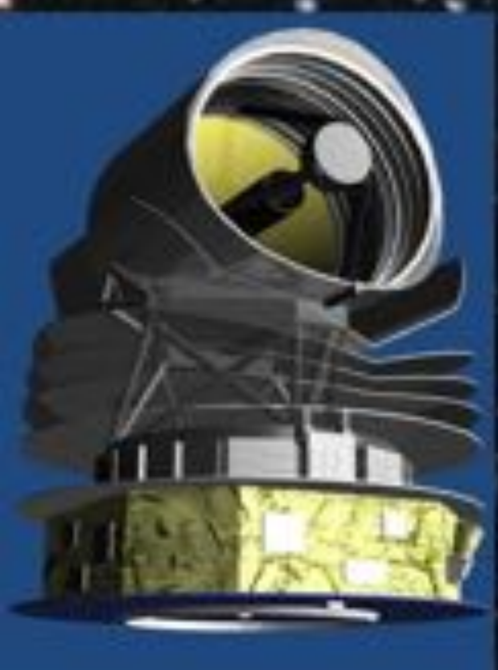
Unveiling the physical processes that regulate Galaxy Evolution with SPICA observations

Luigi Spinoglio – IAPS, INAF, Roma, Italy



SPICA Galaxy Evolution WG leader
SPICA/SAFARI Italian Responsible
Member of the SPICA Science Team of ESA

What are the hot science topics for SPICA in galaxy evolution?

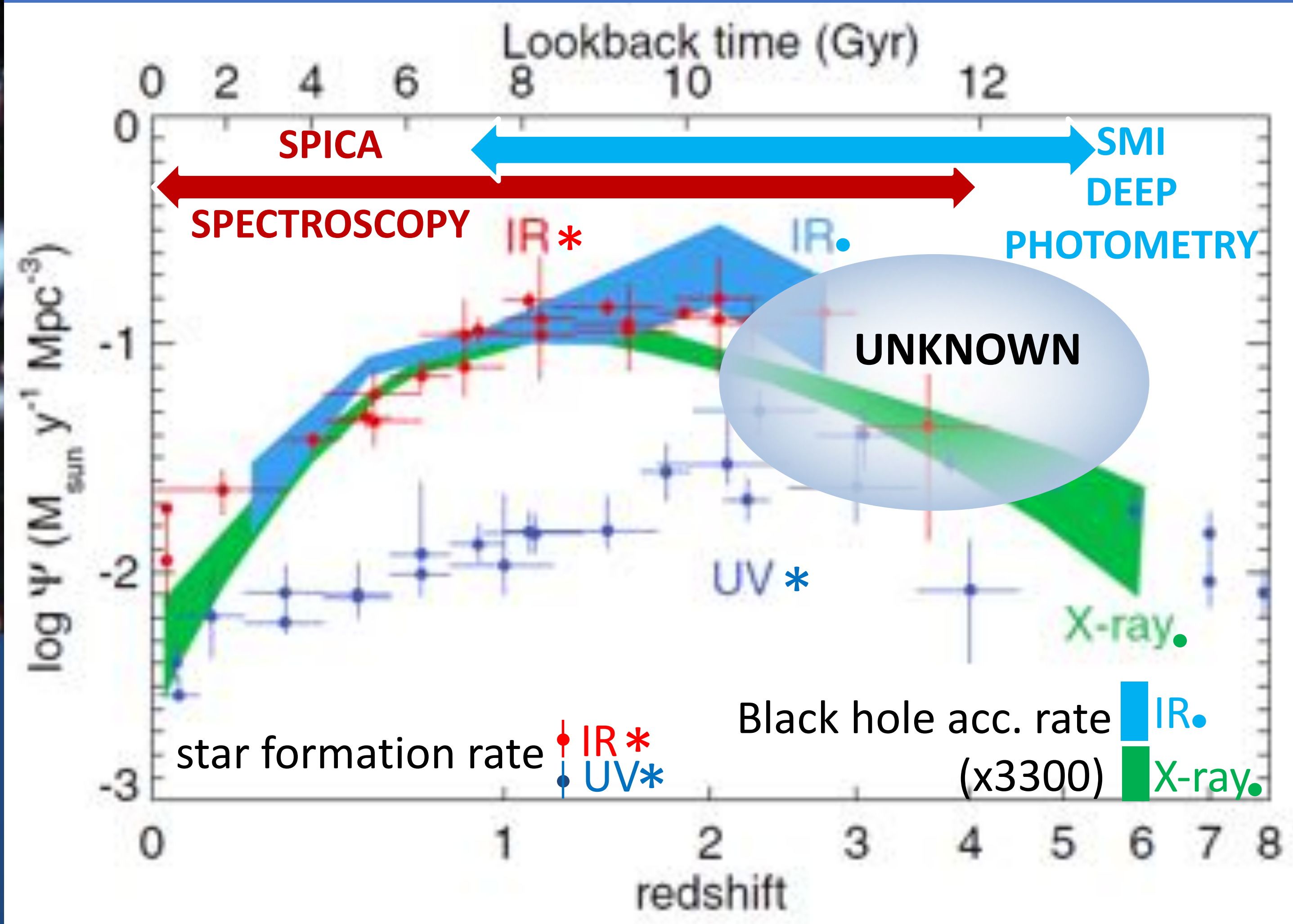
- Galaxy evolution case:

  1. Mapping BHAR and SFR through spectroscopy at $0<z<4$
  2. Feedback & Feeding in the context of galaxy evolution
  3. Chemical Evolution of Galaxies: The Rise of Metals and Dust
  4. Towards the epoch of Re-Ionization through photometric surveys
  5. Towards the epoch of Re-Ionization through deep SAFARI spectroscopy

  Explore:

  SPICA-SMI 34µm +B-BOP 60-70µm (to be implemented) large-area deep surveys would provide 2-band continuum fluxes for unbiased samples of tens of thousands of galaxies

Galaxy evolution is obscured by dust at redshifts of z~1-3



Spitzer + Herschel photometric surveys
➔ bolometric luminosities of galaxies
➔ estimates of the SFR and BHAR density functions.

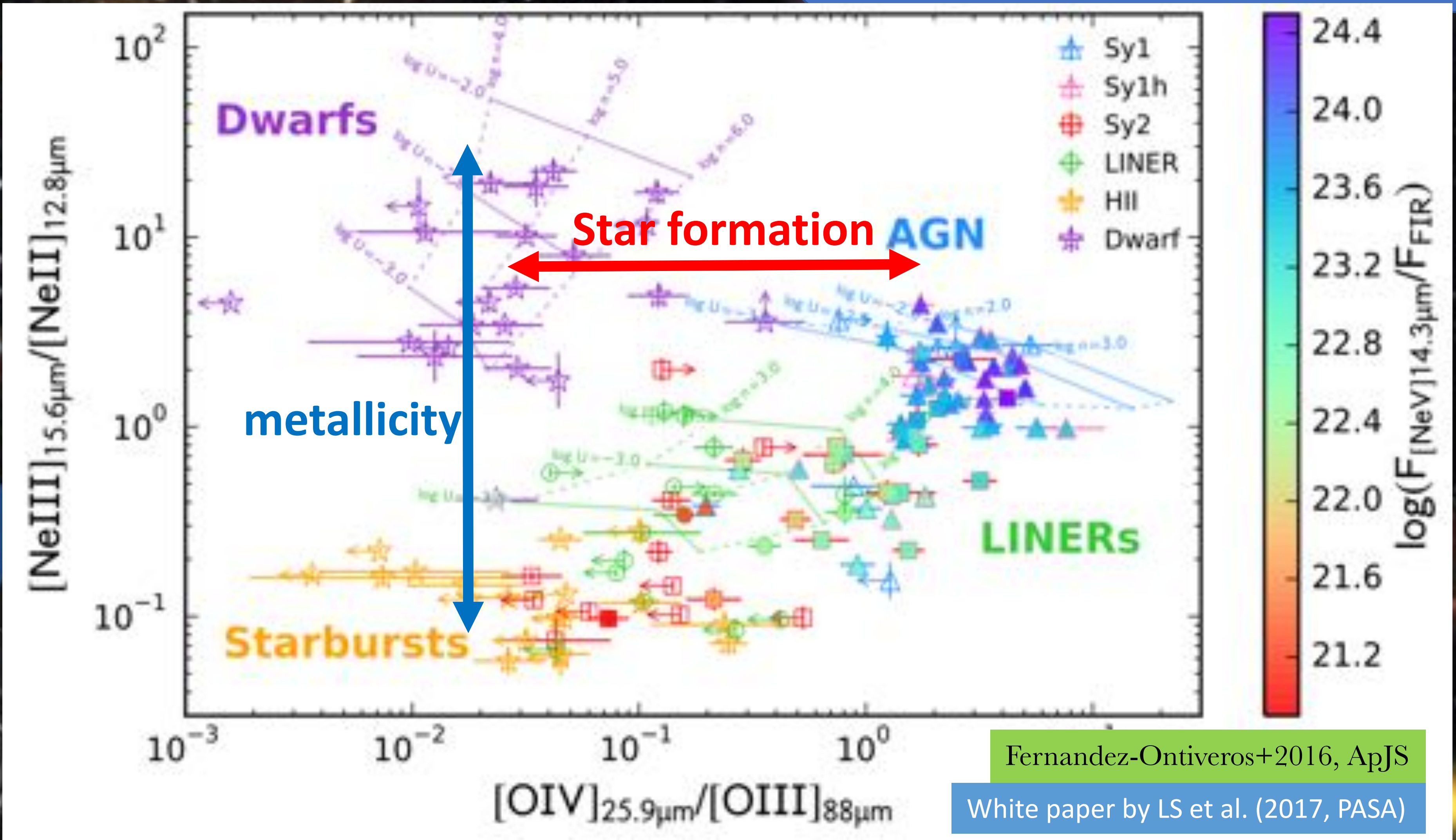
However,
AGN/SF separation is not based on observed physical quantities but is model-dependent (used local SED templates, with large uncertainty and degeneracy).

- UV/opt. spectroscopy (from e.g. SLOAN) track only marginally (~10%) the total integrated light.
- BHAR X-ray estimates are affected by the large uncertainties of the adopted bolometric corrections.
- SFR density at z>2-3 very uncertain, since it is from UV surveys, highly affected by dust extinction.

White paper by LS et al. (2017, PASA)

The new "IR BPT DIAGRAM"

SPICA will study both obscured starbursts and AGN across cosmic history, from a time when the Universe was only 1-2 billion years old.

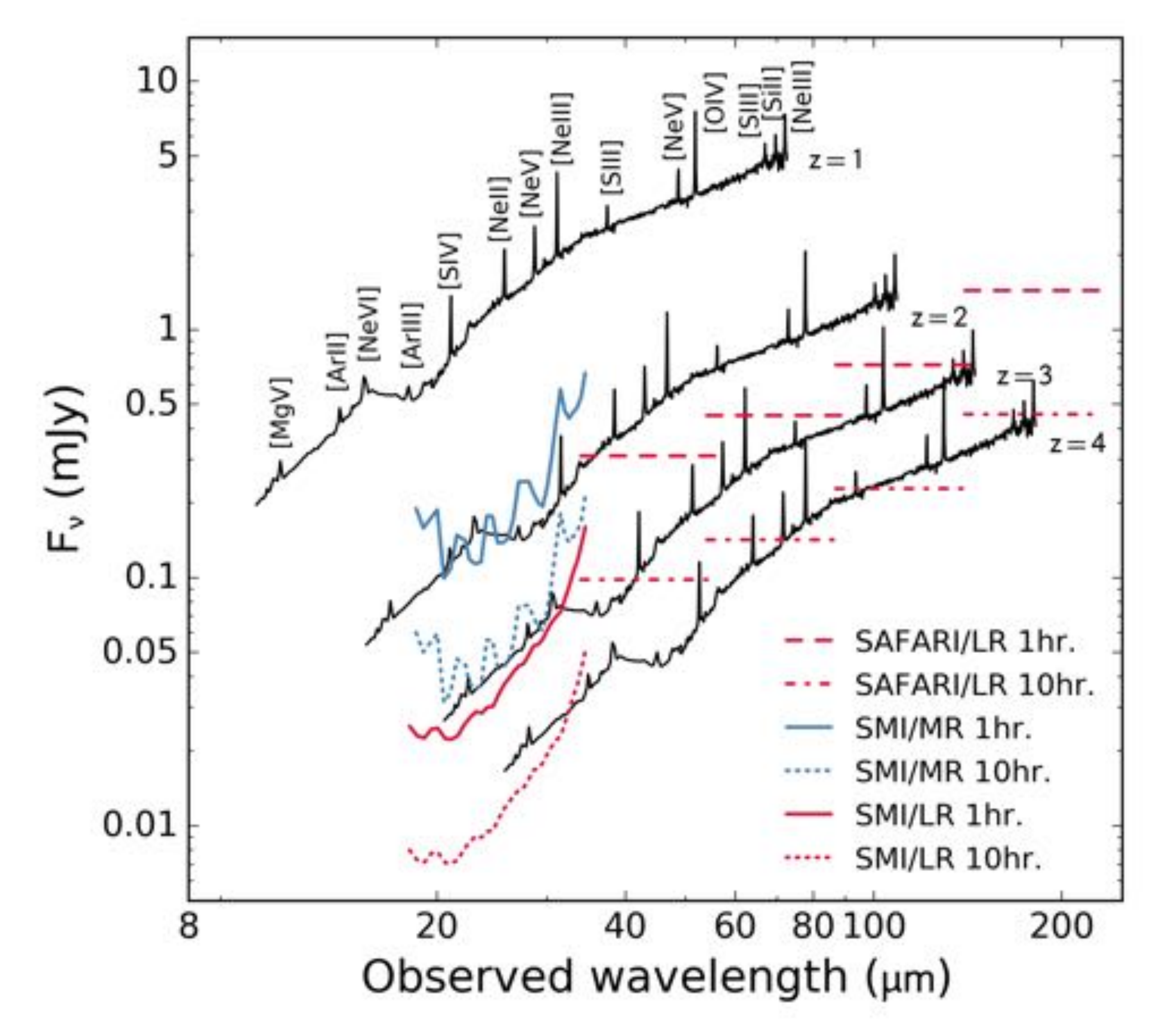


Fernandez-Ontiveros+2016, ApJS

White paper by LS et al. (2017, PASA)

- The new BPT diagram distinguishes any type of AGN (Seyfert and LINER) from any type of Star Formation dominated galaxy (either Starburst or Dwarf galaxies).

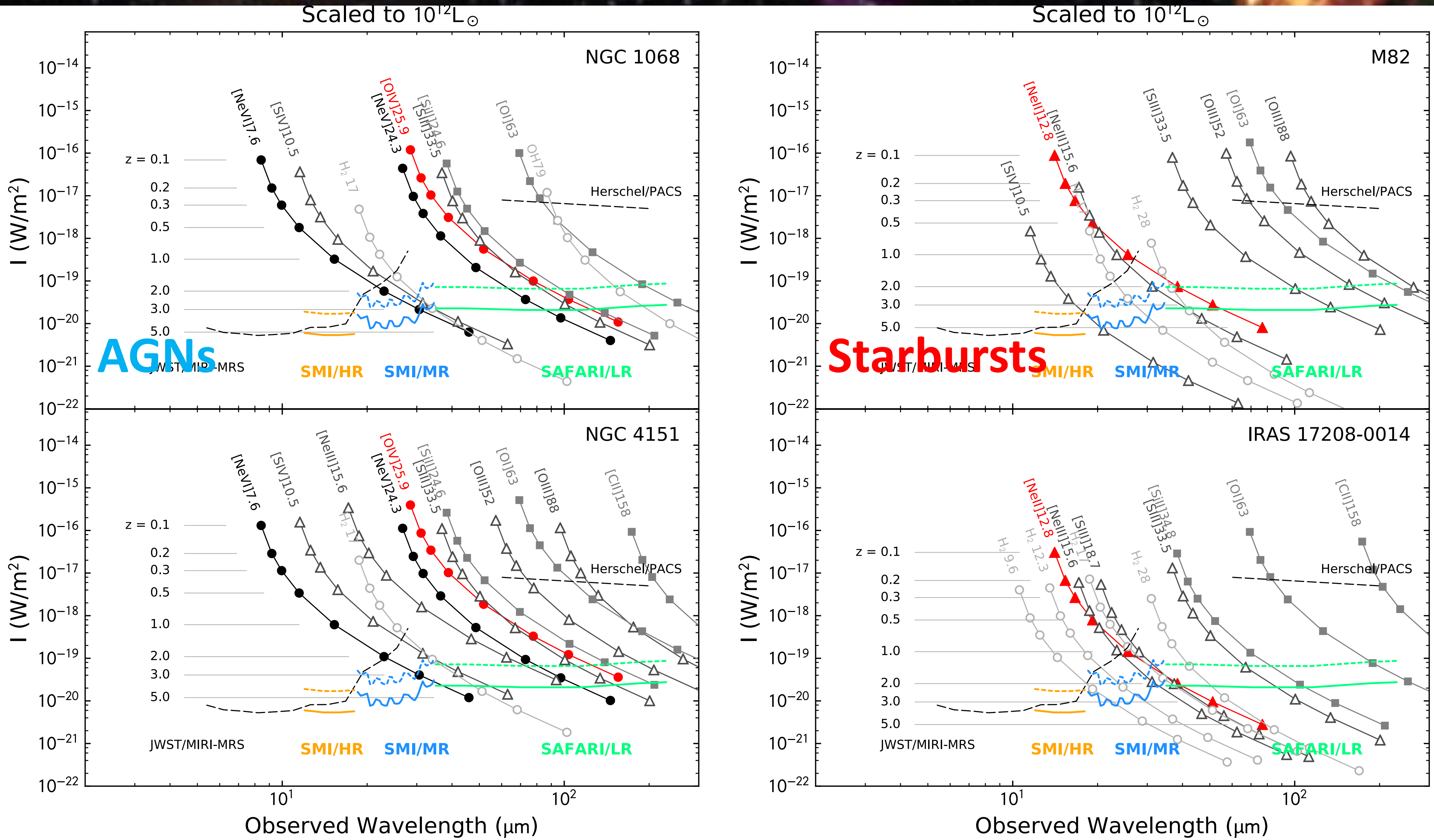
Line detectability with the SPICA spectrometers SAFARI & SMI



The IR spectrum of MCG-3-34-64, a nearby active galaxy, rescaled to a luminosity of L=10^{12} L$_\odot$ at redshifts z from 1 to 4. At z=3, the "main sequence luminosity" L=10^{12} L$_\odot$, implying that we will map the "bulk" of the galaxy population up to this redshift. The SAFARI and SMI sensitivities (in medium and low resolution) are shown.*

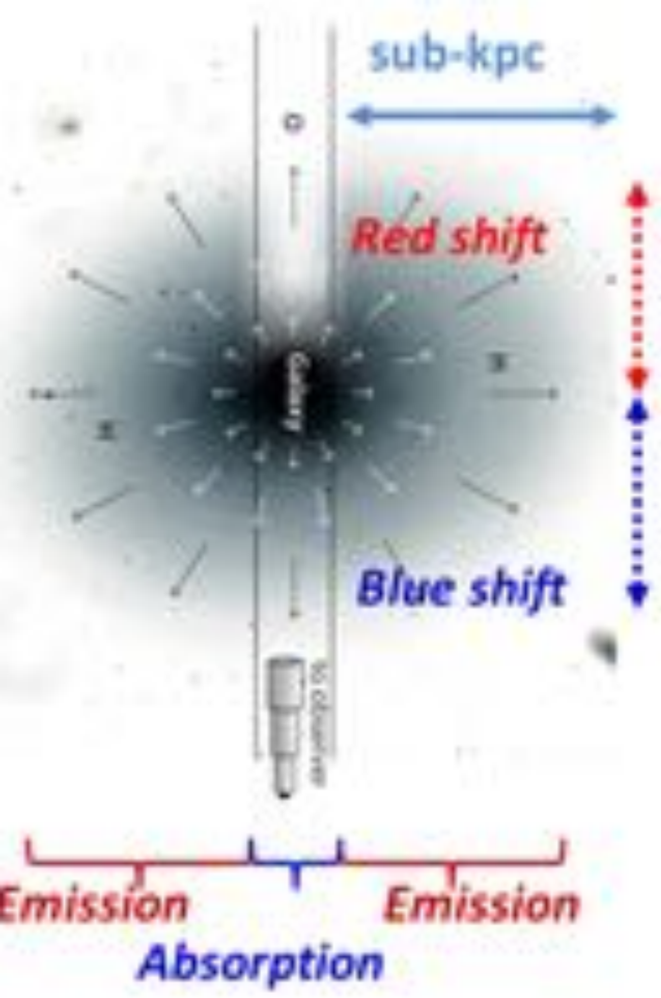
White paper by LS et al. (2017, PASA)

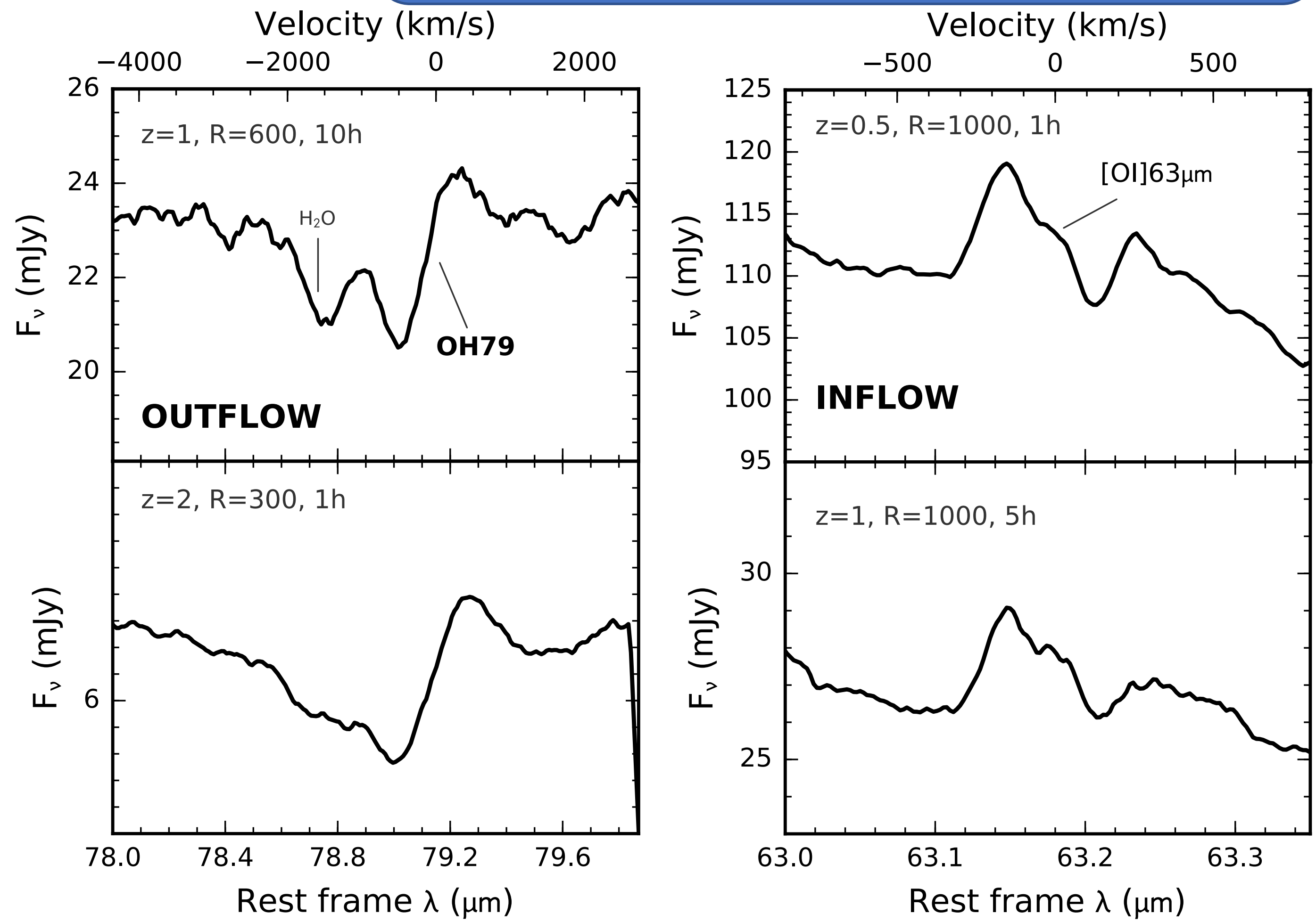
Line detectability with the SPICA spectrometers SAFARI & SMI



AGN feeding and feedback

SPICA will measure the key tracers of atomic and molecular outflows and infall in galaxies to the peak epoch of star formation





Left: Simulated SAFARI OH P-Cygni outflow spectra for a L=2x10^{12} L$_{\odot}$. galaxy at z=1 and z=2, based on Herschel/PACS observations of Mrk231 (Gonzalez-Alfonso et al. 2014). Right: Simulated [OI]63μm inverse P-Cygni infall profile, based on PACS spectra of Zw049.057 (Falstad et al. 2015). SAFARI will detect outflow and inflow motions in ULIRGs up to z~1-

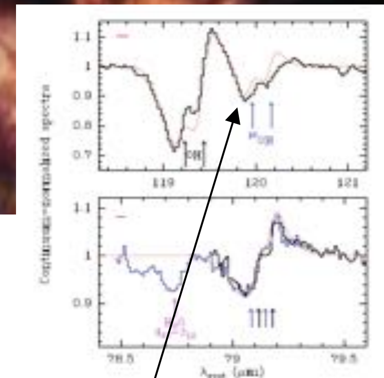
Work provided by: Eduardo Gonzalez-Alfonso, Eckhard Sturm

Feedback & Feeding in the context of galaxy evolution
Does feedback stop star formation?

Low spectral resolution observations to measure statistics (outflow occurrence)

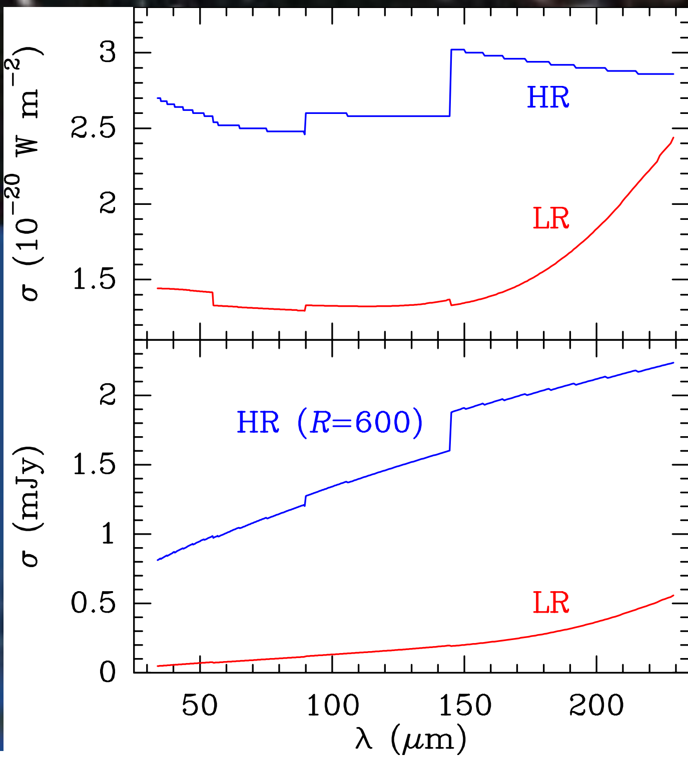
→ key tracers of atomic and molecular outflows/inflows in galaxies near the peak epoch of Star Formation (z < 2).

White paper by Eduardo González-Alfonso et al. (2017, PASA)

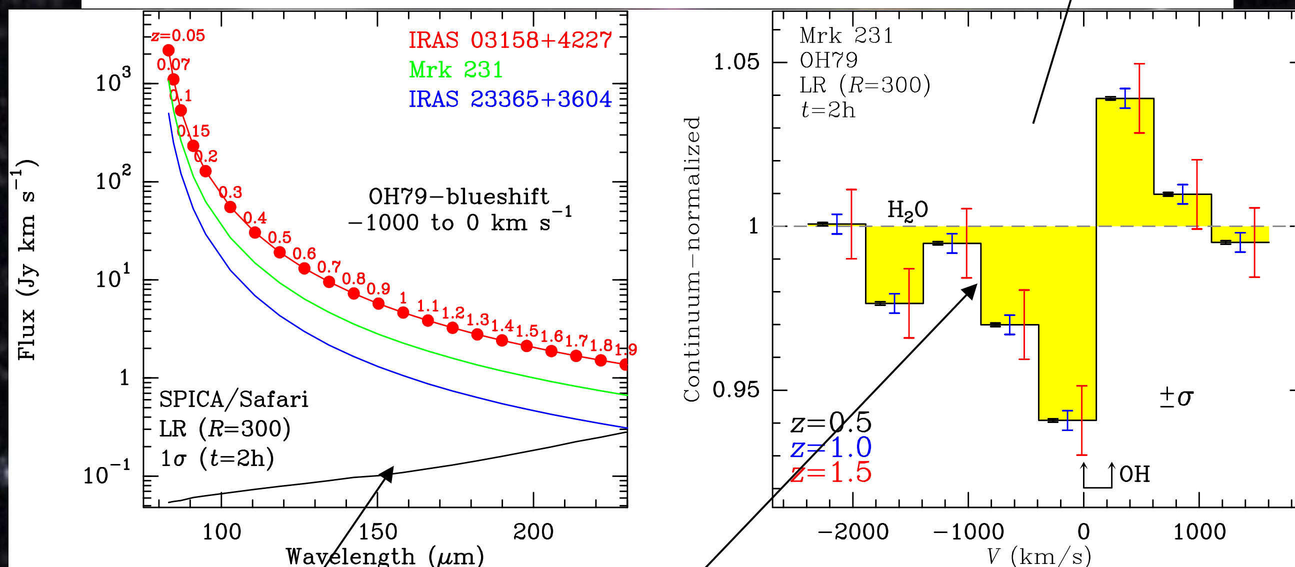


(P-Cygni OH profiles in Mrk 231; Fischer+2010)

The OH doublet at 79 μm can probe outflows up to z~1.4-1.9



Current SAFARI Low resolution (LR) and high-resolution (HR) sensitivities



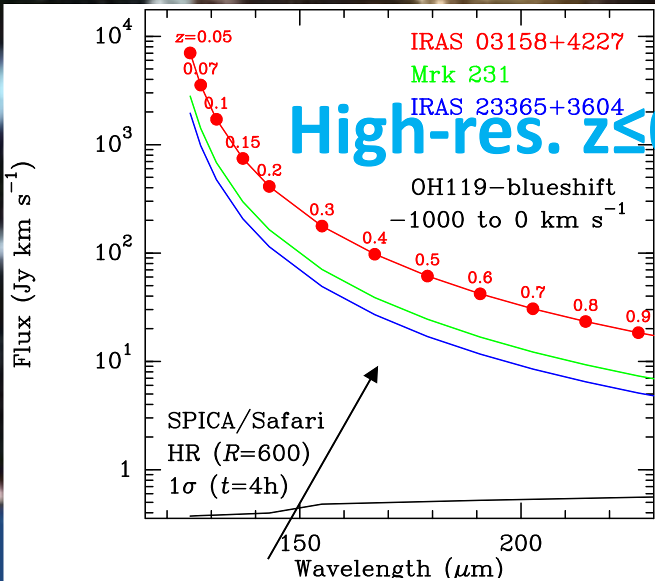
*OH79 shows P-Cygni in many local ULIRGs
*We use 3 templates: flux of blueshifted wings vs z
**Black curve*: Safari sensitivities in LR (R=300) mode
**Continuum-normalized vs velocity* is redshift-invariant
*Errorbars: +/-1σ at z=0.5, 1, 1.5 (Mrk 231, LR-2h)

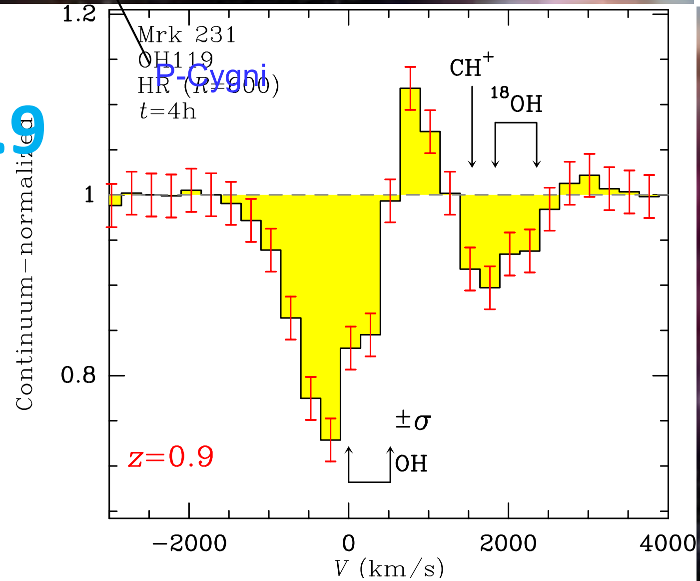
Low-res.
z≤1.9

Feedback & Feeding in the context of galaxy evolution

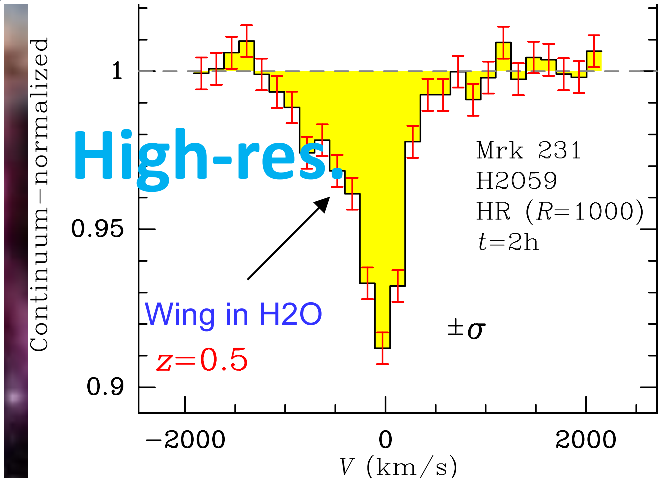
High spectral resolution observations to measure physical parameters (mass, energy, velocity…)

At high-R the OH doublet at 119 μm can be observed up to z~0.93

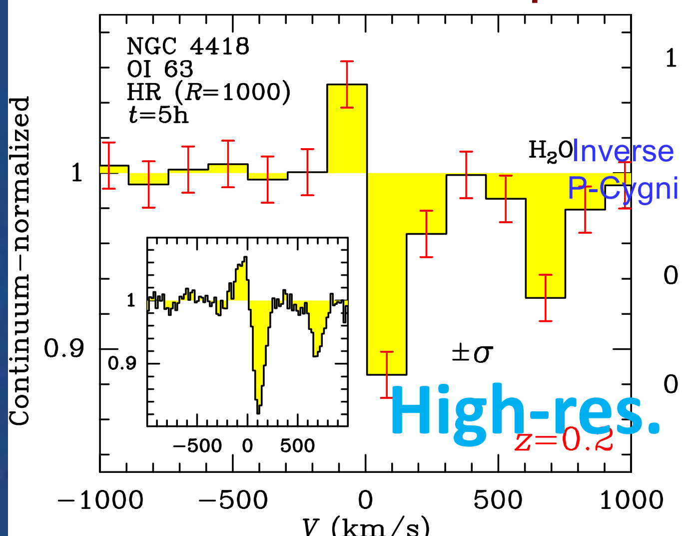


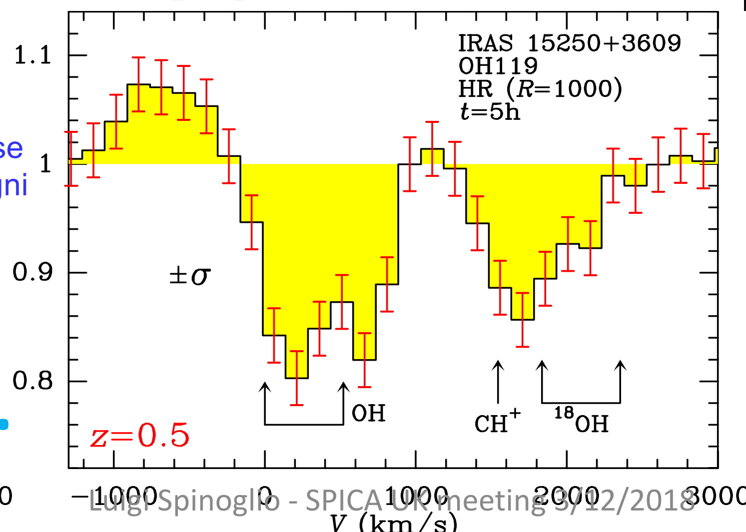


Outflows in other molecules, like H2O

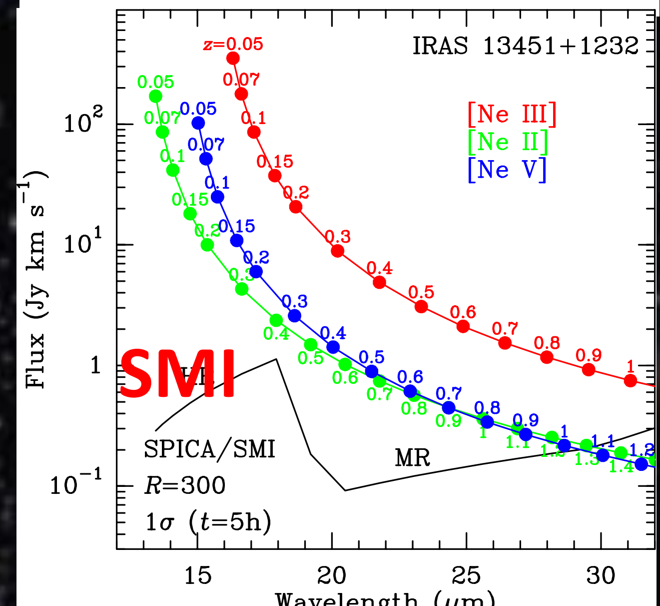


We will also explore inflows in [O I]63μm and OH





SMI will detect outflows in Ne lines

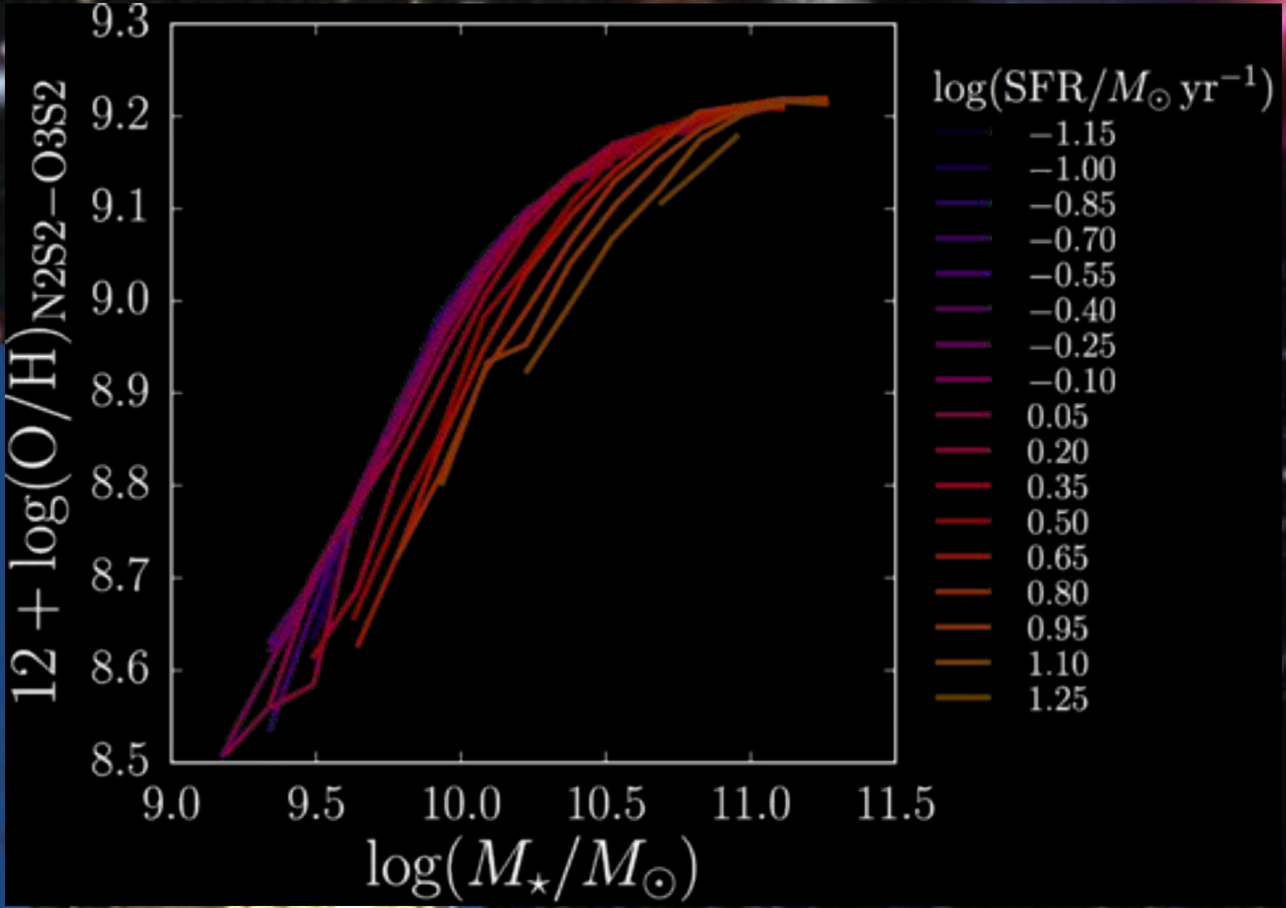


SPICA and the Chemical Evolution of Galaxies: The Rise of Metals and Dust

white paper by Juan Antonio Fernandez-Ontiveros et al. (2017, PASA)

Higher metallicities in massive galaxies (Lequeux+1979) in Local Universe

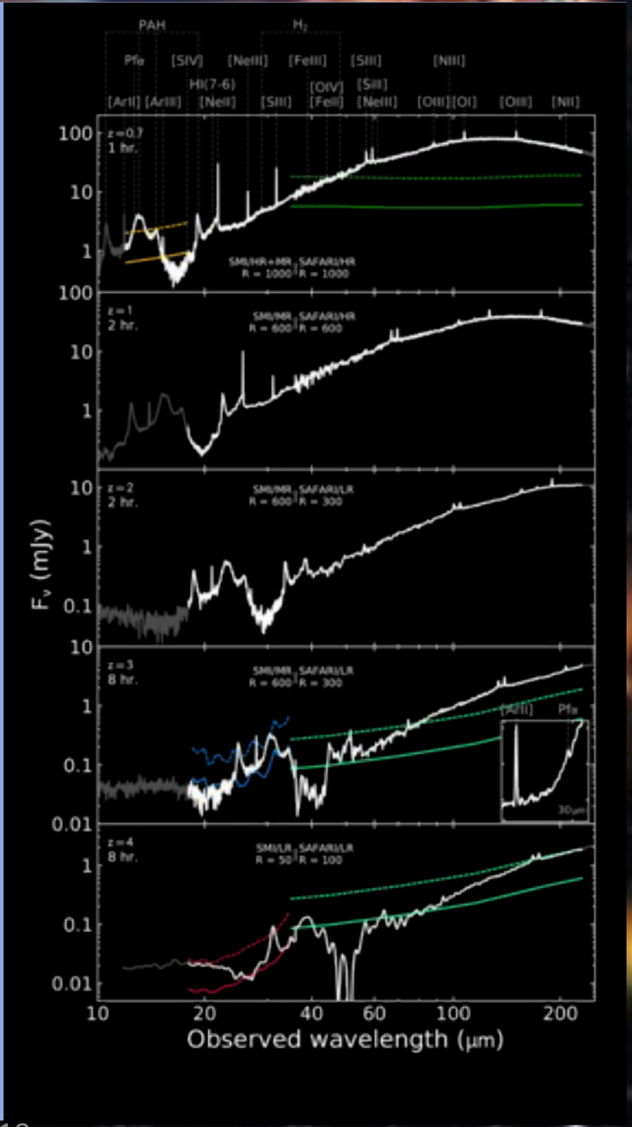
- Input for galaxy evolution models (Davé+2012,2017)
- Optical biased because of dust ➔ **IR** tracers
- Optical tracers depend strongly on **T***e*



Measuring metallicities with SPICA IR lines

Direct method:

- Local Universe: Humphreys-α (12.37 μm)
- $1.5 < z < 3.0$: Pfund-α (7.46 μm)
- **Neon**:
  [NeII]12.8μm, [NeIII]15.6μm
- **Sulphur**:
  [SIV]10.5μm, [SIII]18.7μm
- **Argon**:
  [ArII]6.99μm, [ArIII]8.99μm



Test this with JWST MIRI

SPICA: higher redshift

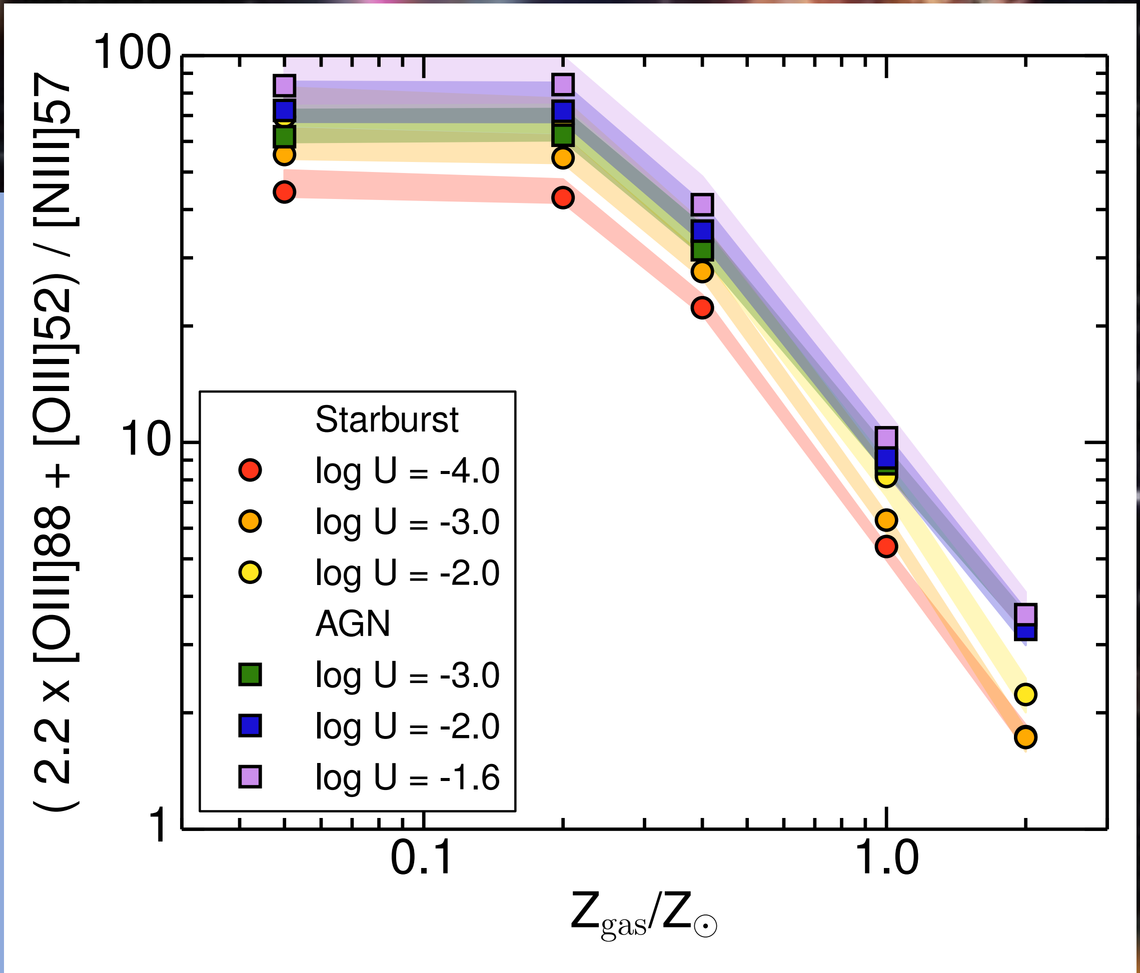
Measuring metallicities with SPICA IR lines

Indirect method:

- Calibration is given by photoionization models (for AGN and starburst)
- z<1.6
- Measure

$$\frac{2.2\times[\mathrm{O\,iii}]88\mu m+[\mathrm{O\,iii}]52\mu m}{[\mathrm{N\,iii}]57\mu m}$$

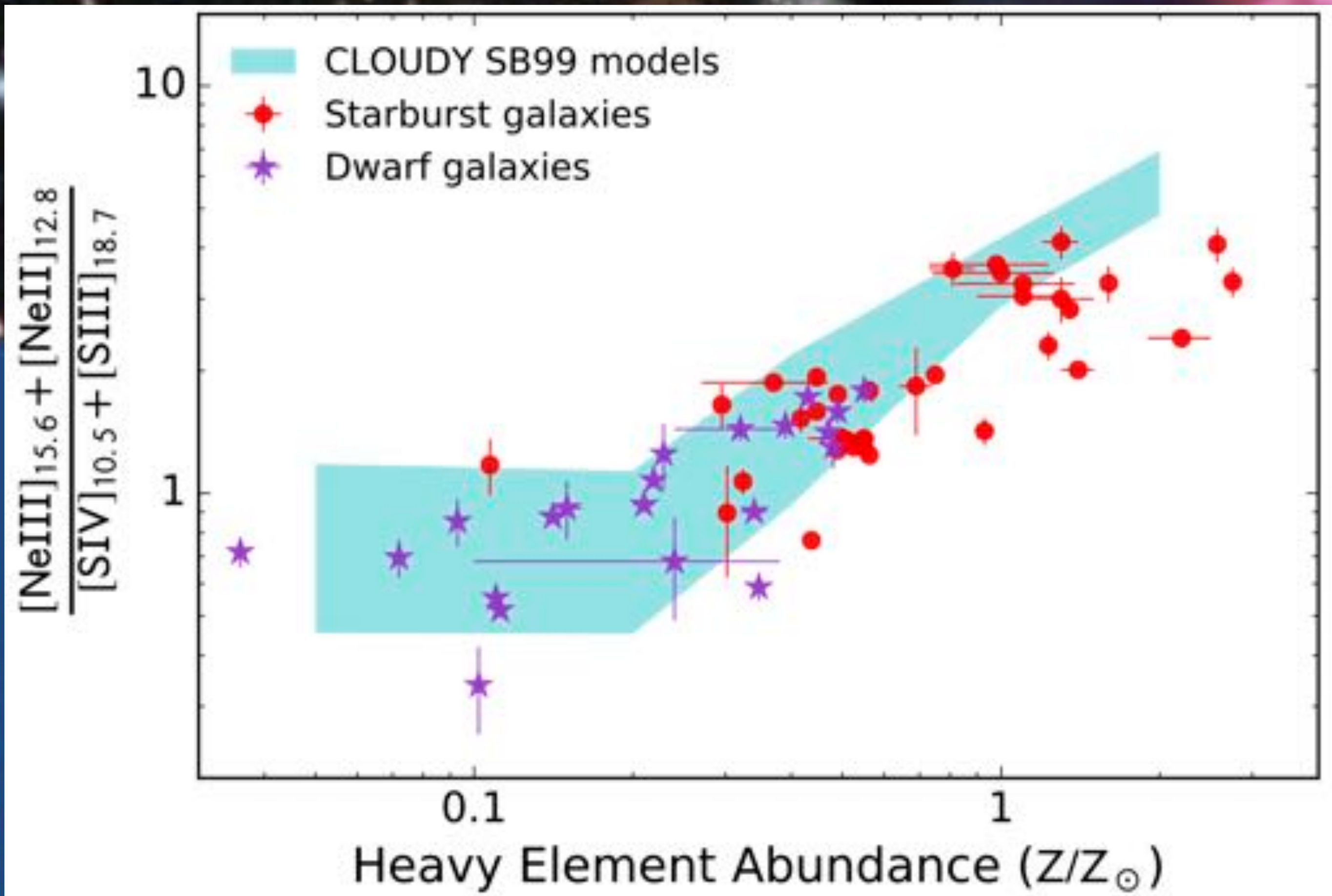
(Nagao+2011 and Pereira- Santaella et al. 2017)



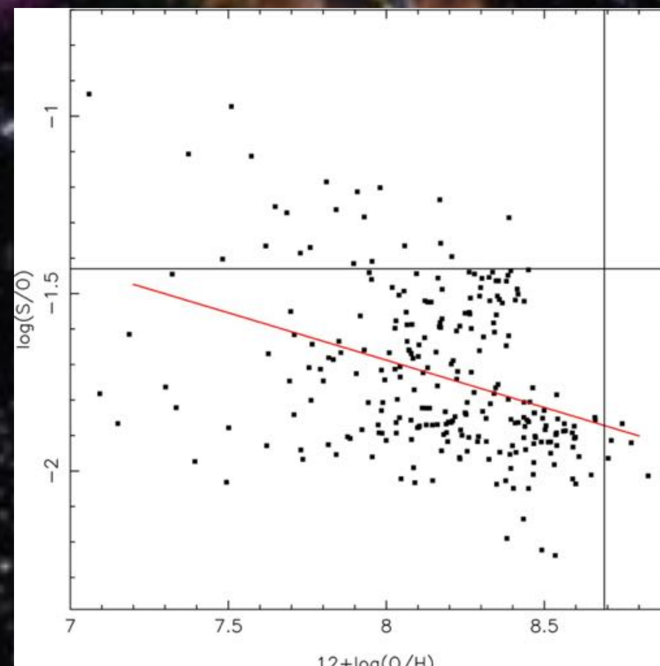
Measuring metallicities with SPICA IR lines

For 0.15 < z < 3
measure:

$$\frac{[\mathrm{Ne\,ii}]12.8\mu m + [\mathrm{Ne\,iii}]15.6\mu m}{[\mathrm{S\,iii}]18.7\mu m + [\mathrm{S\,iv}]\,10.5\mu m}$$



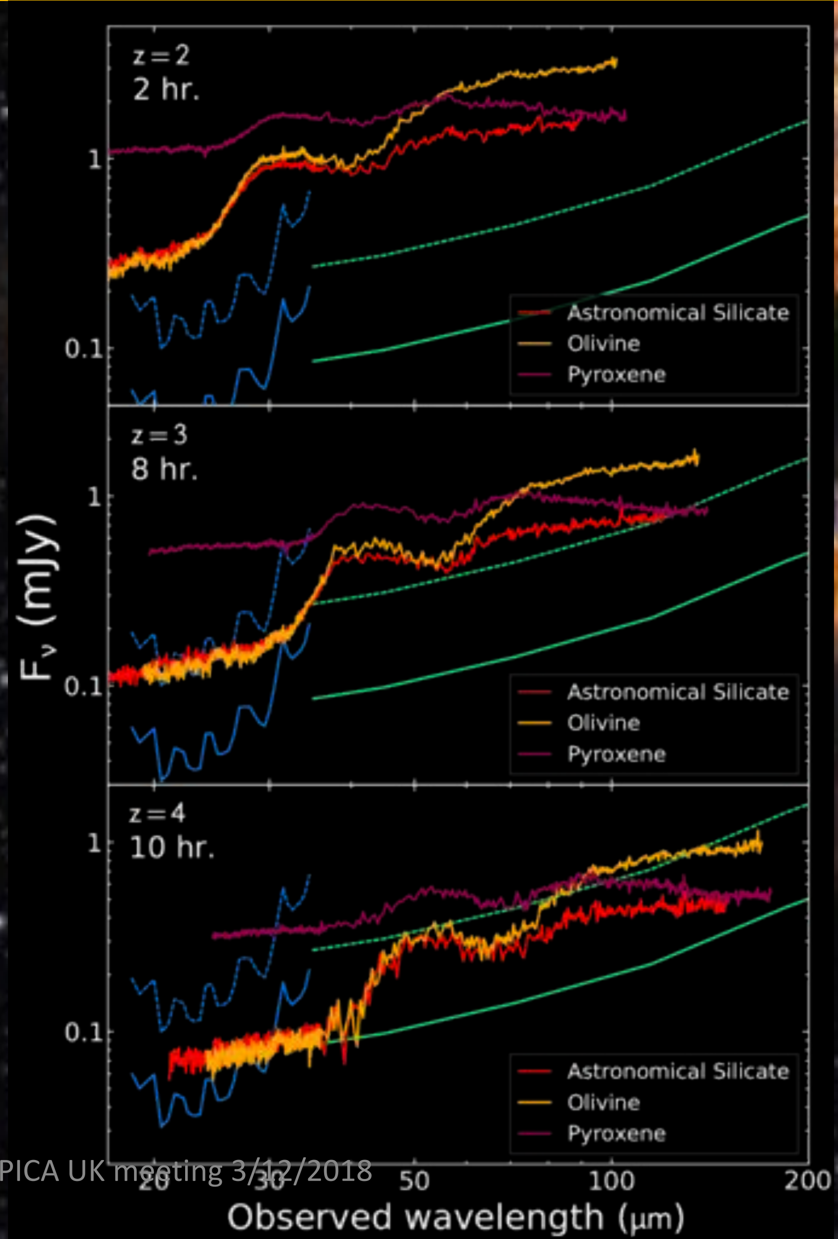
Spitzer /IRS observations of starburst galaxies in the Local Universe vs. indirect gas-phase optical metallicity (Moustakas et al. 2010; Pilyugin et al. 2014). Cloudy models including sulphur depletion above Z > 1/5 Zo are in agreement with the observations (adapted from Fernandez-Ontiveros et al. 2016).



Measuring dust evolution with SPICA

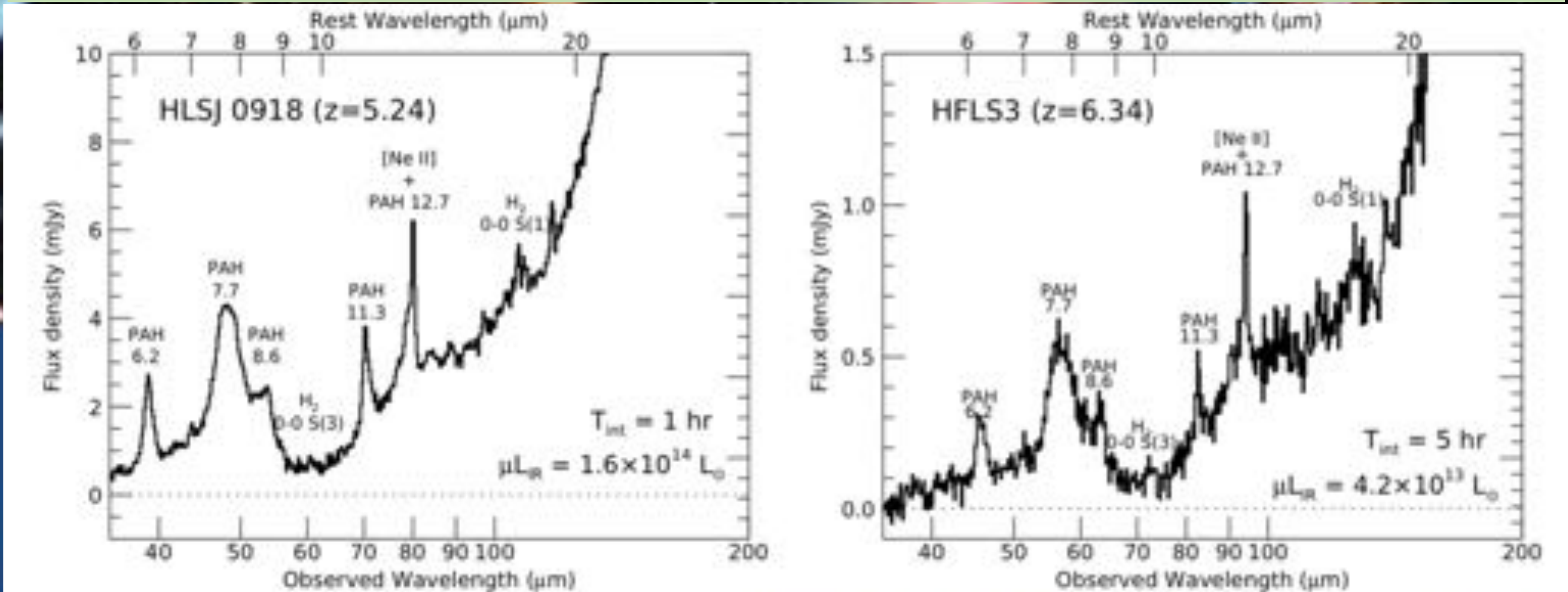
- **Dust** ~**1%** ISM **mass absorbs 30-50%** of light
- **Origin** and **composition?**
- Condensation in **SNR** (Rho+2008)
- **Solid-state** features probe the **dust composition** (Spoon+2006, Xie+2017)

white paper by Juan Antonio Fernandez-Ontiveros et al. (2017, PASA)



Probing the High-Redshift Universe with SPICA spectroscopy

SAFARI will collect rest-frame mid-IR spectra up to z~10 for sufficiently luminous galaxies (L_{IR}>2x$10^{13}L_{\odot}$). These galaxies, mostly gravitationally lensed, are being discovered at z>5, (e.g. Combes et al. 2012; Riechers et al. 2013). SPICA will offer the first opportunity to study the rest-frame mid-IR spectra of galaxies at z>4-5 and up to z~10 in significant numbers.

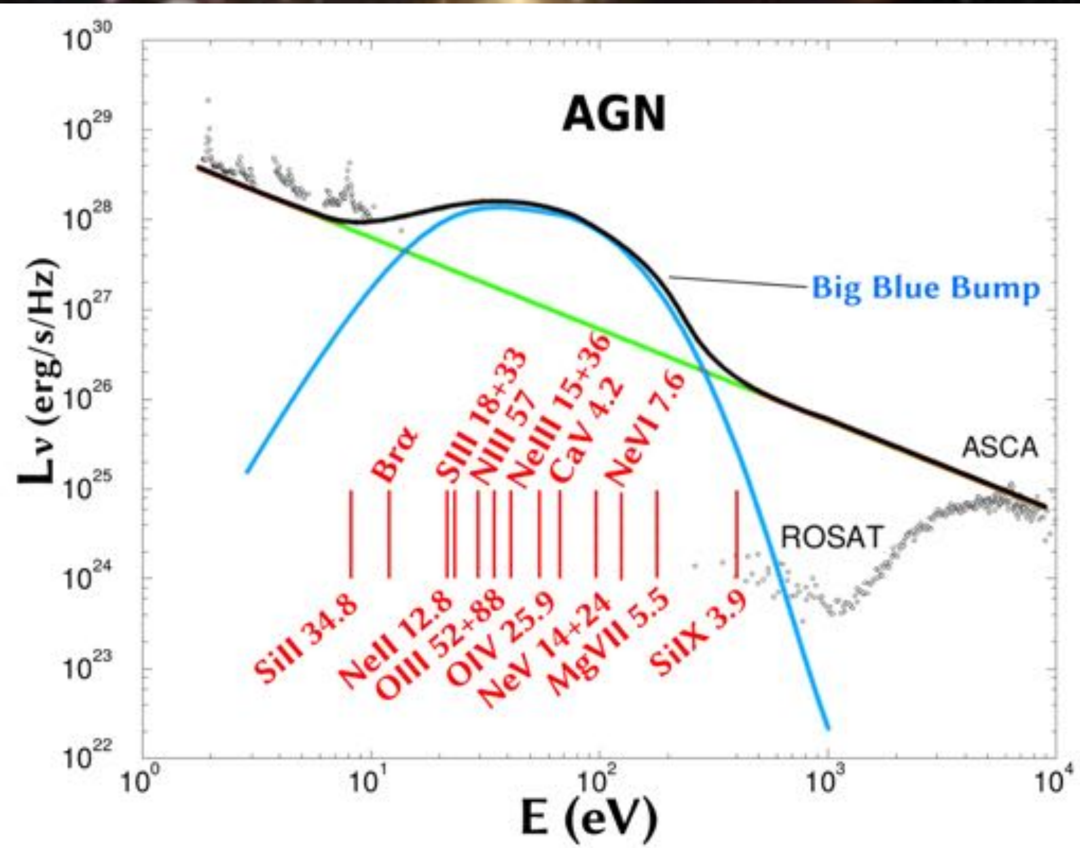


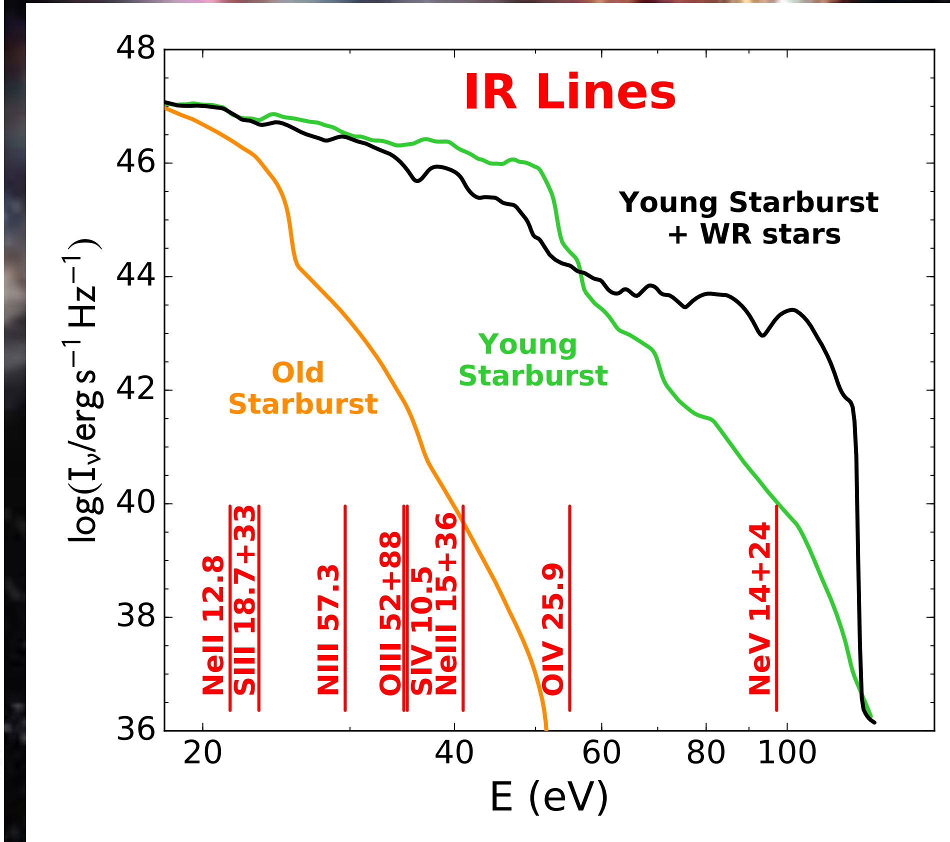
Simulated SAFARI spectra of HLSJ0918 and HFLS3 produced with the L_{IR}~10^{12} $L_{\odot}$ galaxy spectral template (Rieke et al. 2009), scaled to μL_{IR}=16 and 4x10^{13} $L_{\odot}$, respectively. These are both gravitationally lensed by factors of 9 and 2, respectively.

White paper by Eiichi Egami et al. (2018, PASA, in press)

Mapping the primary ionizing spectra of AGN and starburst galaxies

The IR fine structure lines are formed at ionization energies that can map the primary ionizing spectrum, where it is not observable because of absorption from our Galaxy.





Left: Overlay of the NGC4151 primary spectrum (black points) with a sketched "blue bump" and a power law (adapted from Alexander et al 1999). Right: A typical young and old starburst spectrum (models from Leitherer et al 1999). In both cases the key IR diagnostic lines are indicated. SPICA is a powerful probe of of the invisible primary ionizing spectra of both AGN and starbursts.

White paper by LS et al. (2017, PASA)

From the science goals to the SPICA science requirements

How science requirements give the needed sensitivity for spectroscopy

Slice at z=1:

Log(L) (Lo)	F_o4 (W/m2)	F_ne2 (W/m2)	F_ne5 (W/m2)
11.00	3.498e-20	3.406e-20	1.212e-20
11.50	9.649e-20	1.315e-19	3.742e-20
12.00	2.662e-19	5.077e-19	1.155e-19
12.50	7.343e-19	1.960e-18	3.567e-19
13.00	2.026e-18	7.567e-18	1.101e-18
13.50	5.588e-18	2.922e-17	3.400e-18

Slice at z=2:

Log(L) (Lo)	F_o4 (W/m2)	F_ne2 (W/m2)	F_ne5 W/m2)
11.50	1.732e-20	2.360e-20	6.715e-21
12.00	4.777e-20	9.111e-20	2.073e-20
12.50	1.318e-19	3.518e-19	6.401e-20
13.00	3.635e-19	1.358e-18	1.976e-19
13.50	1.003e-18	5.243e-18	6.102e-19

Slice at z=3:

Log(L) (Lo)	F_o4 (W/m2)	F_ne2 (W/m2)	F_ne5 (W/m2)
12.00	1.777e-20	3.390e-20	7.714e-21
12.50	4.903e-20	1.309e-19	2.381e-20
13.00	1.353e-19	5.053e-19	7.353e-20
13.50	3.731e-19	1.951e-18	2.270e-19

The case is very simple:
We want to measure the bulk of the Star Formation Rate (SFR) and of the Black Hole Accretion Rate (BHAR) through cosmic time up to the peak of these functions i.e. at redshift of z=3.

To do this we need to detect the chosen tracers (namely the [OIV]26µm line for BHAR and the [NeII]12.8µm lie for SFR) in the “typical” galaxies which produce most of the emission, i.e. the galaxies lying at the knee of the luminosity functions, at the three chosen redshifts of z=1, 2, 3, which also corresponds to the so-called “main sequence galaxies”.

We therefore adopt as limiting luminosity the “main-sequence” luminosity (in light blue)

We list in the table the expected fluxes of these galaxies at the various redshifts and luminosities.

BASELINE SPECTROSCOPIC SURVEYS (5X10^-20 W/m^2 5σ 1 hr.)

Slice at z=1: [NOTE: MIN. OBSERVING TIME on-source SET TO 0.1 hrs.]

Log(L)	F_o4	time_o4	F_ne2	time_ne2	F_ne5	time_ne5	adopted time
11.00	3.498e-20	2.044	3.406e-20	2.155	(1.212e-20	17.02)	2 hrs.
11.50	9.649e-20	0.269	1.315e-19	0.145	3.742e-20	1.786	2 hrs.
12.00	2.662e-19	0.035	5.077e-19	0.010	1.155e-19	0.187	0.25 hrs.
12.50	7.343e-19	0.005	1.960e-18	0.001	3.567e-19	0.020	0.25 hrs.
13.00	2.026e-18	0.001	7.567e-18	0.000	1.101e-18	0.002	0.1 hrs.
13.50	5.588e-18	0.000	2.922e-17	0.000	3.400e-18	0.000	0.1 hrs.

total time for z=1 bin = $\Sigma_{L\_bin=1,6}$ (time) x 60 sources = 4.7 x 60 sources = 282 hours

Slice at z=2:

Log(L)	F_o4	time_o4	F_ne2	time_ne2	F_ne5	time_ne5	adopted time
11.50	1.732e-20	8.337	2.360e-20	4.489	(6.715e-21	55.4)	8 hrs.
12.00	4.777e-20	1.096	9.111e-20	0.301	2.073e-20	5.82	6 hrs.
12.50	1.318e-19	0.144	3.518e-19	0.020	6.401e-20	0.610	1 hr.
13.00	3.635e-19	0.019	1.358e-18	0.001	1.976e-19	0.064	0.5 hr.
13.50	1.003e-18	0.002	5.243e-18	0.000	6.102e-19	0.007	0.25 hr.

total time for z=2 bin = $\Sigma_{L\_bin=1,5}$ (time) x 60 sources = 15.75 x 60 sources = 945 hours

Slice at z=3:

Log(L)	F_o4	time_o4	F_ne2	time_ne2	F_ne5	time_ne5	adopted time
12.00	1.777e-20	7.914	3.390e-20	2.176	(7.714e-21	42.01)	8 hrs.
12.50	4.903e-20	1.040	1.309e-19	0.146	2.381e-20	4.41	4.5 hrs.
13.00	1.353e-19	0.137	5.053e-19	0.010	7.353e-20	0.462	0.5 hrs.
13.50	3.731e-19	0.018	1.951e-18	0.001	2.270e-19	0.049	0.5 hrs.

total time for z=3 bin = $\Sigma_{L\_bin=1,4}$ (time) x 60 sources = 13.5 x 60 sources = 810 hours

Total Observing time on-source (without overheads) = **2040 hours for 900 sources**

GOAL SPECTROSCOPIC SURVEYS (3X10^-20 W/m^2 5σ 1 hr.)

Slice at z=1: [NOTE: MIN. OBSERVING TIME on-source SET TO 0.1 hrs.]

Log(L)	F_o4	time_o4	F_ne2	time_ne2	F_ne5	time_ne5	adopted time
11.00	3.498e-20	0.735	3.406e-20	0.775	(1.212e-20	6.126)	0.8 hrs.
11.50	9.649e-20	0.097	1.315e-19	0.052	3.742e-20	0.643	0.6 hrs.
12.00	2.662e-19	0.013	5.077e-19	0.003	1.155e-19	0.067	0.1 hrs.
12.50	7.343e-19	0.002	1.960e-18	0.000	3.567e-19	0.007	0.1 hrs.
13.00	2.026e-18	0.000	7.567e-18	0.000	1.101e-18	0.000	0.1 hrs.
13.50	5.588e-18	0.000	2.922e-17	0.000	3.400e-18	0.000	0.1 hrs.

total time for z=1 bin = $\Sigma_{L\_bin=1,6}$ (time) x 60 sources = 1.80 x 60 sources = 108 hours

Slice at z=2:

Log(L)	F_o4	time_o4	F_ne2	time_ne2	F_ne5	time_ne5	adopted time
11.50	1.732e-20	3.000	2.360e-20	1.616	(6.715e-21	19.9)	3 hrs.
12.00	4.777e-20	0.394	9.111e-20	0.108	2.073e-20	2.094	2 hrs.
12.50	1.318e-19	0.052	3.518e-19	0.007	6.401e-20	0.220	0.3 hr.
13.00	3.635e-19	0.007	1.358e-18	0.000	1.976e-19	0.023	0.1 hr.
13.50	1.003e-18	0.001	5.243e-18	0.000	6.102e-19	0.002	0.1 hr.

total time for z=2 bin = $\Sigma_{L\_bin=1,5}$ (time) x 60 sources = 5.5 x 60 sources = 330 hours

Slice at z=3:

Log(L)	F_o4	time_o4	F_ne2	time_ne2	F_ne5	time_ne5	adopted time
12.00	1.777e-20	2.850	3.390e-20	0.783	(7.714e-21	15.12)	3.6 hrs.
12.50	4.903e-20	0.374	1.309e-19	0.052	2.381e-20	1.587	2.0 hrs.
13.00	1.353e-19	0.049	5.053e-19	0.004	7.353e-20	0.166	0.22 hrs.
13.50	3.731e-19	0.006	1.951e-18	0.000	2.270e-19	0.017	0.1 hrs.

total time for z=3 bin = $\Sigma_{L\_bin=1,4}$ (time) x 60 sources = 5.84 x 60 sources = 355 hours

Total Observing time on-source (without overheads) = 760 hours for 900 sources

Summary science requirements: needed sensitivity for spectroscopy

[OIV] line fluxes as a function of z and Luminosity	Grating + 2.5m tel NEP=2x10^-19 W/√Hz	Grating + elliptical tel. 3m equivalent NEP=2x10^-19 W/√Hz or 2.5m tel + det. NEP ≤ 1.4x10^-19 W/√Hz	Grating + elliptical tel. 3m equivalent NEP=2x10^-19 W/√Hz or 2.5m tel + det. NEP ~ 1.0x10^-19 W/√Hz
Line sensitivity 5 sigma 1 hour (W/m2)	7.2E-20 **current**	5.0E-20 **requirement**	3.0E-20 **goal**
	Max int.t/source Total survey time	Max int.t./source Total survey time	Max int.t./source Total survey time
z=1, L≥10^11 Lo 360 sources	4.2 hours 510 hours	2 hours 282 hours	0.8 hours 108 hours
z=2, L≥10^11.5 Lo 300 sources	16.3 hours 1764 hours	8 hours 945 hours	3.0 hours 330 hours
z=3, L≥10^12 Lo 240 sources	15.5 hours 1506 hours	8 hours 810 hours	3.6 hours 355 hours
TOTAL SURVEY TIME	3780 hours	2037 hours	793 hours

Summary science requirements: needed spectral resolution

For most galaxy evolution observations:

1. Mapping BHAR and SFR through spectroscopy at $0<z<4$
2. Chemical Evolution of Galaxies: The Rise of Metals and Dust
3. Towards the epoch of Re-Ionization through deep SAFARI spectroscopy

the required spectral resolution was set to R=500, [able to e.g. separate the [FeII] from the [OIV] fine structure lines at 26µm] however for instrumental constraints it was relaxed to R=300 which is the current baseline for SAFARI

SMI low resolution spectroscopic images (R=50-120) will be adequate for the dust and PAH features and the slope of the MIR continuum, while the medium resolution spectrometer (R=1300-2300) will be used to extend the domain of the spectroscopic surveys to lower wavelengths.

However, the observations related to:

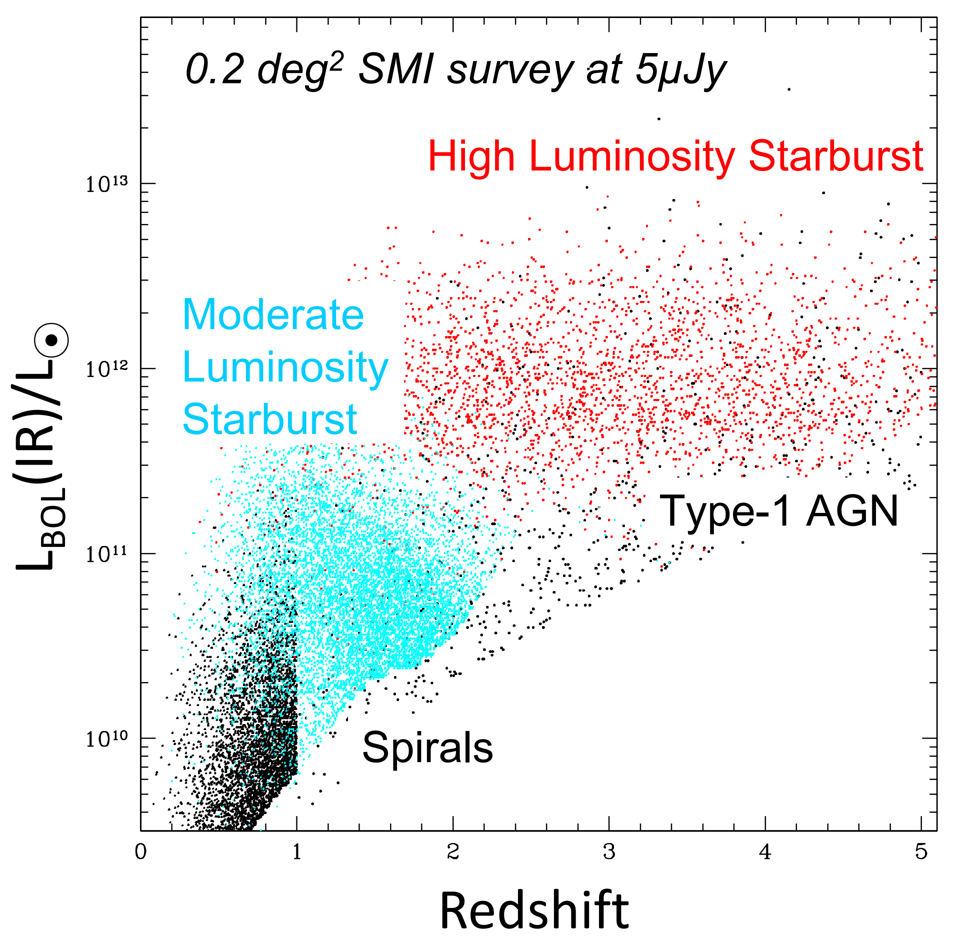
4. Feedback & Feeding in the context of galaxy evolution

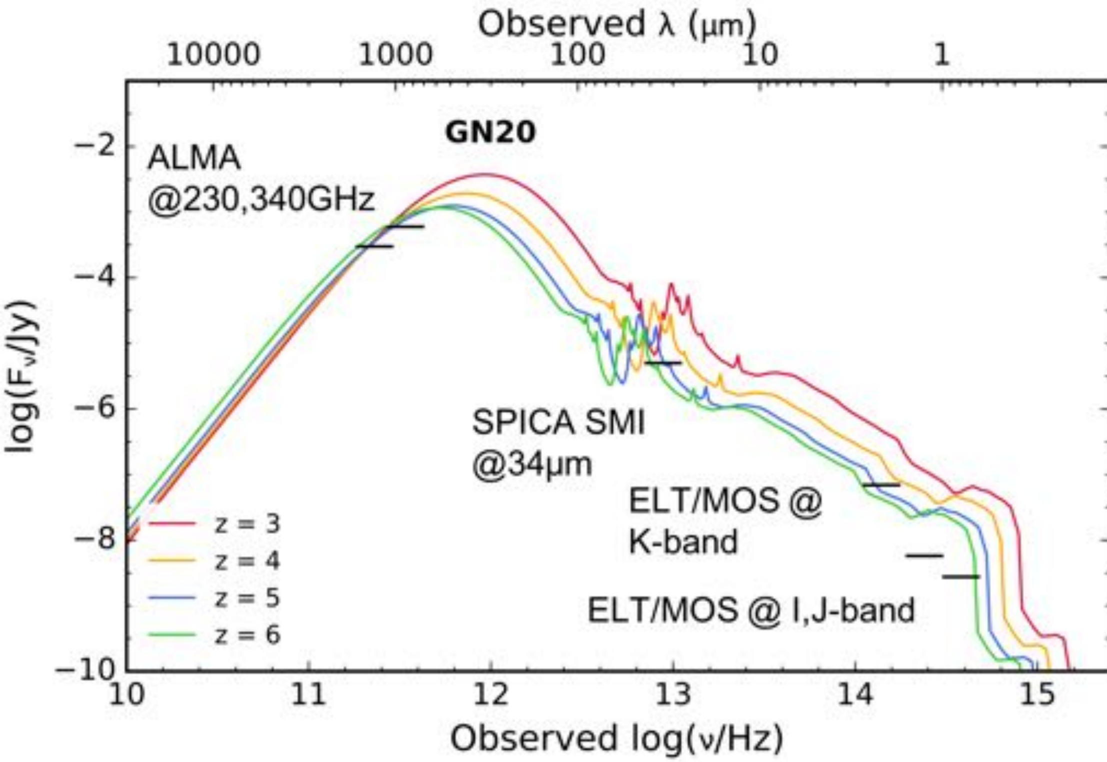
does need high resolution spectra of at least that of the PACS spectrometer. The Martin-Puplett resolution ranges from 2000 to 12000 as inverse function of wavelength (from 35 to 230µm) will be used together with the SMI medium resolution spectrometer (R=1300-2300). The SMI high resolution channel at 12-18µm might be used for profiles exploration.

SPICA PHOTOMETRIC SURVEYS

Towards the epoch of Re-Ionization: early black holes and starbursts

SPICA SMI deep surveys will detect AGN and starburst galaxies up to z~5-6, characterized by SPICA spectral follow-up + ELTs and ALMA





Left: L-z plane coverage of a 0.2 deg² SMI survey at the confusion limit (5μJy, 10 hours/frame).

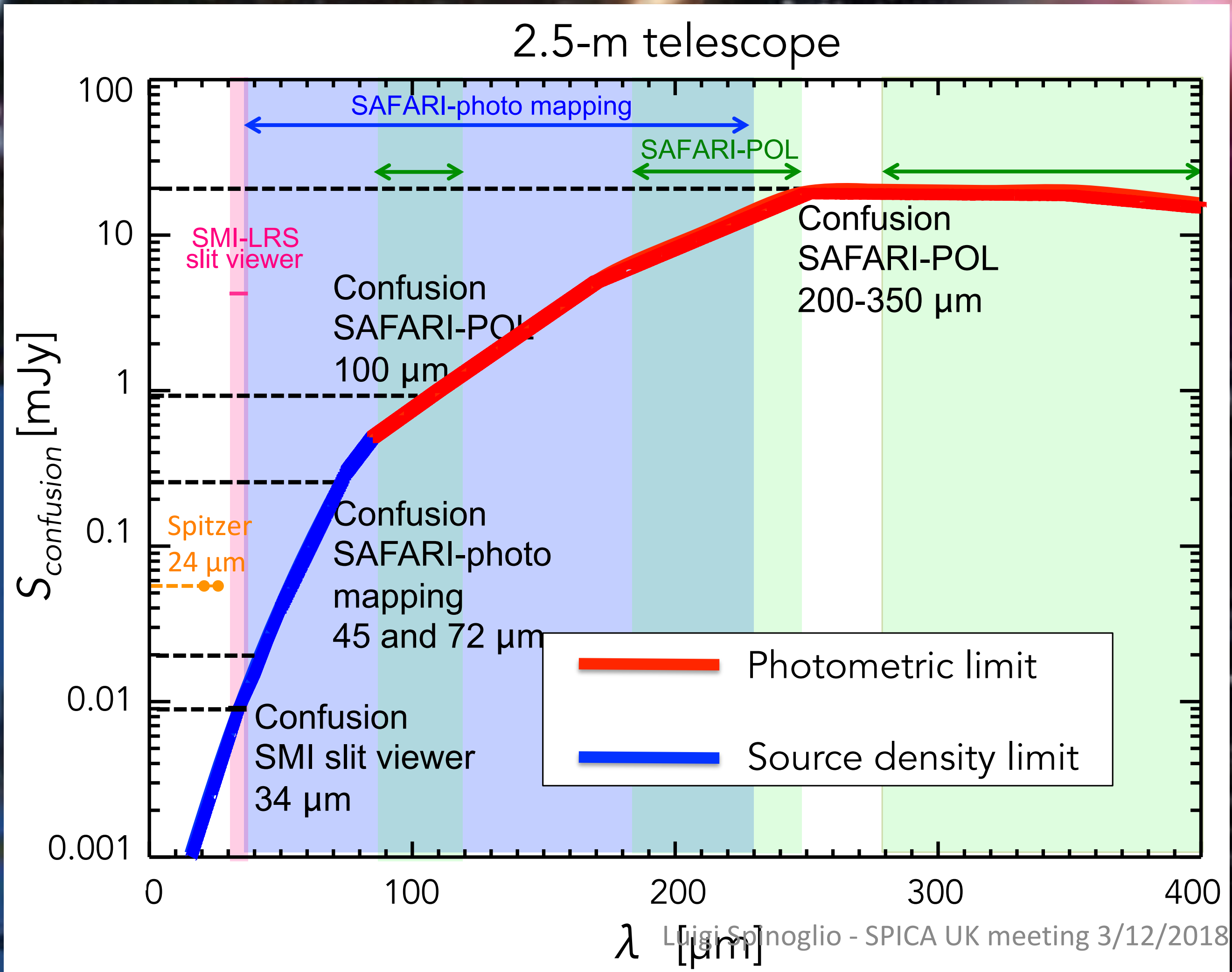
Right: The SED fit to the z=4.3 starburst galaxy GN20 (Efstathiou & Siebenmorgen 2009) rescaled to $L=10^{12}\,L_{\odot}$ for z=3-6. The detection limits of ALMA (10 minutes), ELT/MOS and ELT/ MICADO (3 hours) are shown. SPICA will map large areas to the confusion limit one hundred times faster than JWST, finding large numbers of dust-enshrouded AGN and starbursts at z > 5.

White paper by Carlotta Gruppioni et al. (2017, PASA)

A photometric survey with SPICA

1. SMI/CAM 34μm or
2. SMI/CAM 34μm+ B-POL@60-70μm [34-60] or [34-70] colors

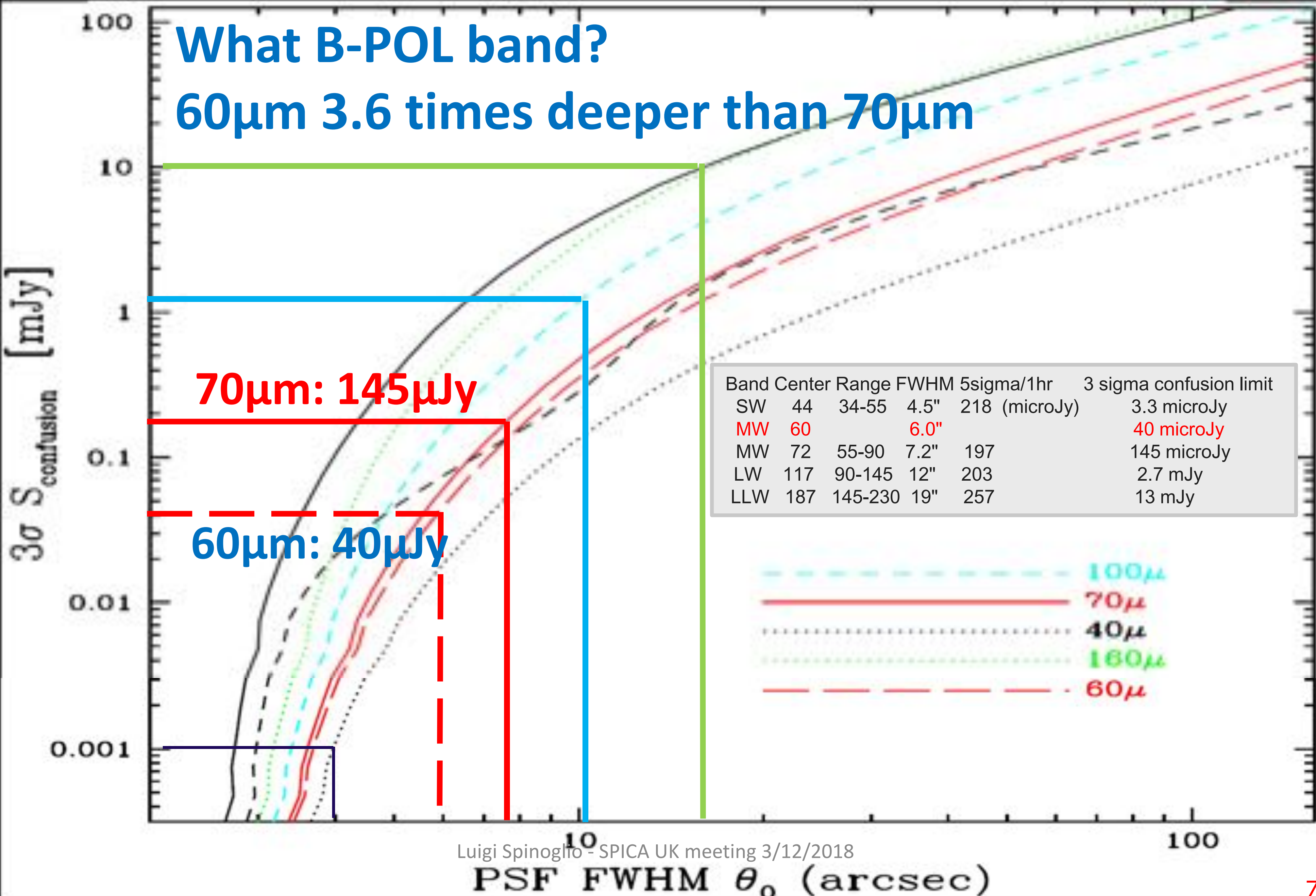
explore the sensitivity with the confusion limit at these bands



Confusion limit for a diffraction-limited 2.5-m telescope.
The blue curve is determined by the source density criterion, while the red one is defined by the photometric criterion.

The 5σ-confusion of SMI/CAM (34μm) is 9 μJy, the SAFARI confusion is 0.02, 0.25 and 1 mJy at 45, 72 and 100 μm, and 18 mJy at > 200 μm.

3σ confusion limits for a 2.5 m SPICA telescope



Band	Center	Range	FWHM	5sigma/1hr	3 sigma confusion limit
SW	44	34-55	4.5"	218 (microJy)	3.3 microJy
MW	60		6.0"		40 microJy
MW	72	55-90	7.2"	197	145 microJy
LW	117	90-145	12"	203	2.7 mJy
LLW	187	145-230	19"	257	13 mJy

A photometric survey with “only” SPICA SMI/CAM
Survey Strategy

White paper by Carlotta Gruppioni et al. (2017, PASA)

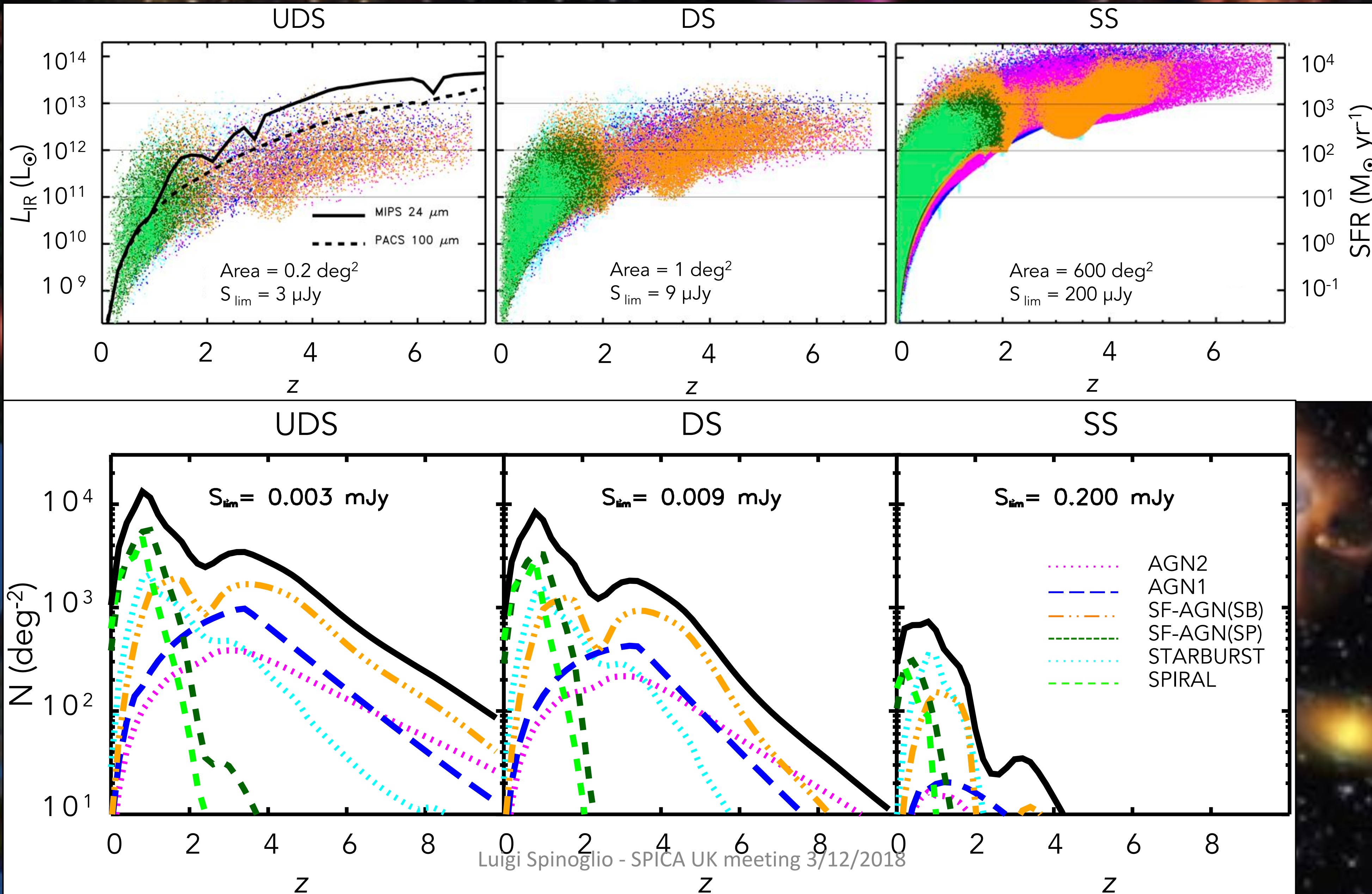
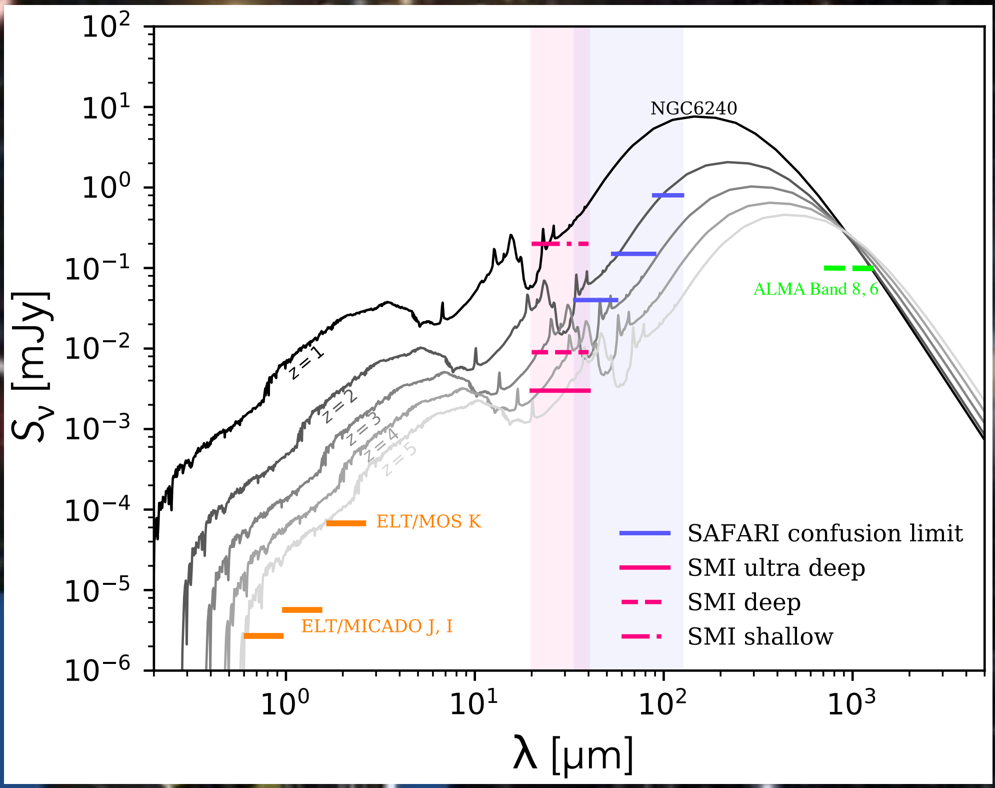


Table 1 Expected No. of sources in the SMI 34-μm survey.

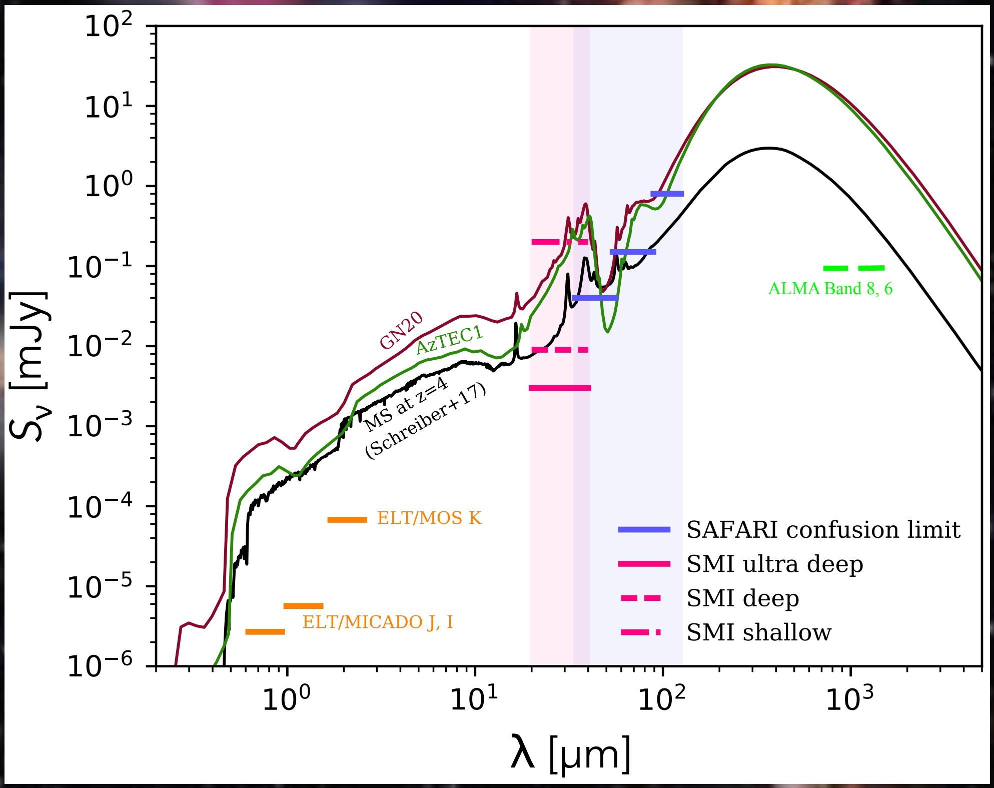
z	No. UDS Tot (AGN)	No. DS Tot (AGN)	No. SS Tot (AGN)
0–1	6.3 (3.0)$\times 10^3$	2.1 (0.9)$\times 10^4$	1.7 (0.8)$\times 10^6$
1–2	7.3 (4.9)$\times 10^3$	2.2 (1.5)$\times 10^4$	1.4 (0.5)$\times 10^6$
2–3	2.7 (2.2)$\times 10^3$	7.1 (5.4)$\times 10^3$	1.4 (0.8)$\times 10^5$
3–4	3.2 (2.9)$\times 10^3$	8.4 (7.3)$\times 10^3$	9.0 (7.2)$\times 10^4$
4–5	2.3 (2.1)$\times 10^3$	5.2 (4.9)$\times 10^3$	2.5 (2.4)$\times 10^4$
5–6	1.2 (1.1)$\times 10^3$	1.9 (1.9)$\times 10^3$	4.1 (4.1)$\times 10^3$
6–7	5.6 (5.5)$\times 10^2$	5.7 (5.7)$\times 10^2$	9.0 (9.0)$\times 10^2$
>7	1.2 (1.2)$\times 10^1$	8.0 (8.0)$\times 10^0$	1.8 (1.8)$\times 10^1$

White paper by Carlotta Gruppioni et al. (2017, PASA)

HOW TO CONSTRAIN THE SEDs OF SMI FAINT GALAXIES



Template SED of the local CT AGN scaled by redshift up to z=5.



Fits to the observed SEDs of: the z≃4 starburst galaxy GN20 (purple) and the z=4.34 sub-mm galaxy AzTEC-1 (green).

White paper by Carlotta Gruppioni et al. (2017, PASA)

From the science goals to the reference mission definition

2.1.1 *Star formation and Black Hole accretion*

1. High-res MIR spectroscopy: $\lambda\lambda$ =17-36μm R~1300-2200
Spatial coverage: ~1000 pointings Line Sensitivity: 5x10-20 Wm-2 [5**σ**] **T.=1300 hrs**

2. Medium-res FIR spectroscopy: $\lambda\lambda$ =35-230μm {Goal: 35-320μm} R~300
Spatial coverage: ~1000 pointings Line Sensitivity: 5x10-20 Wm-2 [5**σ**] **T.=1300 hrs**

3. Low-res MIR spectroscopy: $\lambda\lambda$ =17-36μm R~50-120 **T.= 19 hrs**
Spatial cov.: 0.2° x 0.17° (1 x 10'x 12' frame) **ULTRA-DEEP** Line Sens.: ~2x10-20 Wm-2 [5 σ]
\+ Wide-band MIR imaging: $\lambda\lambda$ =17-36μm R~5 Ang. Res.: ~3"
Spatial cov.: 0.2° x 0.17° (1 x 10'x 12' frame) **ULTRA-DEEP** Cont. Sens.: <3 μJy [5 σ] below confusion

5. Low-res MIR spectroscopy: $\lambda\lambda$ =17-36μm R~50-120 **T.=203 hrs**
Spatial cov.: 1°x1° (spread over several patches) **DEEP** Line Sensitivity: 3x10-20 Wm-2 [5 σ]
\+ Wide-band MIR imaging: λ ~ 34 μm {Goal: 27μm} R~5 Ang. res.: ~3"
Spatial cov.: 1°x1° (spread over several patches) **DEEP** Sens.:<5μJy [5σ] to achieve confusion

7. Wide-band FIR imaging: λ ~ 60 μm R~5 Ang. res.: ~6" **T.=19 hrs**
Spatial cov.: 0.2° x 0.17° (1 x 10'x 12' frame) **ULTRA-DEEP** Cont. Sens.: <15μJy [5σ] below confusion

8. Wide-band FIR imaging: λ ~ 60 μm R~5 Ang. res.: ~6" **T.=138 hrs**
Spatial cov.: 1°x1° (spread over several patches) **DEEP** <30 μJy [5 σ] to achieve confusion-limit

2.1.2 *Feeding and feedback in galaxies*

High-res FIR spectroscopy $\lambda\lambda$=35-230μm {Goal: 35-320μm} R~1800-12000 **T.=480 hrs**
Spatial coverage: ~120 pointings Sensitivity: 1x10-19 Wm-2 [5σ] {Goal: 6x10-20 Wm-2 [5σ]}

2.1.3 *The rise of metals and dust*

Very High-res MIR spectroscopy: $\lambda\lambda$=12-18μm R~28000 (Pf α at z~1) **T.=250 hrs**
Spatial coverage: ~360 pointings Sensitivity: ~2x10-20 Wm-2 [5 σ]

2.1.4 *Detecting Early Black Holes and Starbursts*

1. *Wide-band MIR imaging photometry:* $\lambda\lambda$=34μm R~5 **T.=79 hrs**

Spatial cov.: 625 deg^2 (**SHALLOW**) (spread over several patches) Sensitivity: 0.2 mJy [5 σ]

Or

Spatial cov.: 100 deg^2 (**SHALLOW**) (spread over several patches) Sensitivity: 0.08 mJy [5 σ]

2. *Wide-band FIR imaging photometry:* $\lambda\lambda$=60μm R~5 **T.=138 hrs**

Spatial cov.: 625 deg^2 (**SHALLOW**) (spread over several patches) Sensitivity: 0.75 mJy [5 σ]

Or

Spatial cov.: 100 deg^2 (**SHALLOW**) (spread over several patches) Sensitivity: 0.30 mJy [5 σ]

2.1.5 *Characterizing Early Black Holes and Starburst Galaxies*

1. *Medium-res FIR spectroscopy:* $\lambda\lambda$=35-230μm R~300 **T.=500 hrs**

Spatial coverage: ~50 pointings Sensitivity: 5x10-20 Wm-2 [5 σ] {Goal: 3x10-20 Wm-2 [5 σ]}

2.1.6 Physics of the ISM and activity in Local galaxies

1. High-res FIR spectroscopy $\lambda\lambda$=35-230µm {Goal: 35-320µm} R~1800-12000 **T.=300 hrs**
Spatial coverage: ~600 pointings Sensitivity: 1x10-19 Wm-2 [5σ] {Goal: 6x10-20 Wm-2 [5σ]}

2. High-res MIR spectroscopy: $\lambda\lambda$=17-36µm R~1300-2200 **T.=20 hrs**
Spatial coverage: ~600 pointings Sensitivity: ~5x10-20 Wm-2 [5 σ]

3. Very High-res MIR spectroscopy: $\lambda\lambda$=12-18µm R~28000 (Pf α at z~1) **T.=20 hrs**
Spatial coverage: ~360 pointings Sensitivity: ~2x10-20 Wm-2 [5 σ]

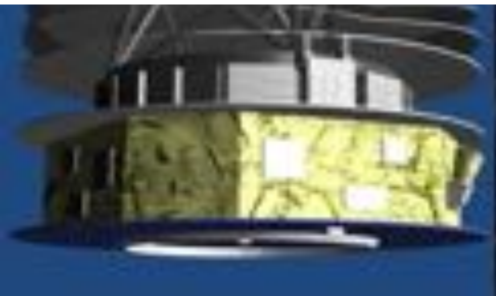
4. Medium-res FIR spectroscopy: $\lambda\lambda$=35-230µm R~300 **T.=40 hrs**
Spatial coverage: ~40 pointings (for HD detection) Sensitivity: 5x10-20 Wm-2 [5 σ]

2.1.7 Nearby (resolved) galaxies

1. *Medium-res Imaging FIR spectroscopy*: $\lambda\lambda$=35-230µm R~300 **T.=200 hrs**
Spatial coverage: ~20 pointings, 10’x7’ coverage Sensitivity: 1x10-18 Wm-2 [5 σ]

2. *High-res Imaging MIR and FIR spectroscopy:* $\lambda\lambda$=*17*-230µm R~1500
Spatial coverage: 20 pointings, 1’x1’ to 10’x10’ coverage (TBC) Sens.: 50x10-20 Wm-2 [5 σ]

3. Imaging FIR polarimetry: $\lambda\lambda$=75-420 µm R~2 Angular res.: ~10” FWHM @ 100 µm
Spatial coverage: ~50 sources @10’x10’ Sensitivity: 1 MJy/sr [5% pol fraction, 5σ]



Mode		Science cases	Type of obs	Resolution	No. srcs	FOV/src	Integ time (hrs)
MIR spectroscopy	Low-res	2.1.1 2.1.1 2.1.4	Stare-step Stare-step Stare-step	Diff Diff Diff	1 1 1	0.2°x0.17° 1.0°x1.0° n/a	19 203 2.1.1
	High-res	2.1.1 2.1.2 2.1.3 2.1.6 2.1.7	Stare Stare Stare Stare Stare-step	Diff Diff Diff Diff 2 @ 20	1000 500 1000 600 20	n/a n/a n/a n/a 1'-10' ^2	1300 2.1.1 2.1.1 75 ?
	Very-high-res	2.1.3 2.1.6	Stare Stare	2 @ 20 2 @ 20	360 600	n/a n/a	250 20
MIR imaging photometry	Wide-band	2.1.1 2.1.1 2.1.3 2.1.4 2.1.4	Stare-step Stare-step Stare Stare-step Stare-step	3 @ 30 3 @ 30 2 @ 20 3 @ 30 3 @ 30	1 1 1000 1 1	0.2°x0.17° 1.0°x1.0° n/a 1.0°x1.0° 25°x25°/10°x10°	2.1.1LR 2.1.1LR 2.1.3MR 2.1.1LR 79
FIR spectroscopy							
	Medium-res	2.1.1 2.1.2 2.1.3 2.1.5 2.1.6 2.1.7	Stare Stare Stare Stare Stare Stare-step	Diff Diff Diff Diff Diff Diff	1000 500 1000 50 40 20	 n/a n/a n/a 10'x7'	1300 2.1.1 2.1.1 500 40 200
	High-res	2.1.2 2.1.6 2.1.7	Stare Stare Stare-step	Diff Diff Diff	120 600 20	n/a n/a <10' ^2	480 300 ?
FIR imaging photometry	Wide-band	2.1.1 2.1.1 2.1.4 2.1.4	OTF OTF OTF OTF	Diff Diff Diff Diff	1 1 1 1	0.2°x0.17° 1.0°x1.0° 1.0°x1.0° 25°x25°/10°x10°	19 138 2.1.1 140