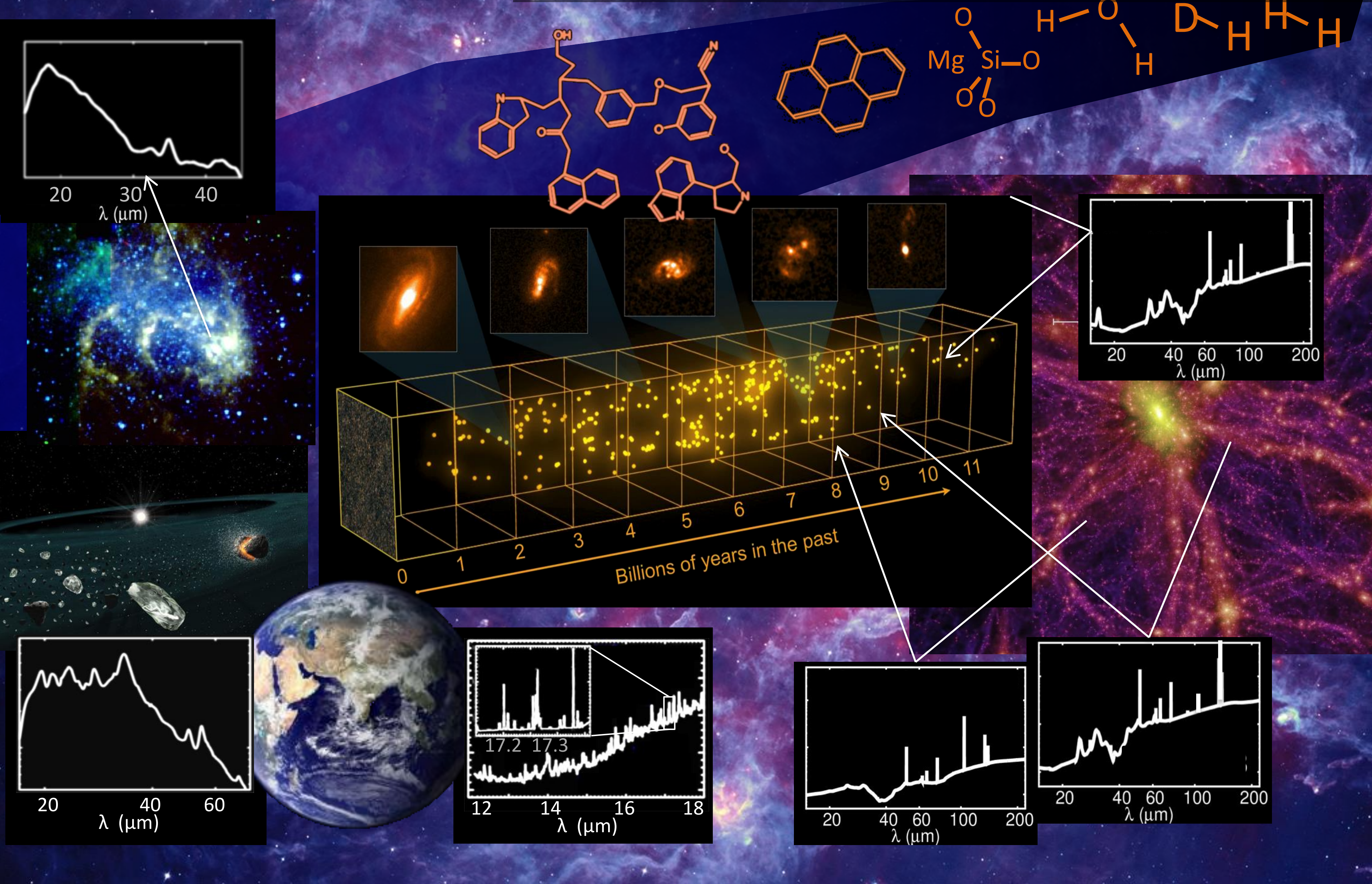
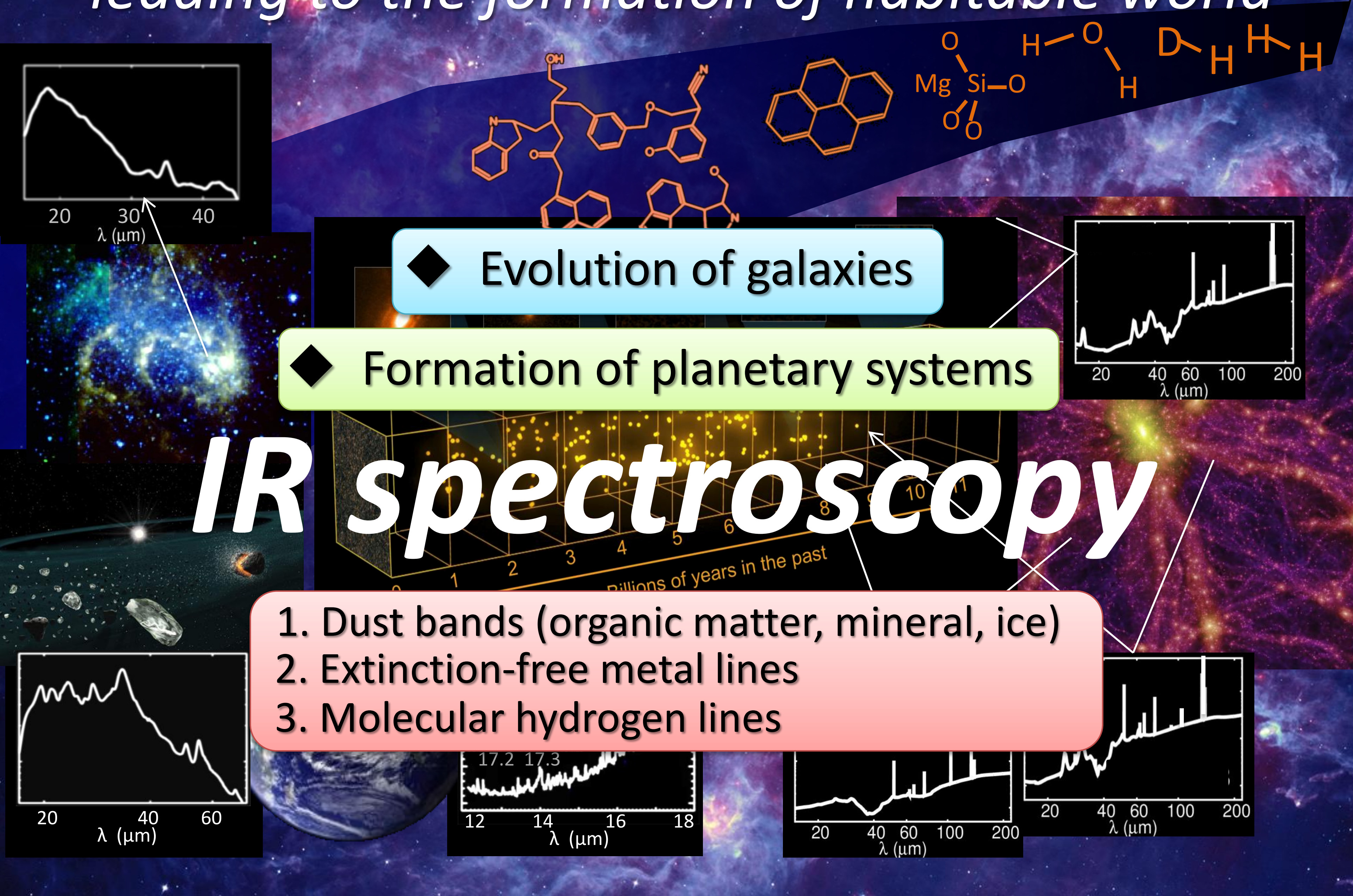
SPICAの現状

金田英宏（名大） 2015/6/5 第二回銀河進化研究会



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

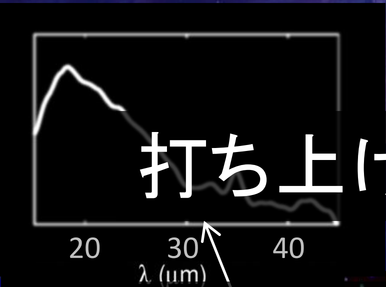


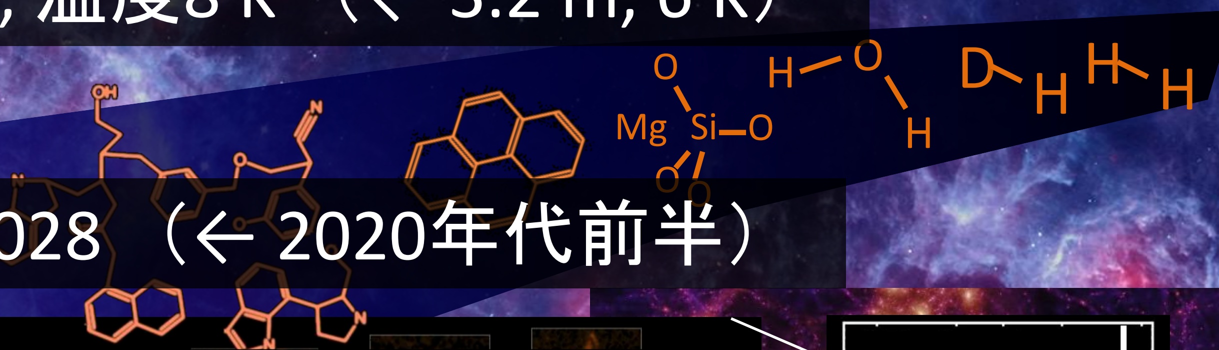
- ◆ Evolution of galaxies
- ◆ Formation of planetary systems

IR spectroscopy

1. Dust bands (organic matter, mineral, ice)
2. Extinction-free metal lines
3. Molecular hydrogen lines

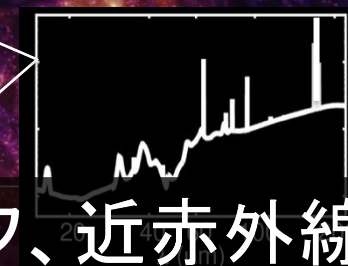
望遠鏡口径2.5 m, 温度8 K （← 3.2 m, 6 K）





打ち上げ: 2027-2028 （← 2020年代前半）

JAXA-ESA共同ミッション （← JAXA主導）



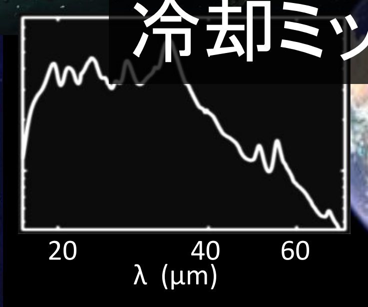
波長17-210 μm + α（← 5-210 μm + コロナグラフ、近赤外線）

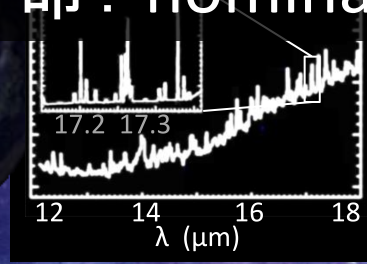
(1) 遠赤外線装置SAFARI（欧州） SAFARI, R=300, 3000 (=λ/δλ)

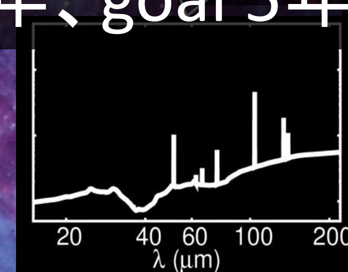
(2) 中間赤外線装置SMI（日本、大学）, R=50, 1000, 25000

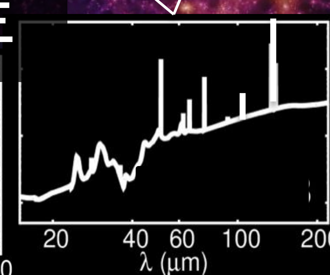
(3) 系外惑星トランジット分光器（UK） SPEChO

冷却ミッション寿命：nominal 3年、goal 5年









SPICA/SAFARI Fact Sheet

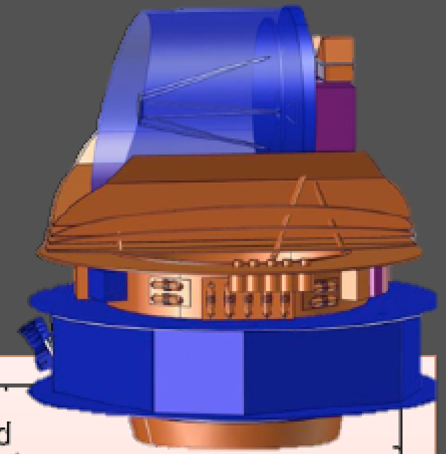
SAFARI Overview

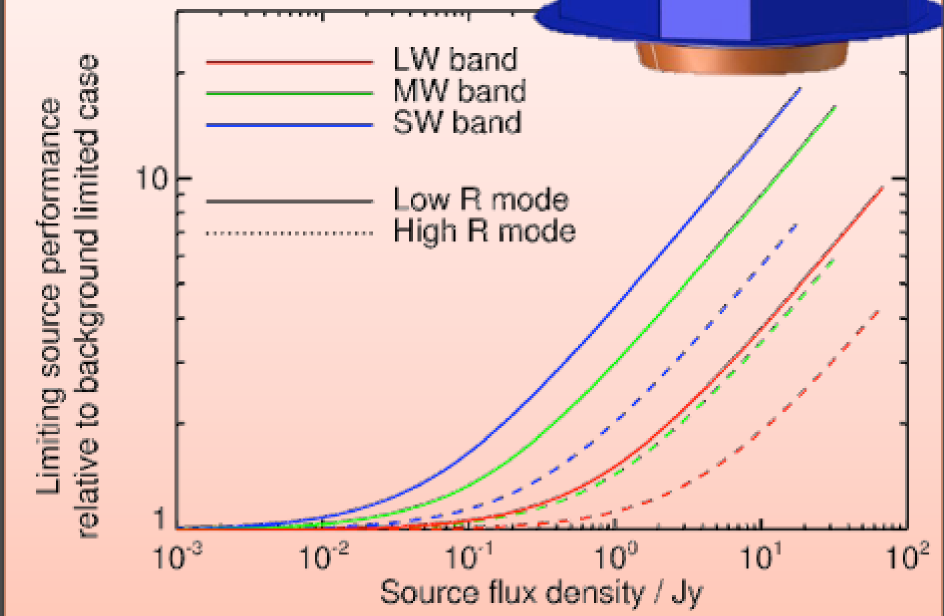
- Three band ***grating spectrometer***
- Continuous spectroscopic capability from 34-210 μm

Parameter	Waveband		
	SW	MW	LW
Band centre / μm	47	85	160
Wavelength range / μm	34-60	60-110	110-210
Band centre beam FWHM	4.7″	8.6″	16″
Point source spectroscopy (5σ-1hr)			
R~300* **Limiting flux / x10^{-20} Wm^{-2}**	5.3	4.5	6.5
R~300* **Limiting flux density / mJy**	0.25	0.36	0.92
R~3000* **Limiting flux / x10^{-20} Wm^{-2}**	25	24	29
R~3000* **Limiting flux density / mJy**	1.2	2.0	4.1
Mapping spectroscopy (5σ-1hr)**			
R~300* **Limiting flux / x10^{-20} Wm^{-2}**	59	28	22
R~300* **Limiting flux density / mJy**	2.8	2.3	3.0
R~3000* **Limiting flux / x10^{-20} Wm^{-2}**	340	190	120
R~3000* **Limiting flux density / mJy**	17	15	17
Photometric mapping (5σ-1hr)**			
Limiting flux density / mJy	0.3	0.2	0.3

SPICA Mission

- ESA/JAXA collaboration
- Telescope effective area 5 m^2
- Primary mirror temperature 8K
- Goal mission lifetime – 5 years





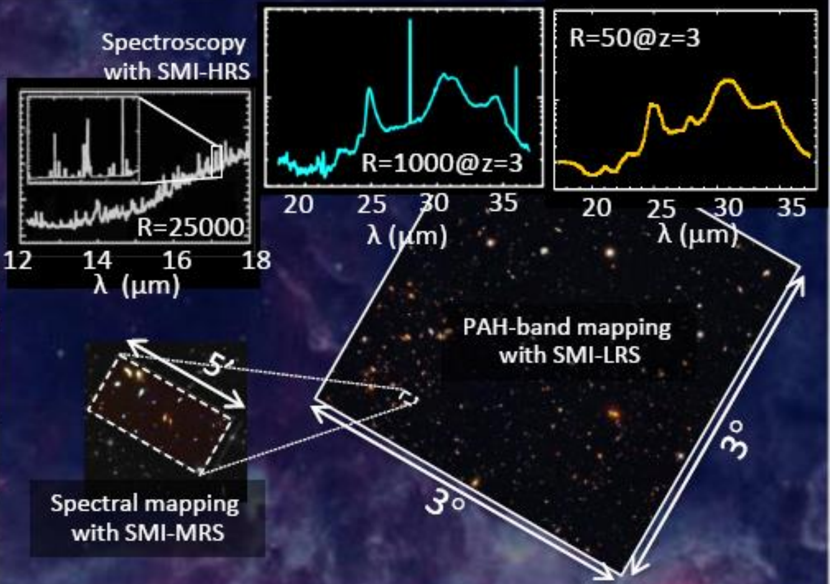
- Change in system performance, as a function of target flux density, relative to the background limited case.
- The decrease in sensitivity is a result of the increased photon noise from the target source
- Data given up to the instrument saturation limits for each band (22, 37 and 73 Jy for the SW, MW and LW bands respectively.

* Resolving powers are all calculated at band centre
** Mapping performance is for a reference area of 1 arcmin^2

Grating spectrometer with sensitivity ~5x10^{-20} W/m^2

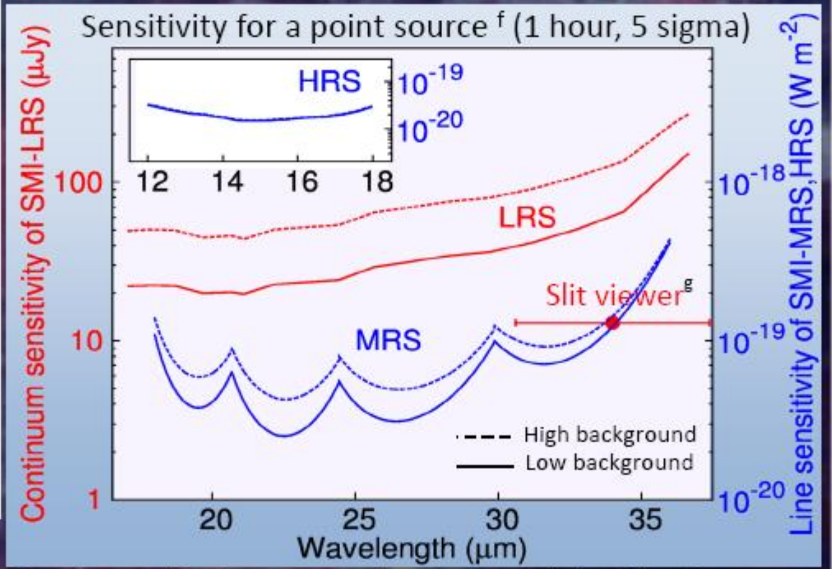
SPICA / SMI Fact Sheet

SPICA Mid-infrared Instrument (SMI) covers
the wavelength range of 12–37 μm
with three spectroscopic channels: LRS, MRS and HRS.



Parameter		Function: LRS (multi-slit with slit viewer)	MRS	HRS
Wavelength range		17-37 μm	18-36 μm	12-18 μm
Spectral resolution		50	1000-2000 [a] (point source) 1000 [c] (diffuse)	22000-33000 [b] (point source) 25000 [c] (diffuse)
Field of View		600"x 3."7 x 5 slits	60" x 3."7 (slit)	6"x1."4 (slit)
FWHM		1."2 (12 μm) - 3."7 (37 μm)		
Pixel scale		0."7x 0."7	0."7	0."5
Detector		Si:Sb 1K x 1K	Si:Sb 1K x 1K	Si:As 1K x 1K
Point source	Cont. sensitivity (1 hr, 5 sigma)	20 – 140 μJy	200 – 4000 μJy	2 – 4.2 mJy
Point source	Line sensitivity (1 hr, 5 sigma)	(6 – 23) x 10^{-20} W/m^2	(3 – 40) x 10^{-20} W/m^2	(1.5 – 3) x 10^{-20} W/m^2
Point source	Survey speed [d]	~ 45 arcmin^2/hr	~ 1.5 arcmin^2/hr	-
Diffuse	Sensitivity [e] (1 hr, 5 sigma)	Continuum	Line	
Diffuse		0.1 – 0.5 MJy/sr	(0.5 – 2) x 10^{-9} W/m^2/sr	(4 – 8) x 10^{-10} W/m^2/sr
Saturation limit		~ 2 Jy	~ 140 Jy	~ 1200 Jy

a: λ/δλ=1000 at λ=35 μm b: λ/δλ=25000 at λ=16 μm
c: λ/δλ does not change with wavelength.
d: survey speed for the 5 sigma detection of a point source with the continuum flux of 100 μJy and the line flux of 3×10^{-19} W/m^2 for LRS and MRS, respectively.
e: sensitivity for a diffuse source in a 4" x 4" area



f: Background levels are assumed to be 80 MJy/sr (High) and 15 MJy/sr (Low) at 25 μm.
g: Slit viewer for LRS: 10'x10' FoV, λ=30-37 μm (λ_c=34 μm)

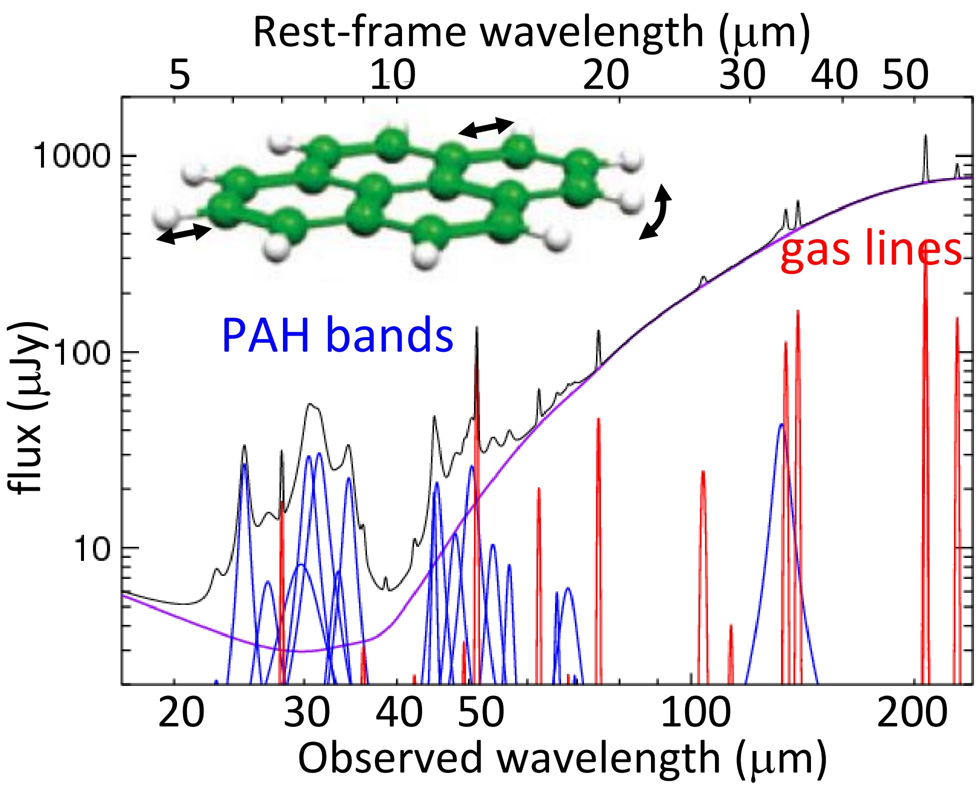
SMI Factsheet v4 – 18 May 2015

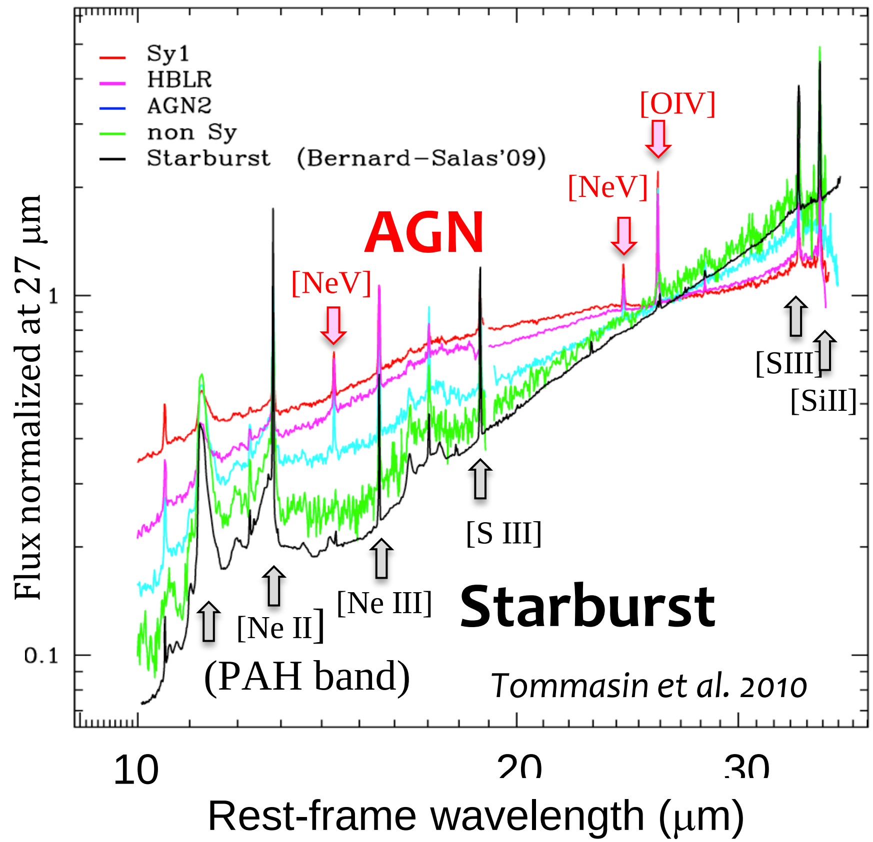
3 channels: LRS (10' slit x 5 + 10'x10' viewer), MRS, HRS (R=25000)

IR spectroscopy of galaxies

SPiCa

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





[Ne V], [O IV] are robust tracers of AGN.
[Ne II], [S III], [O III], [N III], etc.: tracer of gas density, temperature, metallicity.
Gas Lines: reliable estimate of physical conditions of star formation activity.

EW (PAH): SF/AGN power ratio

PAH bands: much stronger than gas lines

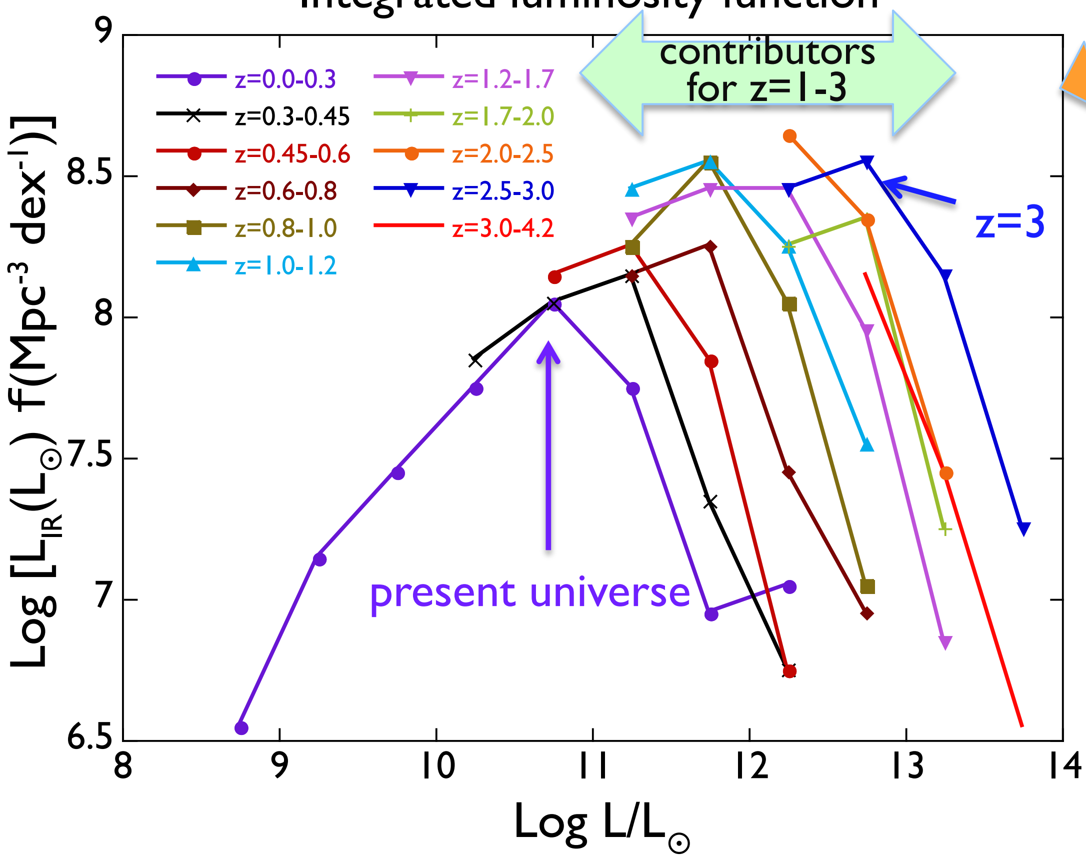
How deep do we need to observe?

SPiCa

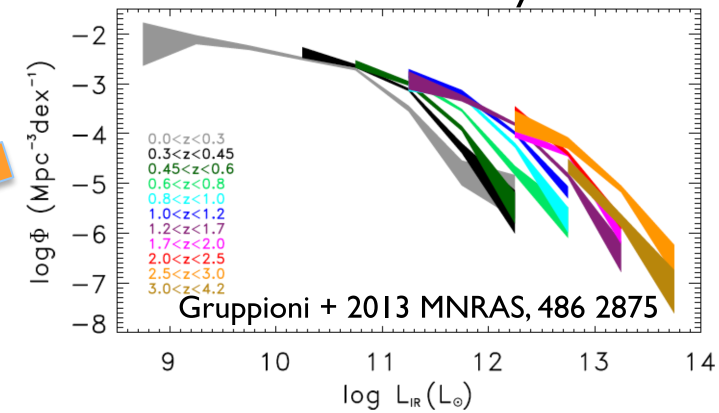
Integrated luminosity function suggests that major contributors to the IR luminosity ('main sequence' galaxies) become more luminous with redshift.

At z=3, galaxies with $L=1\times10^{12}\ L_\odot$ have to be observed to understand the IR luminosity density.

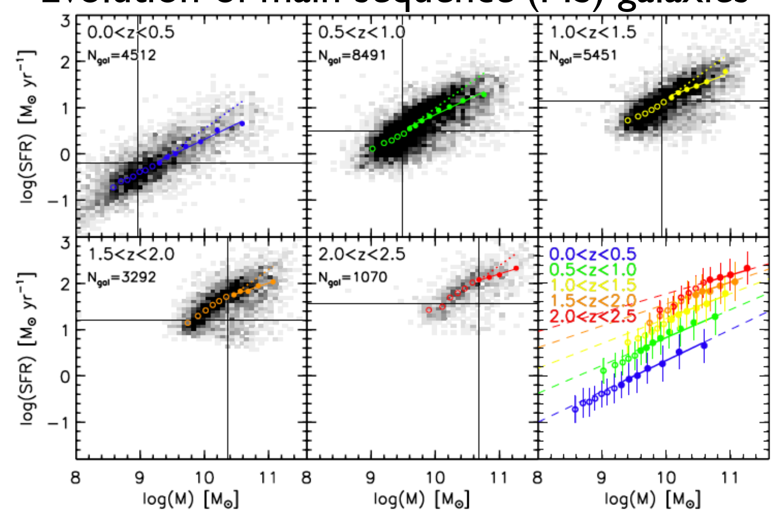
Integrated luminosity function



Evolution of luminosity function

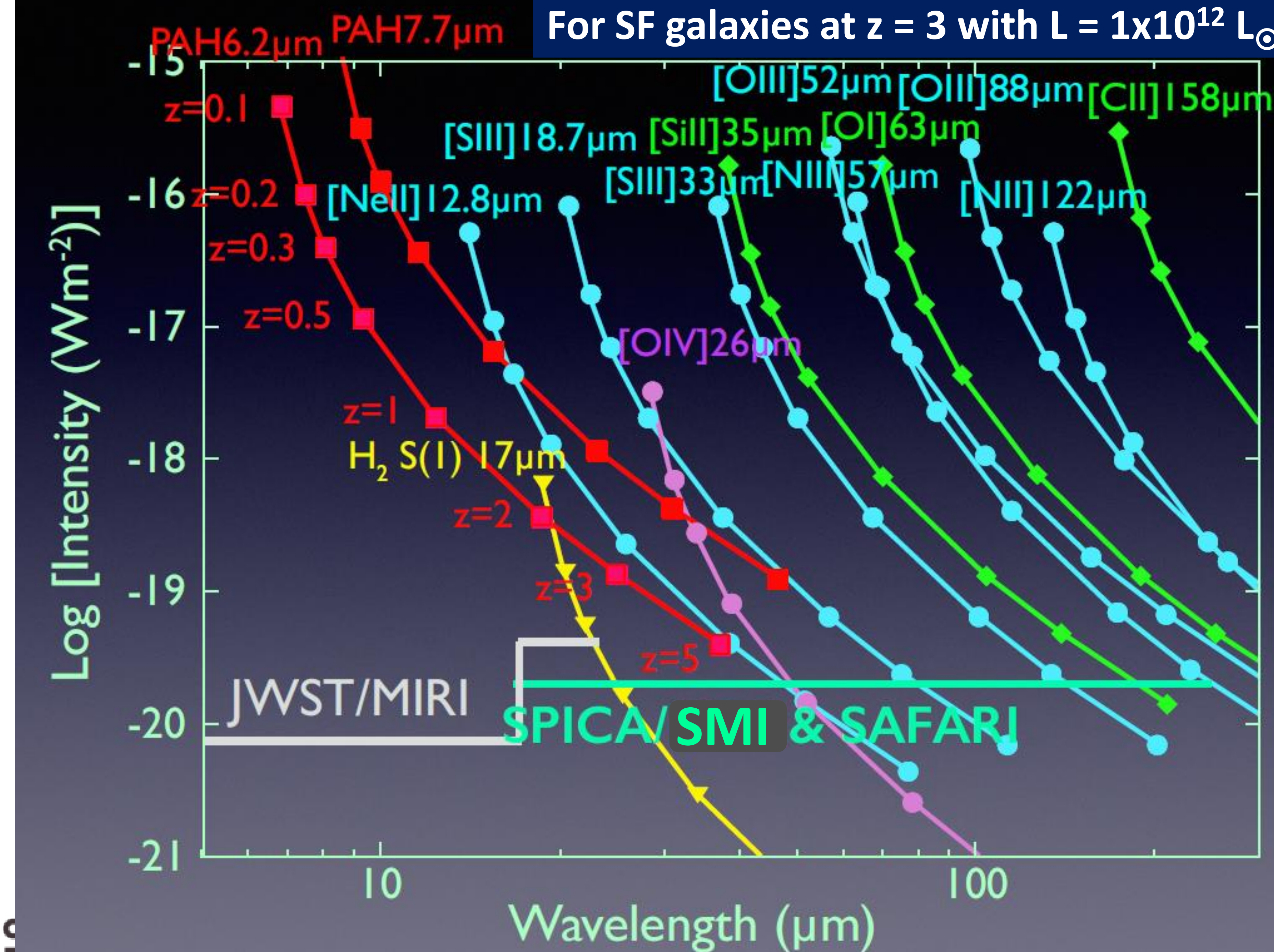


Evolution of main sequence (MS) galaxies

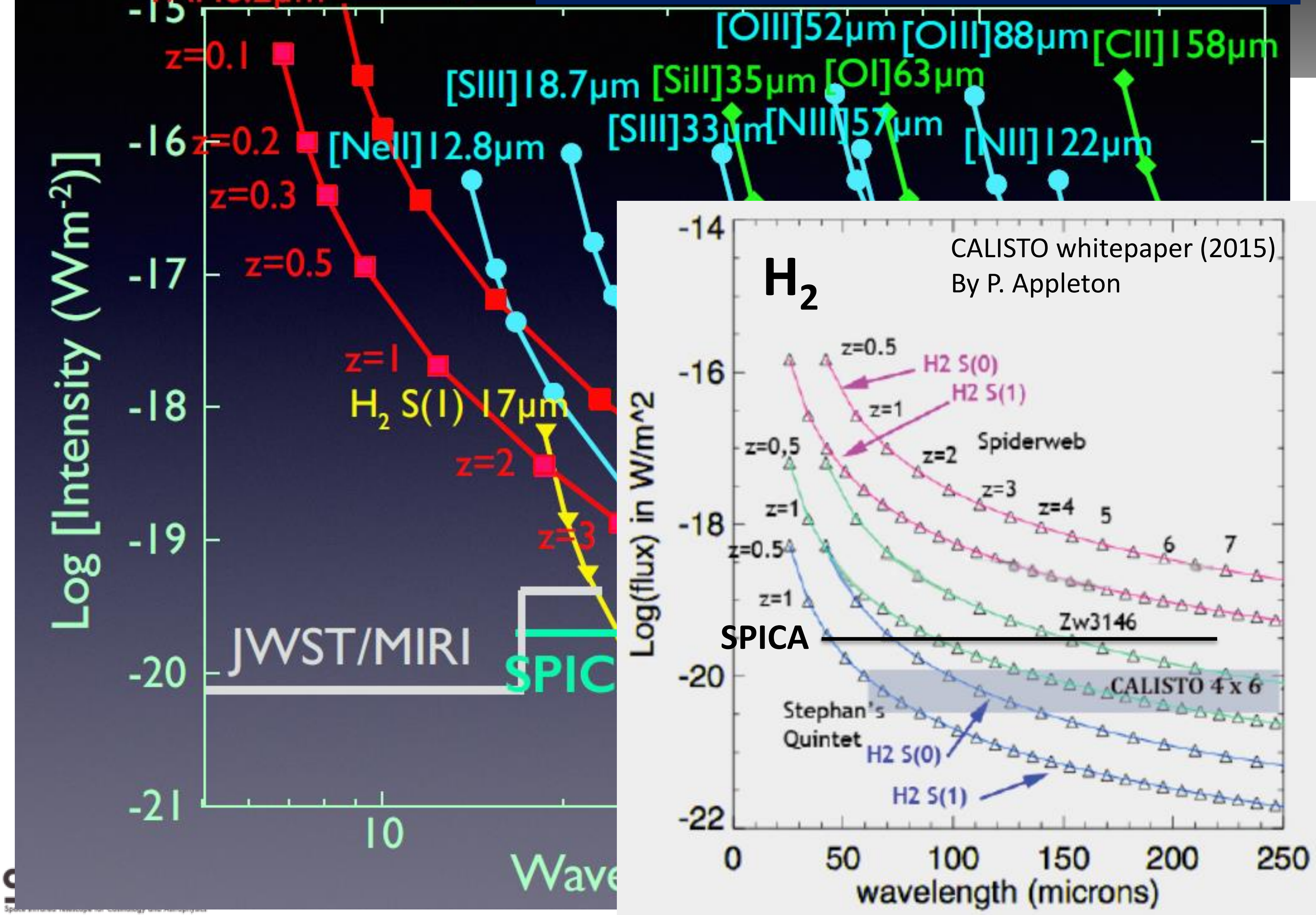


Whitaker+ 2012, ApJ 754, L29

For SF galaxies at z = 3 with L = $1 \times 10^{12}\ L_{\odot}$



For SF galaxies at z = 3 with L = 1x10^{12} $L_\odot$



Gas line & dust band diagnostics: nearby Universe → distant Universe

SPiCa

Atomic gas line	indicator	purpose
[SIII] 18.7 μm	SF	$n_e \sim 10^4$ cm^{-3}
[Cl IV] 20.4 μm	SF	
[ArIII] 21.8 μm	SF	$n_e \sim 10^5$ 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	$n_e \sim 10^4$ cm^{-3}
[SiII] 34.8 μm	J-shock/PDR	
[NeIII] 36.0 μm	SF	$n_e \sim 10^5$ cm^{-3} (w JWST)
[OIII] 51.8 μm	SF	$n_e \sim 10^3$ cm^{-3} metallicity
[NIII] 57.3 μm	SF	temperature metallicity
[OI] 63.2 μm	PDR/C-shock	n_H
[OIII] 88.4 μm	SF	$n_e \sim 10^3$ cm^{-3} metallicity
[NII] 121.7 μm	SF	$n_e \sim 10^2$ cm^{-3}
[OI] 145.5 μm	PDR	n_H
[CII] 157.7 μm	PDR	N_H
[NII] 205.2 μm	SF	$n_e \sim 10^2$ cm^{-3}

Molecular gas lines	indicator	purpose
H_2 17.0, 28.2 μm	PDR/ C-shock	N_{H2}
HD 56, 112 μm	PDR	CO-dark gas tracer
OH 53, 84, 119, 163 μm	PDR/ C-shock	
High-J CO	C-shock	
H_2O	SF	

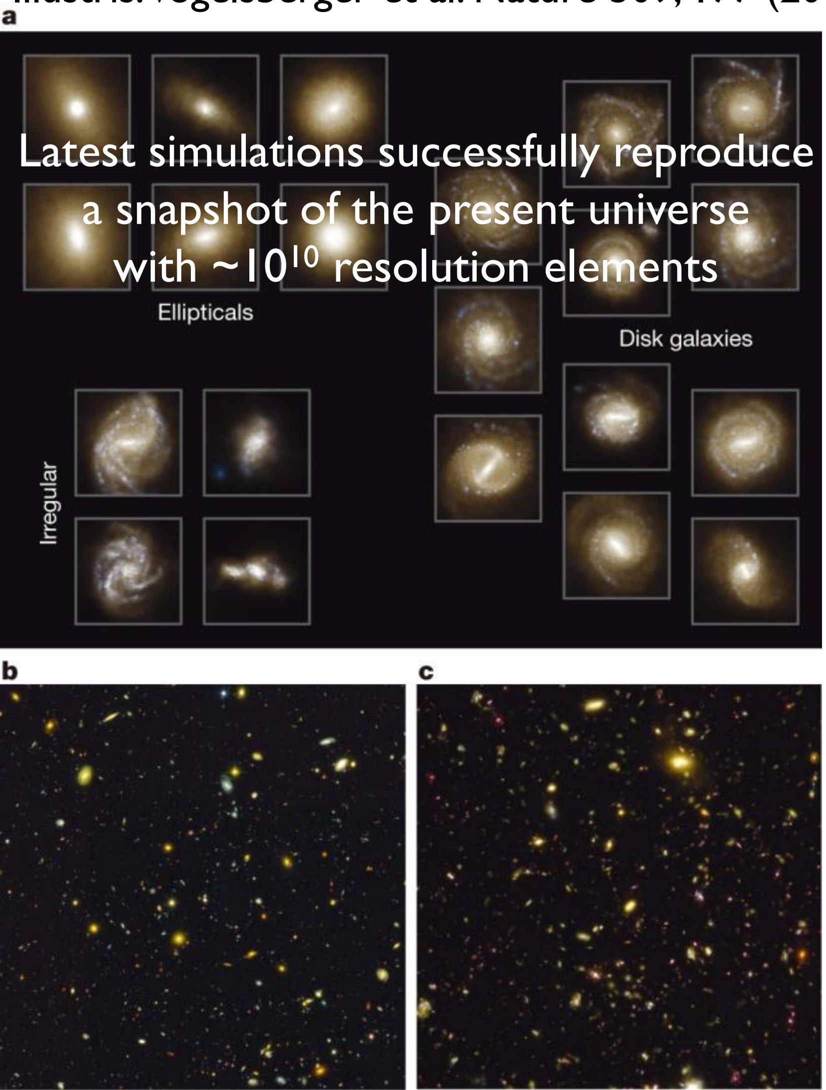
Dust band	indicator	purpose
H_2O ice 44, 62 μm	PDR/MC	crystallinity
Crystalline silicate 24 – 69 μm	PDR/MC/CSM/SNR	mineralogy, crystallinity temperature
graphite 30 μm	PDR/XDR	crystallinity
FeO 20 μm	SNR	
MgS 30 μm	CSM/SNR	
FeS 30-50 μm	SNR	
Carbonate 20-100 μm		

Evolution of galaxies
How well do simulations simulate our Universe ?

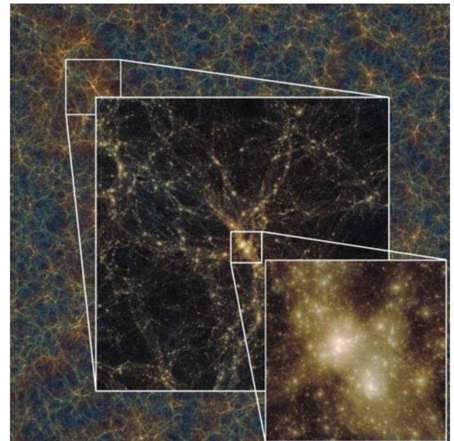
SPiCa

Cosmological hydro-dynamical simulations (CHS) are performed based on the first principle

Illustris: Vogelsberger et al. Nature 509, 177 (2014)



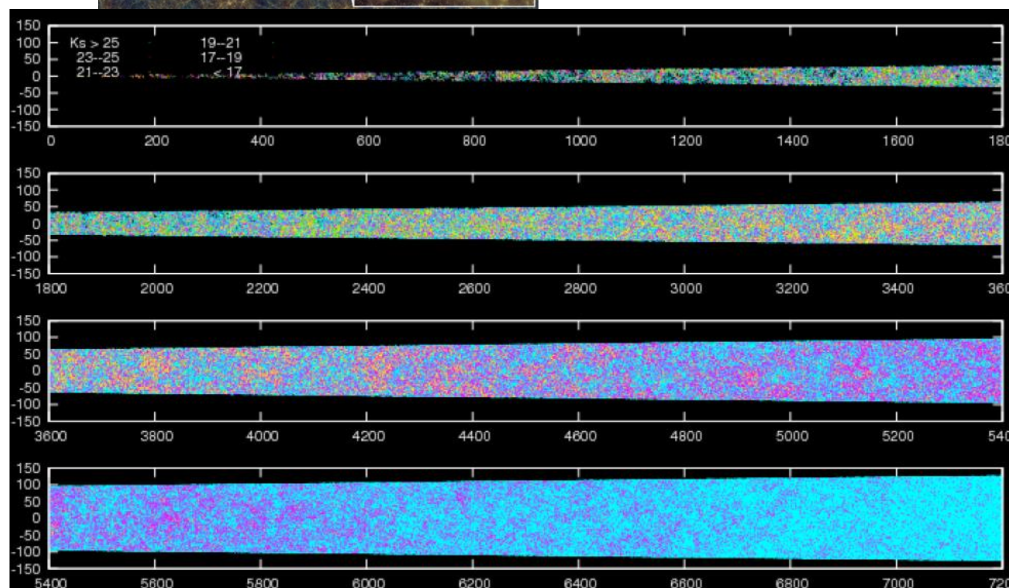
Semi-analytical models (SAM) can explore a large parameter space



DM halo N-body simulation (Ishiyama+15)

\+

Mitaka model (Makiya+15 in prep)



Evolution of galaxies
How well do simulations simulate our Universe ?

SPiCa

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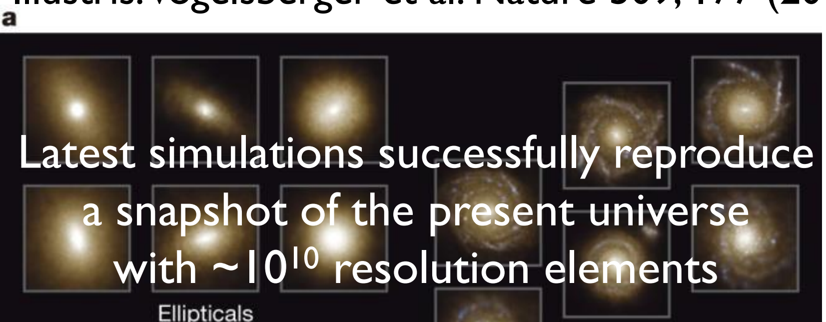
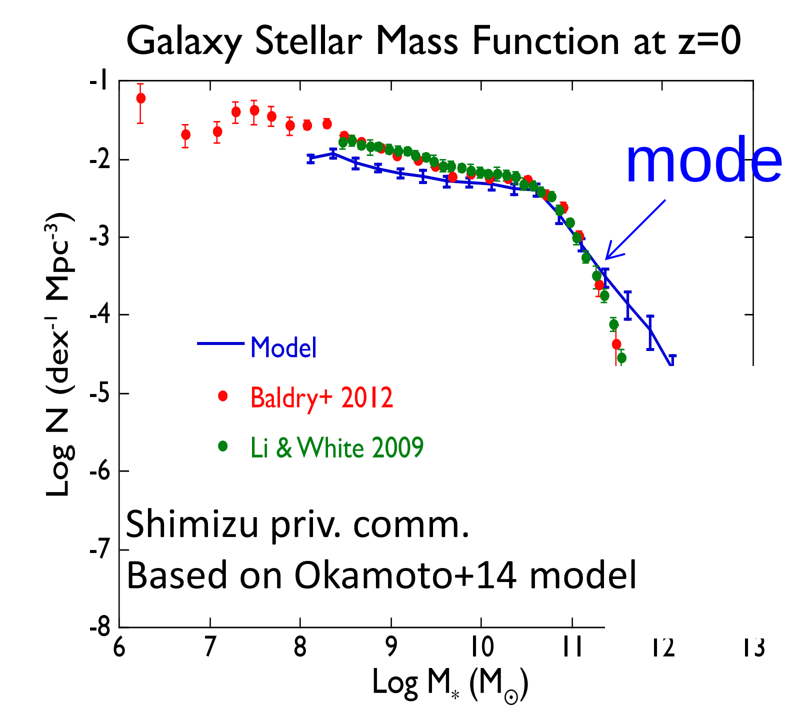
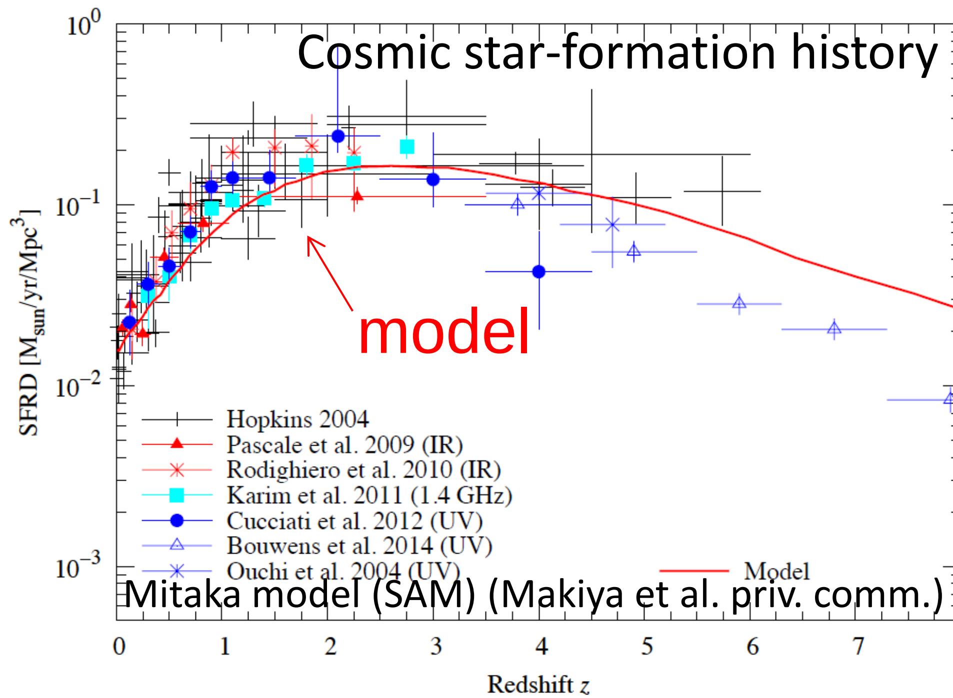


Latest simulations successfully reproduce a snapshot of the present universe with ~10^{10} resolution elements

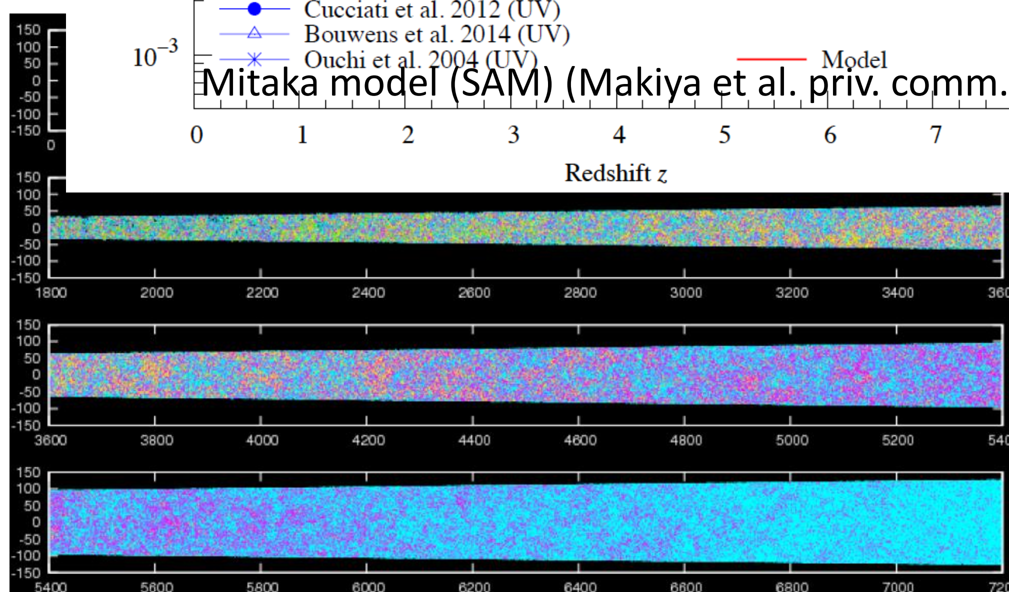


Shimizu priv. comm.
Based on Okamoto+14 model

Semi-analytical models (SAM) can

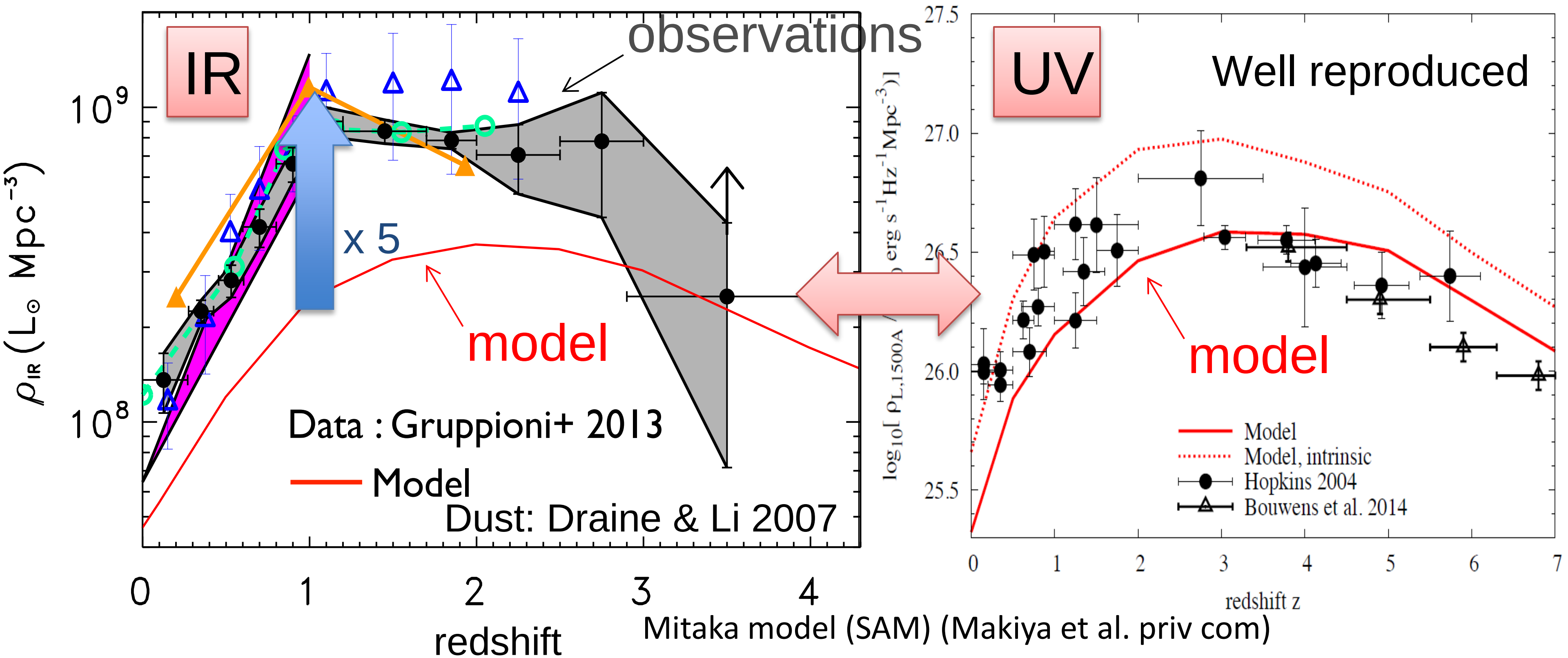


Mitaka model (SAM) (Makiya et al. priv. comm.)



Discrepancy in IR luminosity density (Herschel)

Total IR luminosity density vs redshift



Mitaka model (SAM) (Makiya et al. priv com)

- ◆ Top-heavy IMF in starburst is proposed to solve the discrepancy.
- ◆ Dust process (growth and destruction) needs to be correctly treated in simulations.

Key issues to be answered by SPICA

SPiCa

There are still significant discrepancies between observations and simulations.

Key issues to be answered:

(1) AGN contribution to IR luminosity at z~1-3

→ To correctly estimate star-formation contribution to IR luminosity

(2) Variations, if any, in IMF in IR-bright galaxies as a function of redshift

→ To understand the discrepancy in IR luminosity density at z=1-3

(3) Evolution of metallicity and dust as a function of redshift

→ To understand the dust process in dusty IR bright galaxies correctly

(4) Effects of AGN feedback on the star-formation as a function of redshift

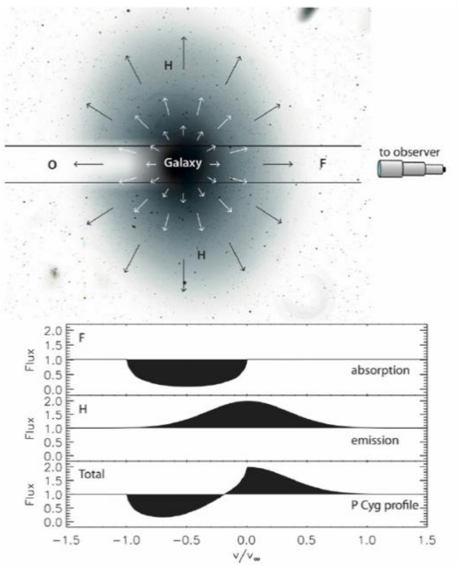
→ To understand the decline of SFRD for z<1 and the GSMF

Observations of AGN feedback

SPiCa

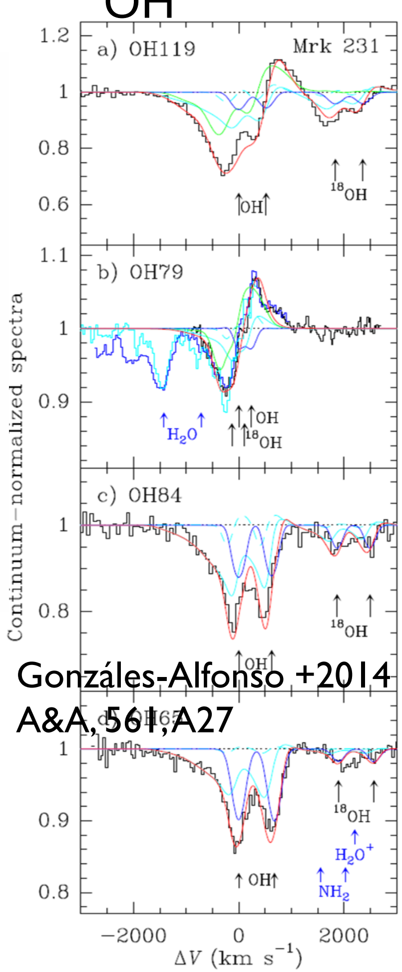
To study quenching star formation, molecular outflow has to be investigated.
P Cygni profile of OH lines detected by Herschel/PACS unambiguously shows the presence of molecular outflow of ~200 km/s.

Multiple H_2 lines for z = 0 – 2 &
P Cyg profiles of CO (v = 1-0) lines for z = 1.5-2.5 with SMI-HRS



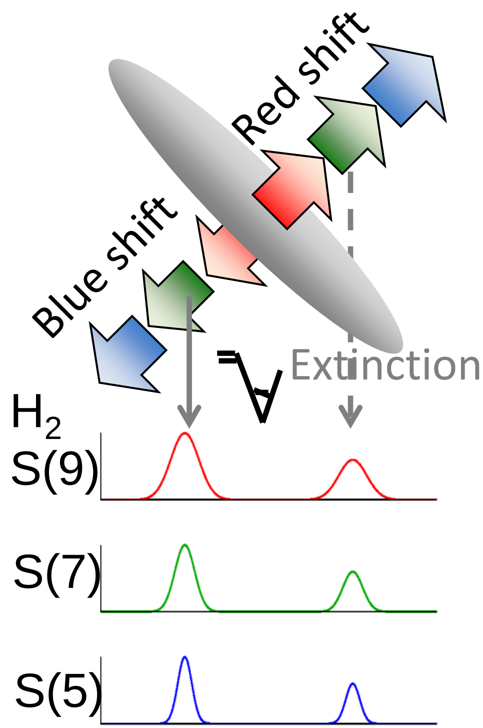
Spoon+ 2013 ApJ 775, 127

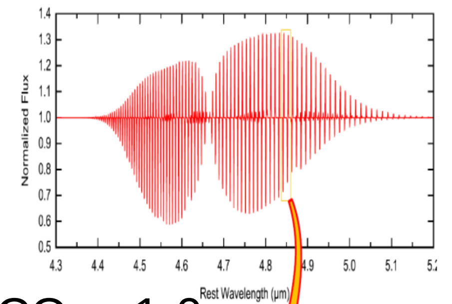
OH



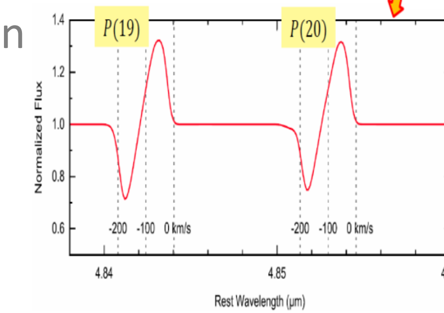
Gonzáles-Alfonso +2014
A&A, 561, A27

P Cyg profiles of OH lines for z < 1.5 with SAFARI





CO v=1-0



CO v=1-0 simulation
by Baba et al. priv. comm.

+

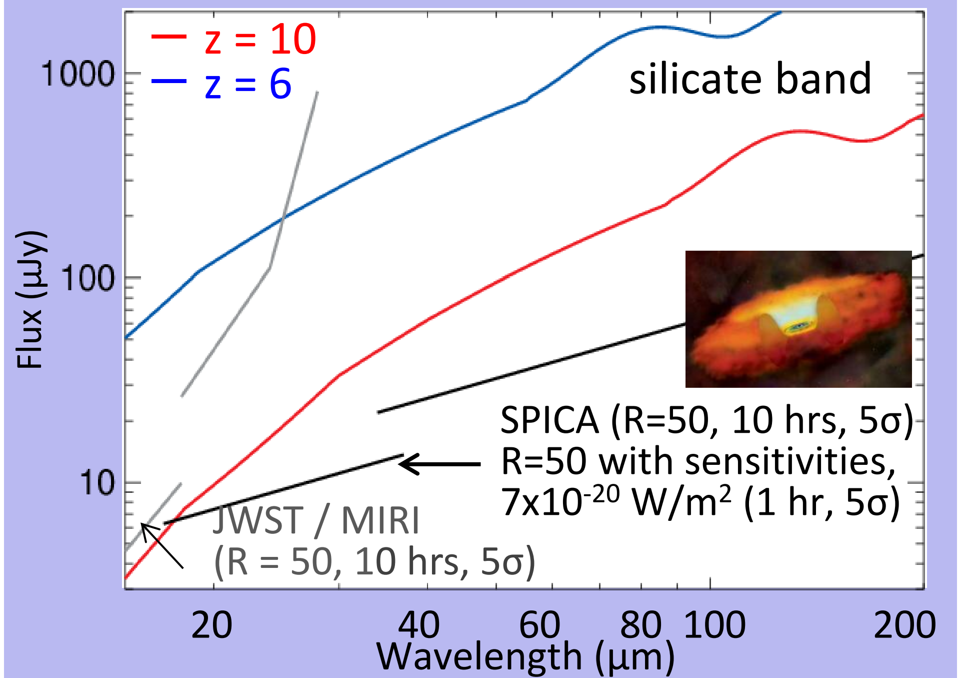
Multiple atomic & ionic lines with SAFARI & SMI

The first formation of mineral & organic matter

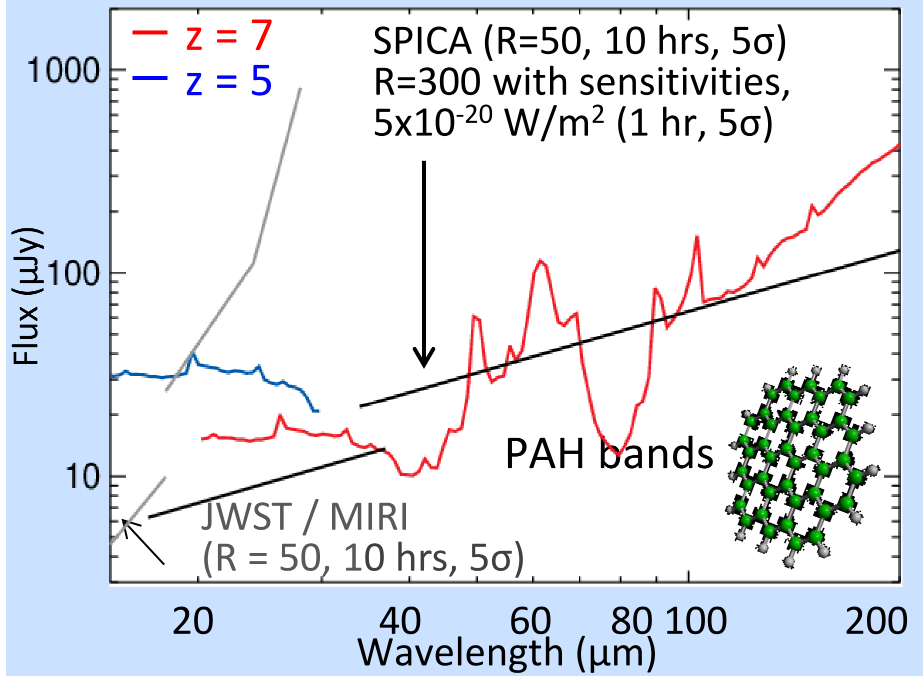
How were the first mineral & organic matter formed?

MIR & FIR targeted spectroscopy of high-z quasars & star-forming galaxies

High-z quasars (1×10^{13} $L_\odot$)



High-z star-forming galaxies (1×10^{13} $L_\odot$)



- Detection of dust from z = 10 quasars. Only ~ 50 $M_\odot$ dust is detectable, thanks to high dust temperature.
- Study of all the bands of PAHs in z = 7 star-forming galaxies.

Not only detection, but also characterization of the first mineral & organic matter.

Observation plan

SPiCa

Targets observed by

AKARI, Subaru, Spitzer, Herschel, ALMA, JWST, Euclid, SKA, TMT, ATHENA, TESS, PLATO,,,

- ◆ high-z galaxies, AGN outflow, nearby dwarf galaxies,,,
- ◆ proto-planetary disks, debris disks, exo-planets,,,

Follow-up observations

SAFARI | SMI-HRS | SMI-MRS | SPEChO

- ◆ Pointed spectroscopy
- ◆ Spectral mapping of nearby galaxies
- ◆ Spectral mapping of Galactic objects

Unbiased survey SMI-LRS

(17-37 μm, R=50-100) + (34 μm R=5)

◆ 10 deg^2 blind survey (600 hrs)

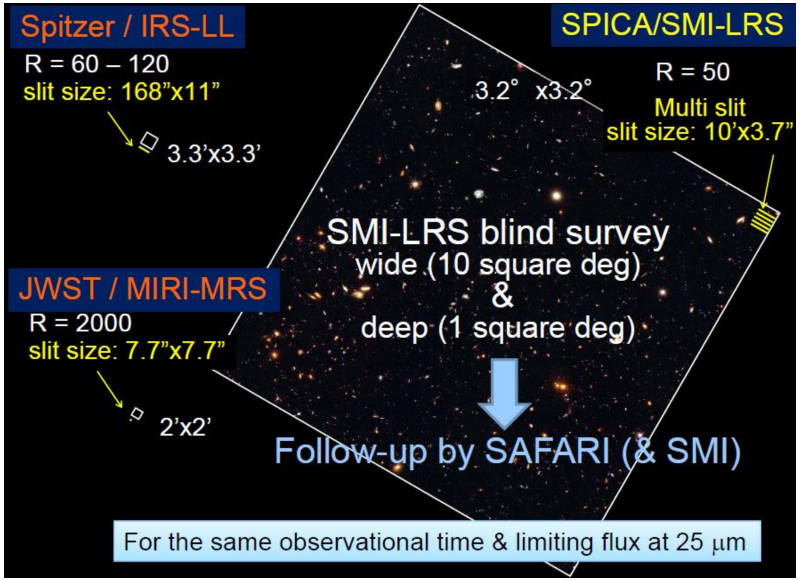
<u>Better statistics</u>

(51,000 PAH galaxies 3,700 AGNs 13,000 MS stars)

◆ 1 deg^2 blind survey (500 hrs)

<u>Fainter objects</u>

(sub-L* galaxies, Debris disks with ~2 zodi)



SPICAプロジェクトの経緯

2007年度　大型衛星計画に提案。これまでのMロケットを用いた衛星の規模（中型衛星計画）を超えた、多くの分野が共同して支え、実施する、フラッグシップミッション。

2008年度　大型衛星計画としてミッション定義審査MDR　合格
以降プリプロジェクト発足

2010年度　大型衛星計画としてシステム要求審査SRR　合格

2011年度　中型衛星を超える規模ならば、宇宙科学の外側からの貢献（資金、人的体制）が必要
以降、リスク低減フェーズ
宇宙科学ロードマップ、大型は難しくなる

2013年度　PLAN-Bへの変更　戦略的中型
コストオーバーラン問題

2014年度　PLAN-D（SPICA再定義）　ESA-JAXA共同技術検討

2015年度　JAXA側：国際評価委員会、（ΔMDR＋SRR相当）審査、計画変更審査。 **ESA側：2016年1月募集開始予想のM5に提案。**

Work-Sharing Plan

Telescope (ESA)

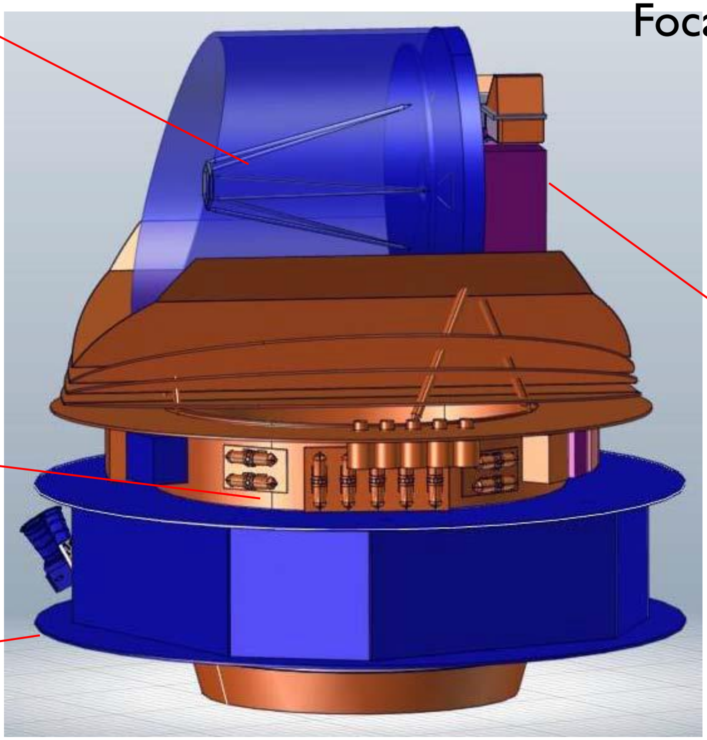
Payload Module

Cryocooler

Bus Module

Launcher

SPICA Data Center (NAOJ)



Focal Plane Attitude Sensor

Focal Plane Instrument Assembly

FIR Spectrometer (SAFARI)
NL + European countries + Canada & US

MIR Instrument (SMI)

Exoplanet Spectroscopy (SPEChO)
UK & European countries

Science Community
JP, Europe, US, KR, TW,,,

まとめ

- ◆ 赤外線分光による「銀河成長・物質進化過程」と「惑星系形成過程」の解明
- ◆ 望遠鏡口径2.5 m, 温度8 K, 2027-2028年打ち上げ
- ◆ JAXA-ESA共同ミッション。
  JAXA審査：今夏、ESA: 来年1月C-V proposal call予定
- ◆ コア波長：17-210 μm、ライン感度：～5×10^{-20} W/m^2
  - ・17-37 μm低分散分光撮像 ＋ 34 μm広帯域撮像
  - ・高分散 12-18 μm, ～2×10^{-20} W/m^2

(1) 遠赤外線装置SAFARI（欧州） SAFARI, R=300, 3000
(2) 中間赤外線装置SMI（日本、大学）, R=50, 1000, 25000
(3) 系外惑星トランジット分光器（UK） SPEChO

ひきつづきのご支援・ご協力をよろしくお願いいたします。

Most important: very low IR background