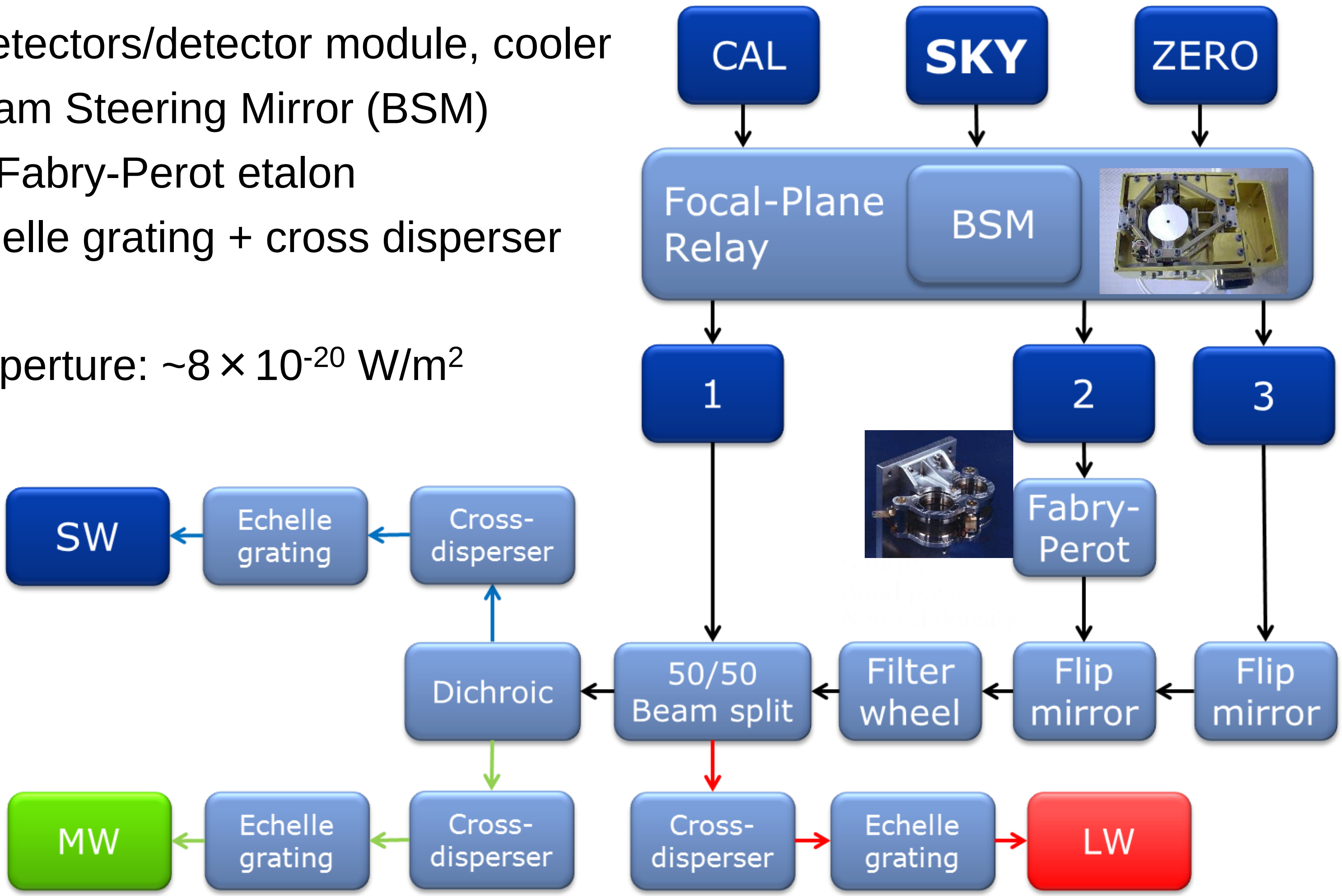
Heritage:

- SAFARI detectors/detector module, cooler
- SPIRE Beam Steering Mirror (BSM)
- ISO/SWS Fabry-Perot etalon
- BLISS echelle grating + cross disperser

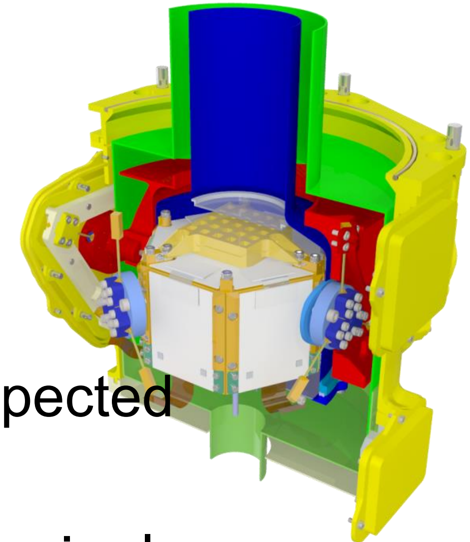
Sensitivity:

- For 6 m^2 aperture: $\sim 8 \times 10^{-20}$ W/m^2



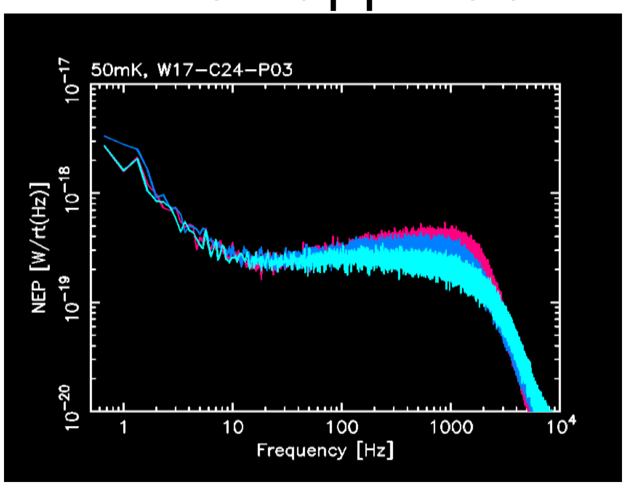


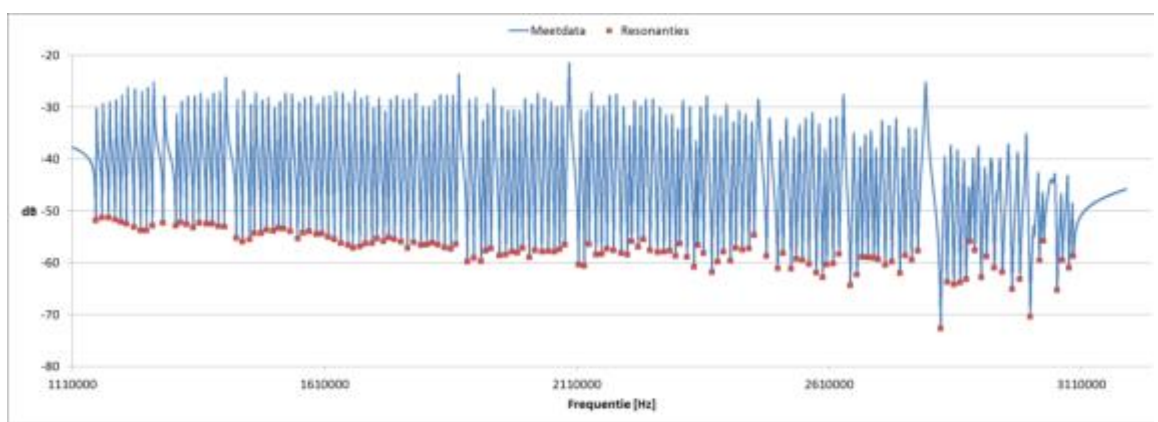
Performance of TES and Electronics



- 2.5 x 10^{-19} W/$Hz^{1/2}$ demonstrated in the lab.
- Cambridge 388-pixel LW array measured
- SRON 64 and 72-pixel SW arrays measured
- 20 x 20 SW array fabrication demonstrated
- Measured optical efficiency ~ 60% → >80% expected
- 160 pixels/channel FDM demonstrated
- Design well established – thermal, mechanical, EMC/magnetic shielding (SAFARI/ATHENA FPA)

→ all applicable to Grating based spectrometer

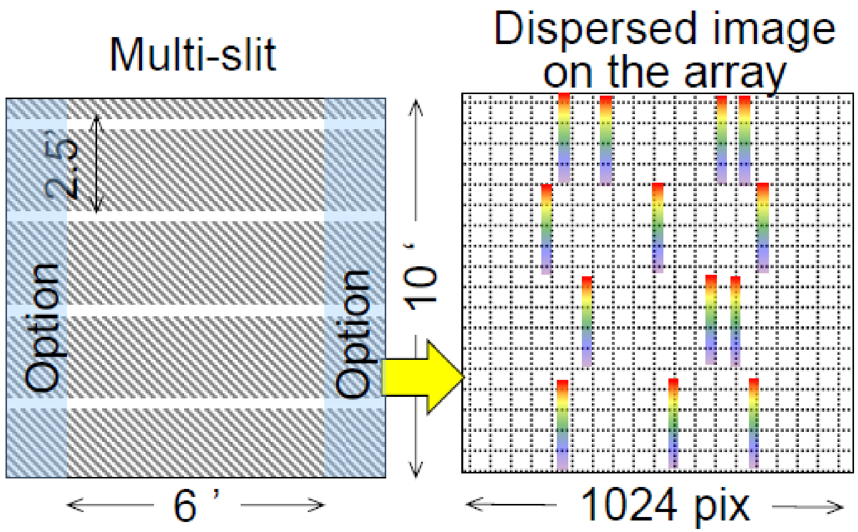




SMI-Cam design, characteristics (updated)

☐ Concept

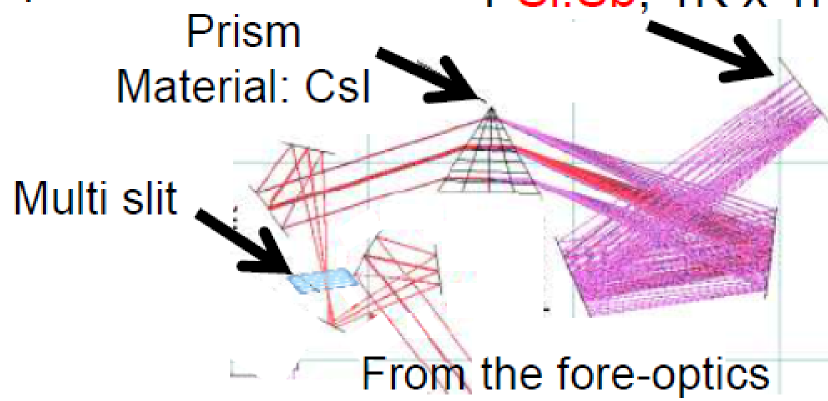
4 slits at the focus & R=50 prism in the pupil.

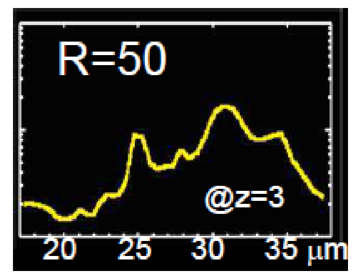


4 slits (>6' in length, 3.7" in width)

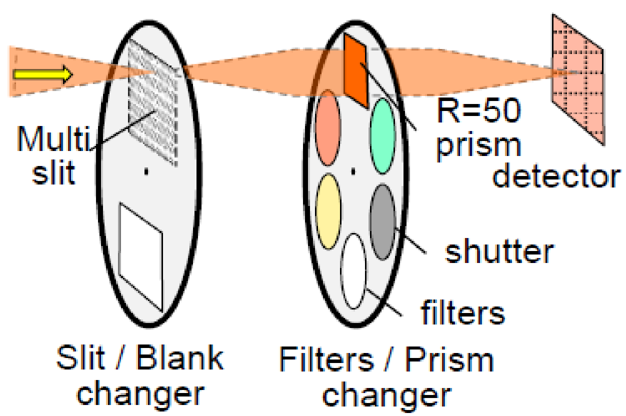
rear-optics

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





<u>Camera mode?</u>
Change
the camera mode /
multi-slit Spec mode
by the changers??
(TBD)

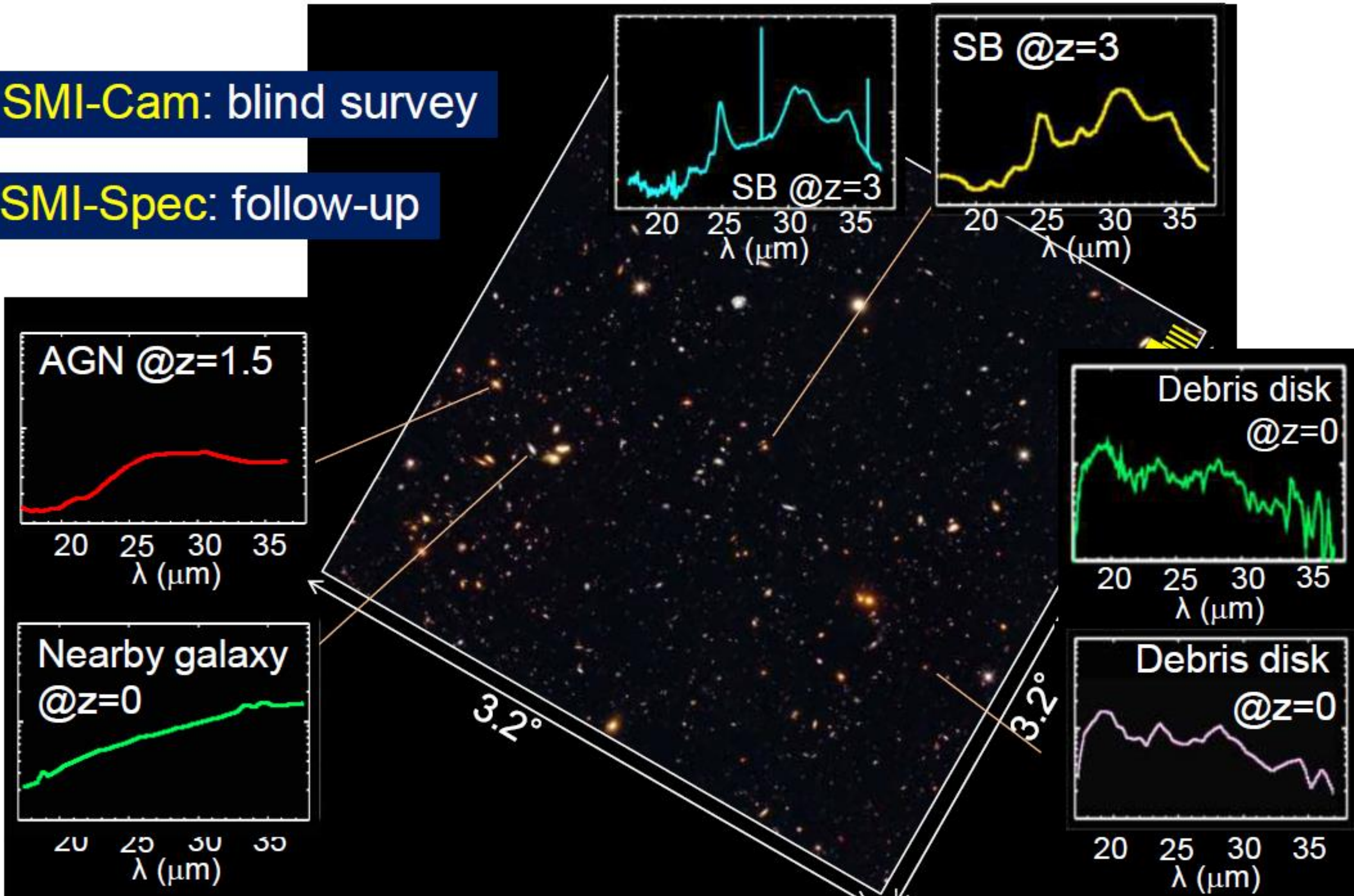


- wide FoV (>6' x 3.7" x 4 slits)
- high continuum sensitivity
  30 μJy (1hr, 5σ)
- good spatial resolution
  0.6"/pixel, 3.7" beam
- R=50 spectral mapping

SMI-Cam: dust-band surveyor

SMI-Cam: blind survey

SMI-Spec: follow-up



New Sharing Plan (Preliminary)

Telescope (ESA)

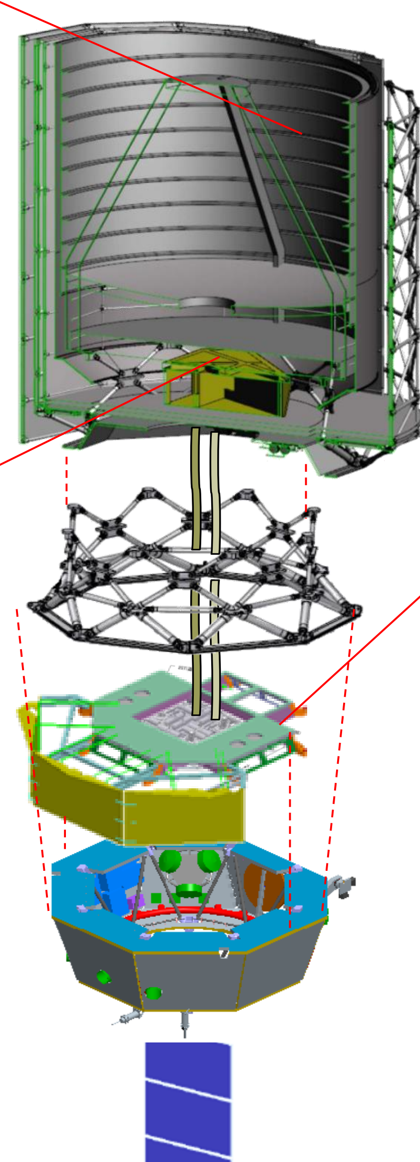
Focal-Plane Instruments(FPIA)

FIR Instrument（SAFARI）
Netherlands＋European

MIR Instrument（SMI）

Focal-Plane Attitude Sensor (FAS)

Service Module (SVM)



Payload Module (PLM)

Coolers (JAXA)

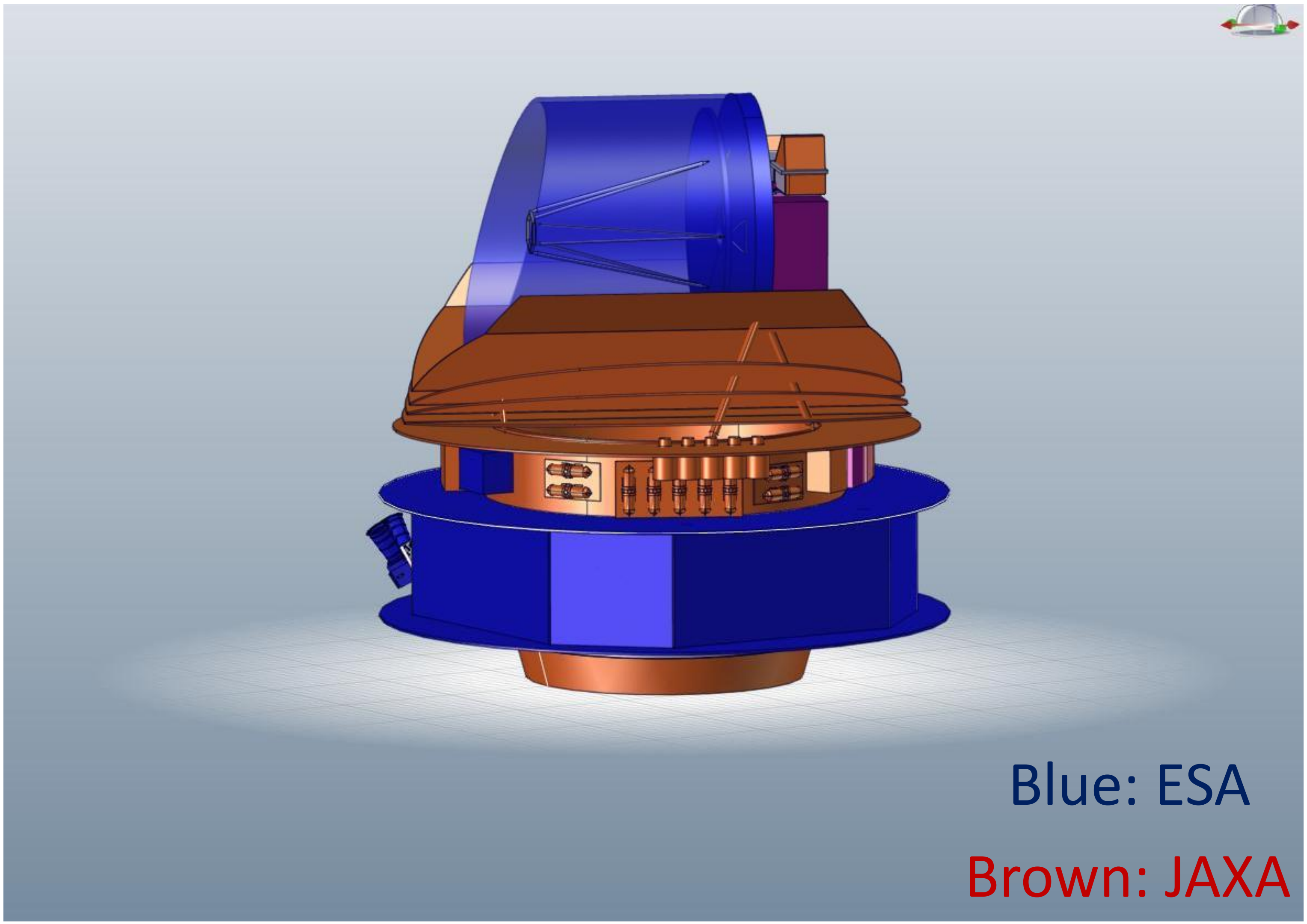
Operation/Data Center
（NAOJ）

Science Planning
（JP, EU, US, KR, TW）

Launch

Extended PLM + SVM Configuration

Technically Feasible and Financially Affordable as a Collaborative Mission by Both Space Agencies



SMI R50 1deg^2 blind survey + SAFARI-grating follow-up

Obs. time: SMI-Cam (R50) = 42days (10hrs/field x100, 1 field = 6' x 6', sensitivity based on 2.5 m telescope).
Detectable with 10 hrs exp. for the 1 deg^2 area.

z	0-1	1-1.5	1.5-2	2-2.5	2.5-3	3-4	>4
PAH galaxies total	**1833**	**3060**	**3978**	**2499**	**1733**	**549**	**60**
$\mathrm{Log}_{10}\, L_{IR} / L_{sun}$							
>13	0	2	9	25	46	23	20
12.5 – 13.0	6	65	159	[illegible]	[illegible]	161	40
12.25 – 12.5	26	182	[illegible]	[illegible]	356	175	0
12.0 – 12.25	89	[illegible]	552	540	484	146	0
11.75 – 12.0	219	779	812	652	404	44	0
11.5 – 11.75	415	988	1031	540	135	0	0
11.0 – 11.5	1018	599	1114	141	0	0	0
<11	60	0	0	0	0	0	0
Galaxies for gas line diagnosis	12447	5428	3005	2012	1506	386	N.A.

Typical Galaxies to be Diagnosed

SMI R50 1deg^2 blind survey + SAFARI-grating follow-up

Obs. time: SMI-Cam (R50) = 42days (10hrs/field x100, 1 field = 6′ x 6′, sensitivity based on 2.5 m telescope). **SAFARI: sensitivity 8x10^{-20} W/m^2 (2 hr, 5 σ). Detectable with 10 hrs exp. for the 1 deg^2 area.**

z	0-1	1-1.5	1.5-2	2-2.5	2.5-3	3-4	>4
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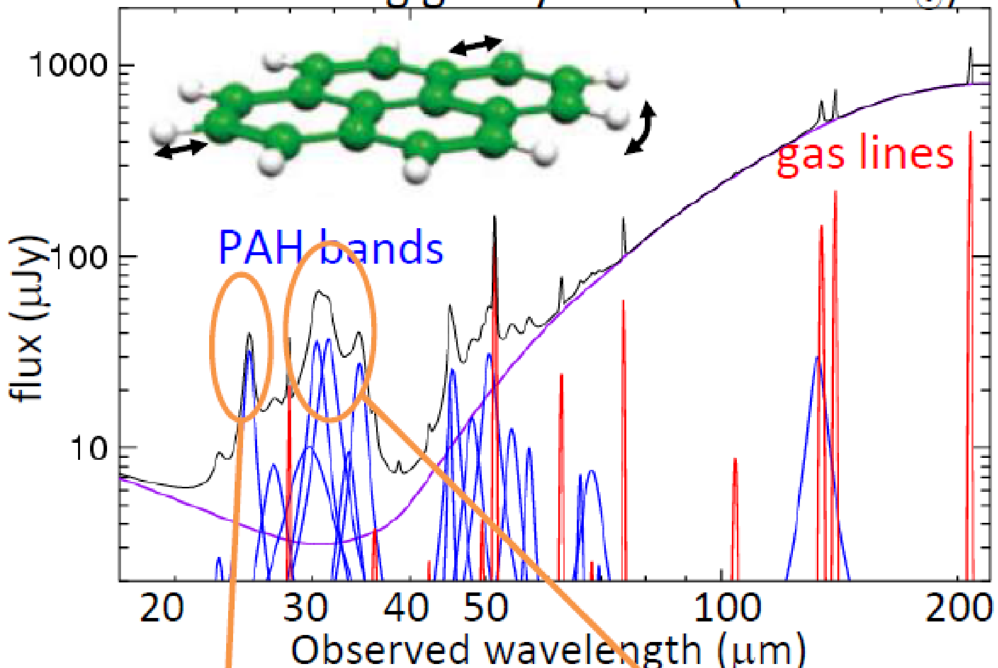
$\mathrm{Log}_{10}\, L_{IR} / L_{sun}$							
>13	0	2	11	30	58	31	0
12.5 – 13.0	8	69	173	280	[illegible]	173	0
12.25 – 12.5	34	189	[illegible]	[illegible]	427	135	0
12.0 – 12.25	120	[illegible]	588	601	501	47	0
11.75 – 12.0	316	842	861	628	153	0	0
11.5 – 11.75	658	1259	870	80	0	0	0
11.0 – 11.5	2962	2511	182	0	0	0	0
<11	8349	98	0	0	0	0	0

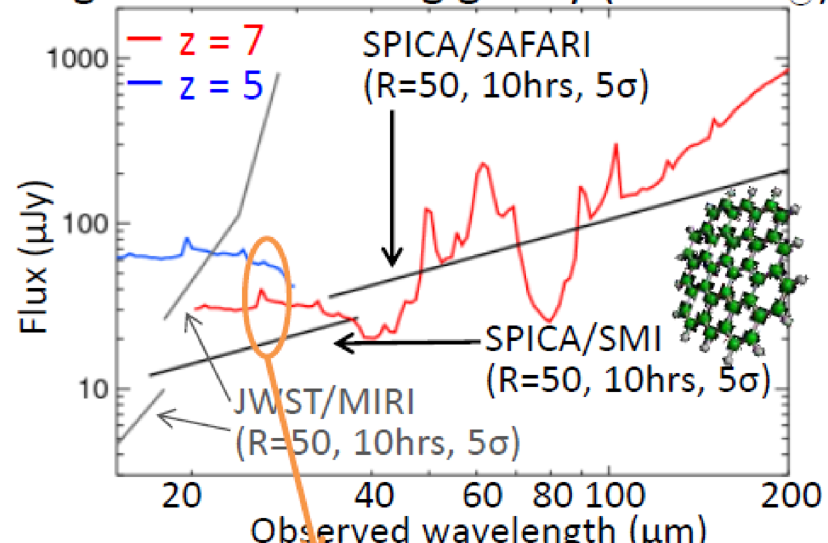
Typical Galaxies to be Diagnosed

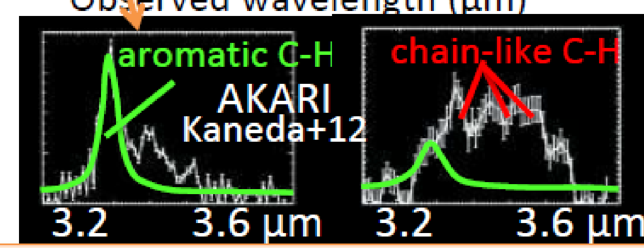
Science driver: Organic matter in the early universe

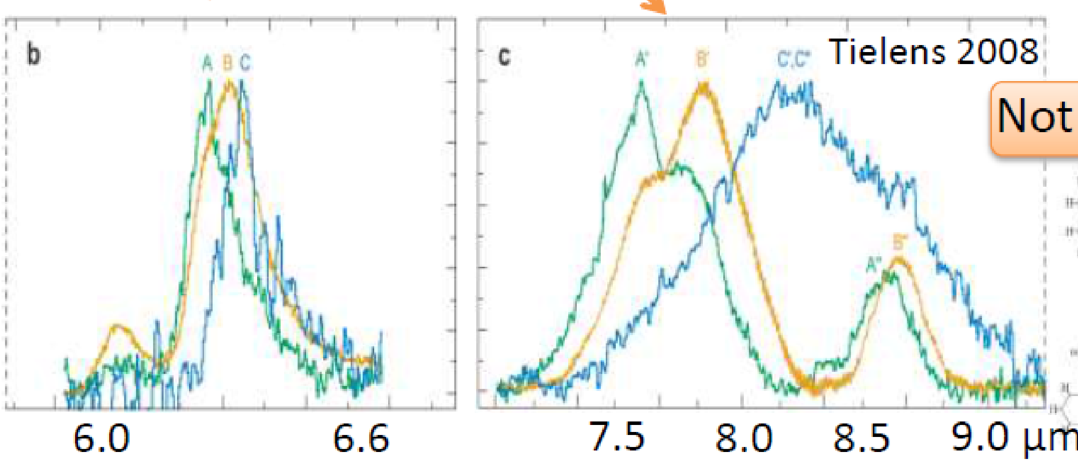
Star-forming galaxy at z = 3 (1×10^{12} $L_\odot$)



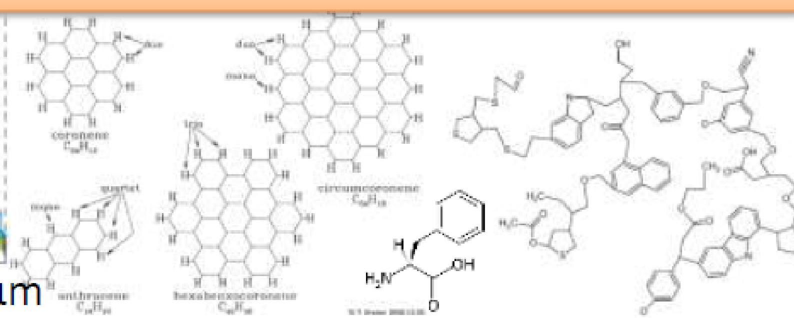
High-z star-forming galaxy (2×10^{13} $L_\odot$)



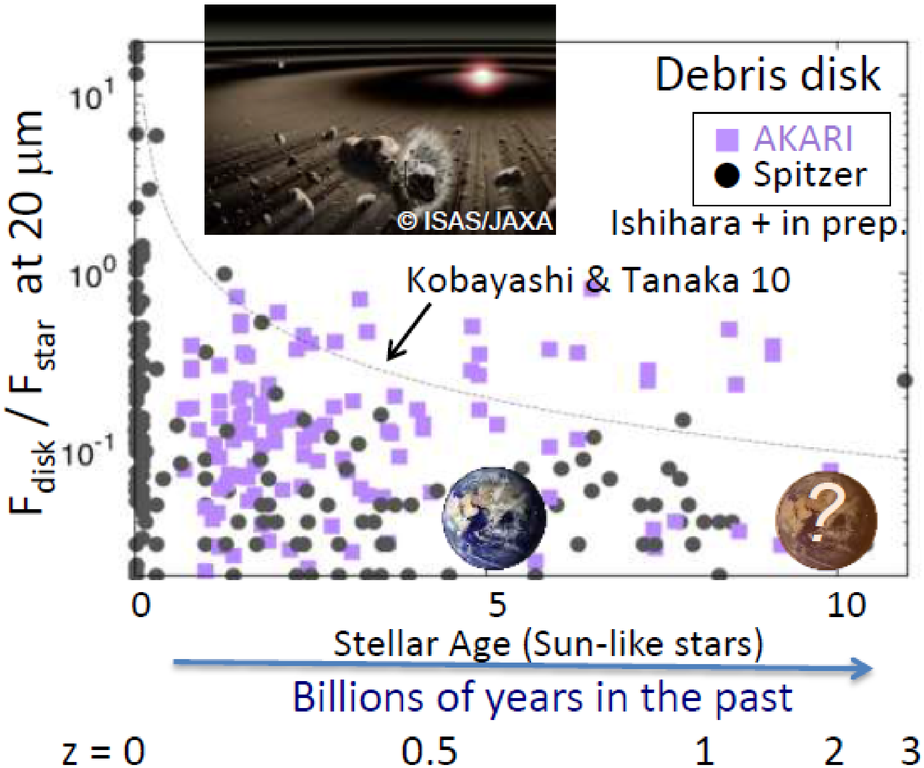


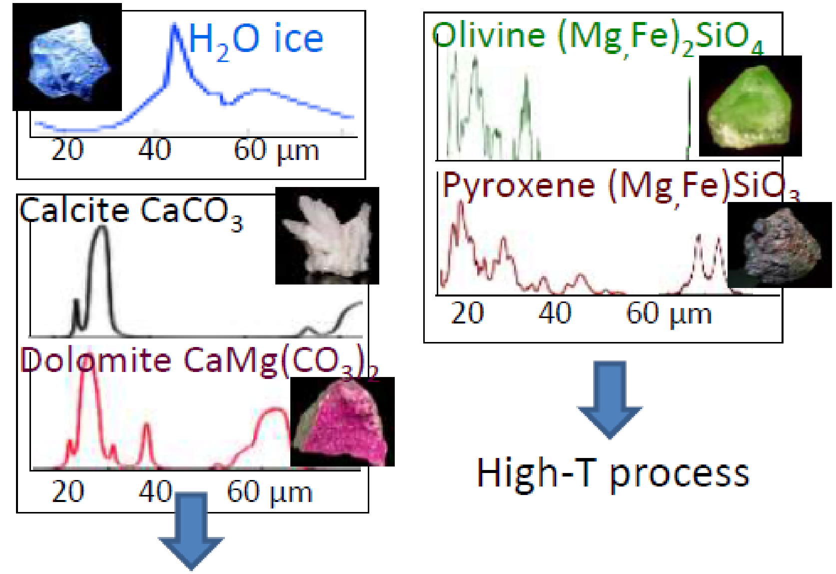


Not only detection, but characterization



Science driver: Mineralogy for interplanetary dust





Low-T process, presence of CO_2 & H_2O
Environments for life (e.g. Halevy+11)

Change of mineral properties with age?

Required capabilities:
- Dust-band blind survey to select targets, to gain statistics & serendipity.
- High-sensitivity spectrometer for detailed characterization.

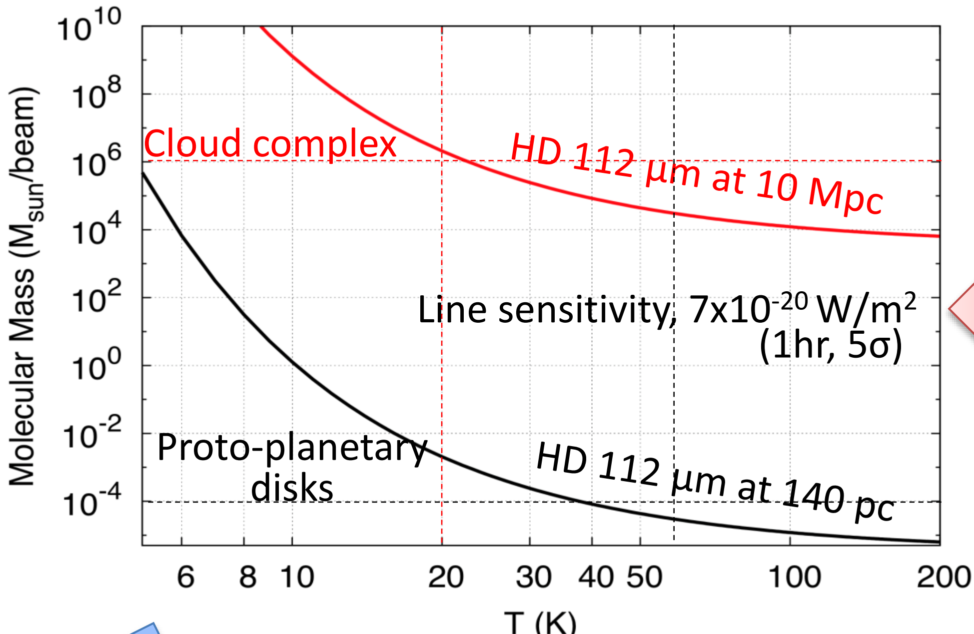
SMI-Cam (low-resolution spectral surveyor)
SMI-Spec (medium-resolution spectrometer)

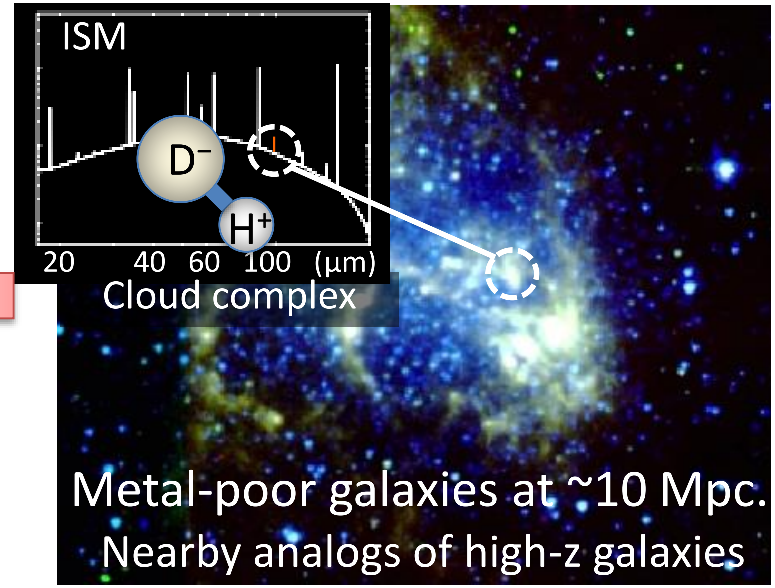
Related Science Goals - 3

Present Universe: Interplay of H_2 with material enrichment

Open Question: How much molecular gas is contained in SF clouds? (i.e. CO/H_2 ratio) How is gas being dissipated in proto-planetary disks?

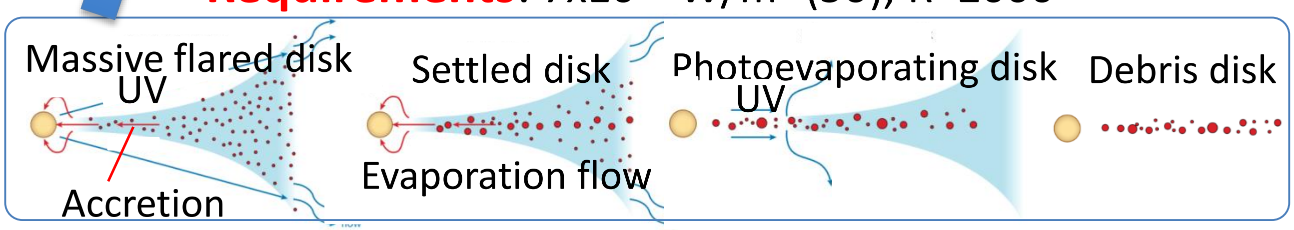
Method: The first-ever robust estimate of H_2 mass. FIR targeted spectroscopy of the HD lines. Pre-determination of temperature distribution by CO is necessary.





Science Goals: Detection of a typical $10^6 M_\odot$ cloud complex in a galaxy at 10 Mpc, $10^{-4} M_\odot$ gas from disks at 140 pc for $T_{gas} > 60$ K.

Requirements: 7×10^{-20}W/m^2 (5σ), R=2000



Notes: 3 major molecules:

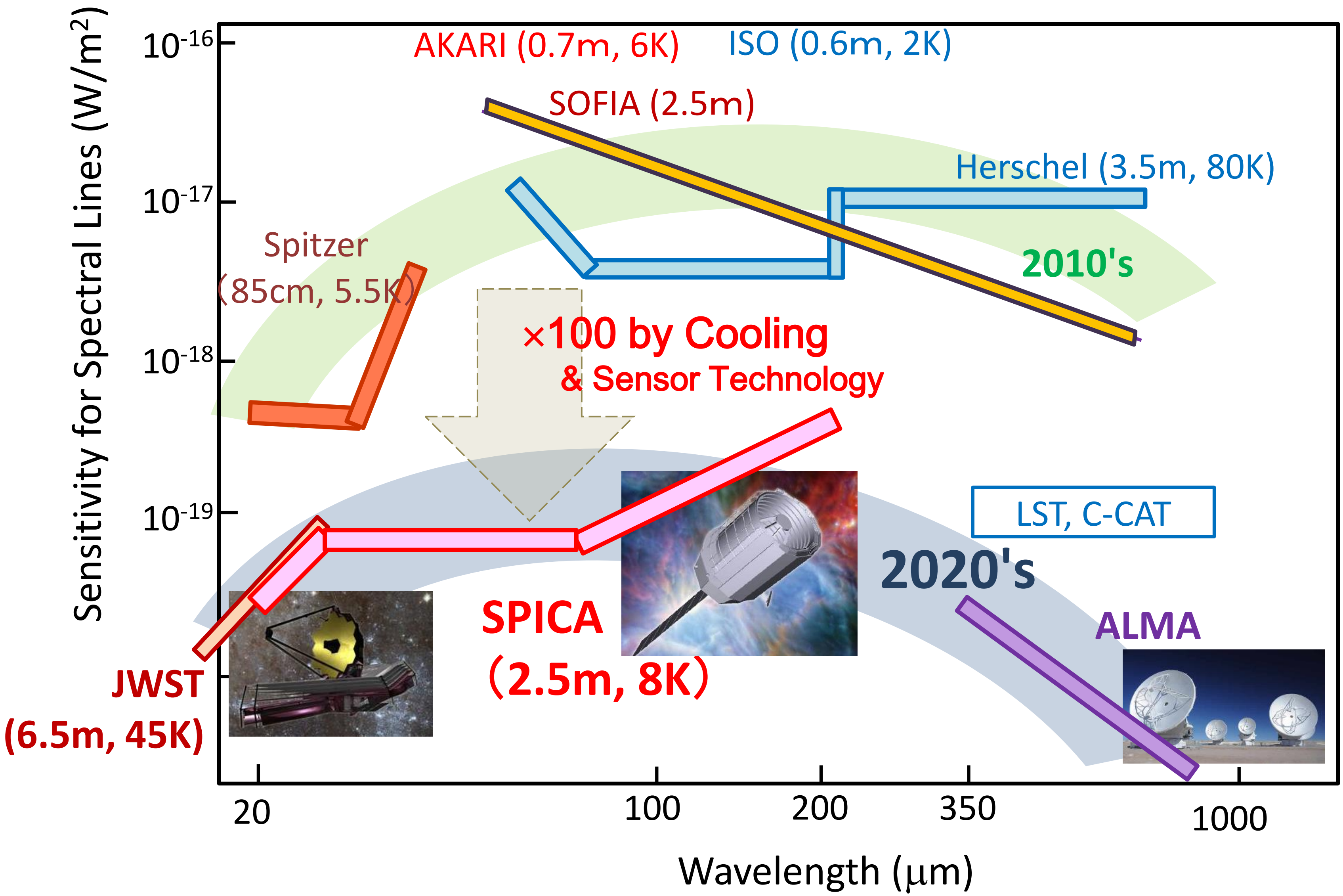
- H_2 (SPICA) → primary
- CO (ALMA, SPICA): 2nd
- H_2O (SPICA, JWST): 3rd

Extensions (under Consideration)

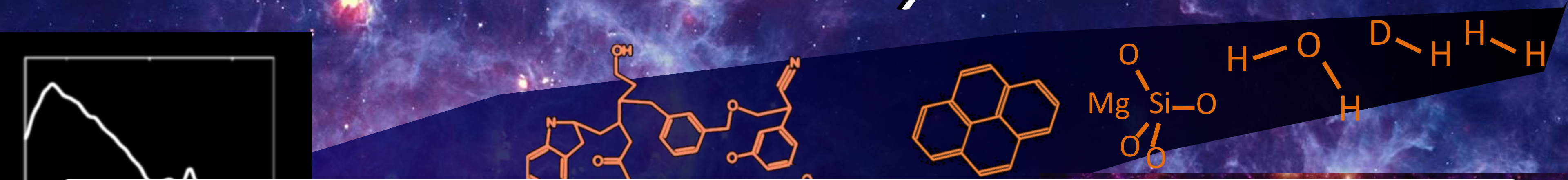
- Longer Wavelength Coverage up to 350 μm
  - In order to cover the longer wavelength gap to ALMA, the telescope temperature must be below 6 K. US scientists are going to join SAFARI/Grating. SAFARI might be able to include a part of the capability of BLISS type instruments.

- Shorter Wavelength Coverage down to 5 μm
  - Japanese exoplanet scientists wants to make 'Exoplanet Transit IR Spectroscopy.' As SMI is a grating spectrometer, the shorter wavelength capability may be able to be extended to 5 μm with little resources for the purpose of this science.

Comparison of Infrared Telescopes



Summary



◆ SPICA will reveal when and how our Universe becomes material-rich and provides habitable places there.