FIR Spectroscopic Cosmological surveys with SPICA

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- main energy-generating mechanisms in galaxies: black hole (BH) accretion and star formation (SF)
- SF and AGN linked in a physical way (feedback) or in an evolutionary sequence
- IR spectroscopy able to distinguish between BH accretion and SF, shown in the past by ISO and recently by Spitzer.

- Spitzer and Herschel spectroscopy together can trace the AGN and the Star Formation component, with extinction free lines, BUT ONLY IN THE LOCAL UNIVERSE

- GALAXY EVOLUTION: the goal is to understand the history of the luminosity source of galaxies along evolution with SPICA spectroscopic cosmological surveys

- FEASIBILITY: use galaxy evolution models linked to the observed IR-FIR counts (including Herschel) to predict the number of sources and their IR lines fluxes, as derived from observations of local galaxies.

What we want to know

- 1) Full Cosmic History of Energy Generation by Stars (Fusion) and Black Holes (Accretion)

  (it's not just quasars, but Seyfert galaxies which dominate at the 'knee'' of the Luminosity Function)

- 2) These energy production rates correspond to built up MASS (of central black hole, or galactic stars), and must--ultimately--be consistent.

- 3) Uncover how much of this is partly or heavily extinguished

- 4) Seek cosmic connections between a galaxy's stars and its massive Black Hole: understand the how and why of these systems

Global Accretion power (X-rays) and Star Formation (Hα) were ~20 times higher at z=1-1.5 than today

- Recent examples of attempts to measure:
- Black Hole Accretion Power

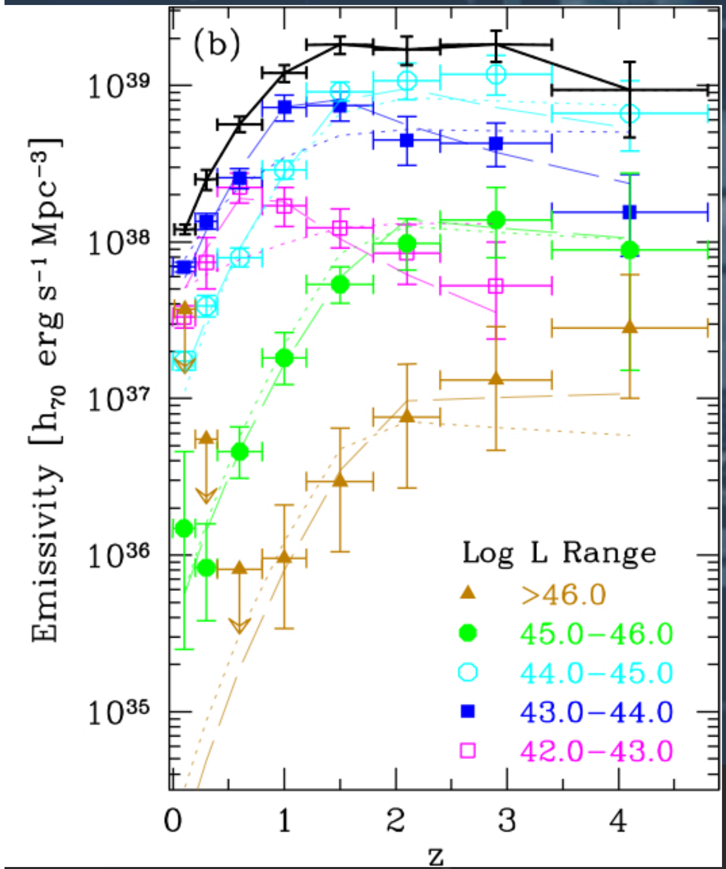
(but Bolometric Corrections could easily be off more than an order of magnitude)

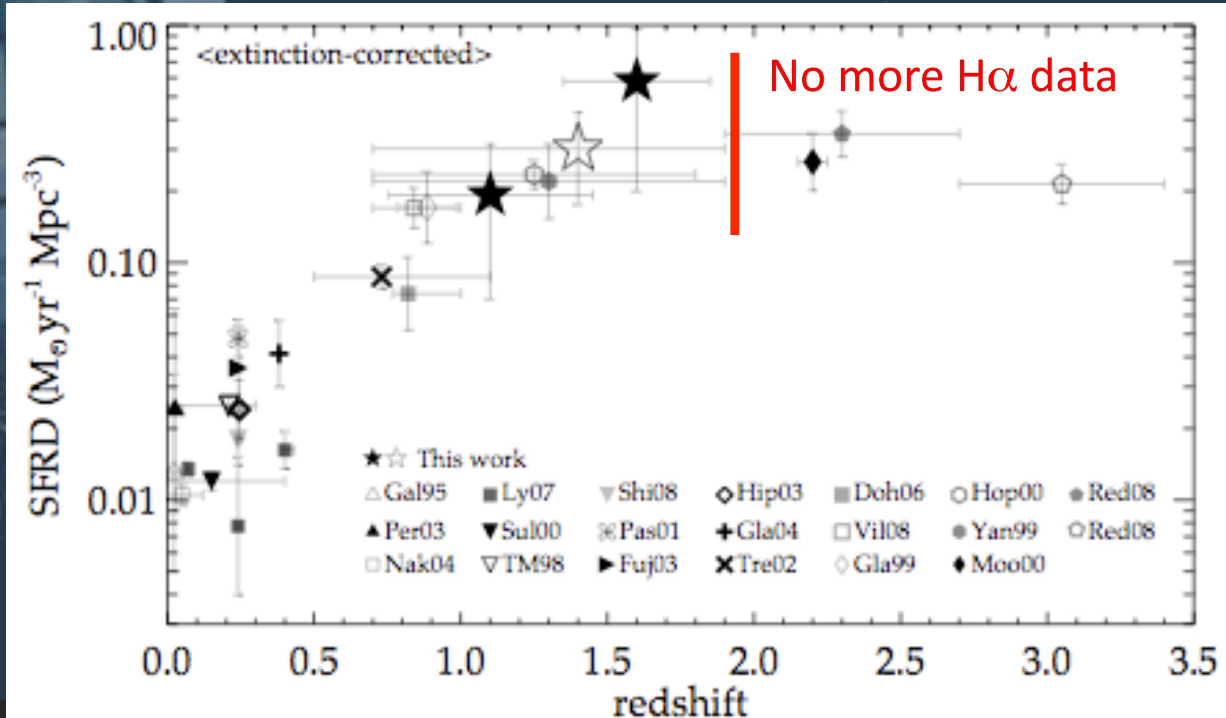
Hasinger et al 2005

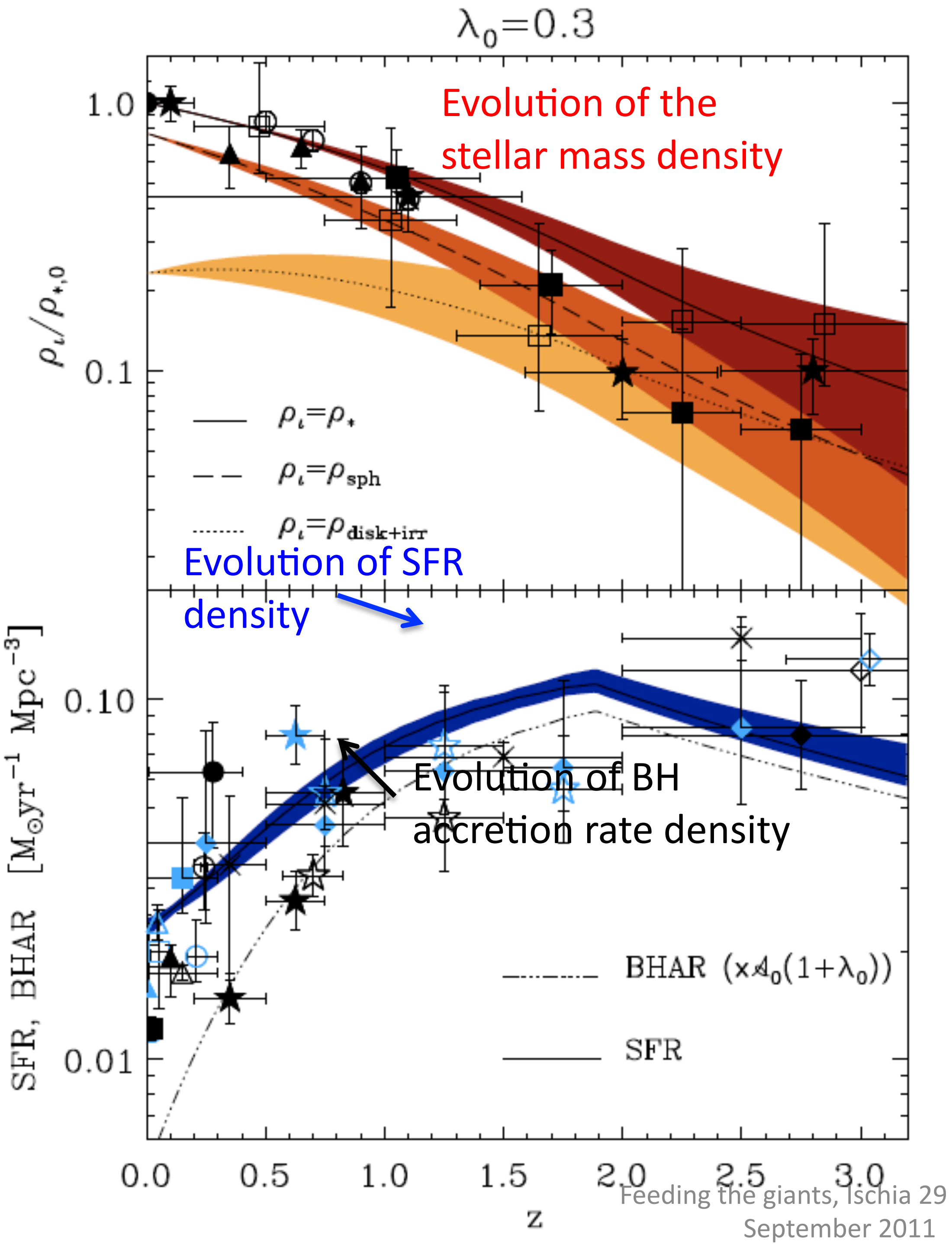
Young Star Power,

Assuming 1 magnitude of absorption at Hα

Shim et al 2009







On a cosmic scale, the evolution of supermassive black holes (SMBHs) appears tied to the evolution of the star-formation rate (SFR) (Marconi et al 2004; Merloni et al 2004).

Merloni et al 2004 (mnras 354, L37)

Comparing different wavelengths for separating AGN and SF

No single criteria distinguish AGN & SF ➔ limits and potentialities of different techniques

– UV/Optical/NIR observations ➔ galaxy morphology and spectra,
BUT they seriously suffer from dust obscuration

– X-ray observations ➔ good tracers of AGN,
BUT only weak X-ray emission can be detected from star formation
BUT heavily-obscured AGN (Compton-thick) completely lost.

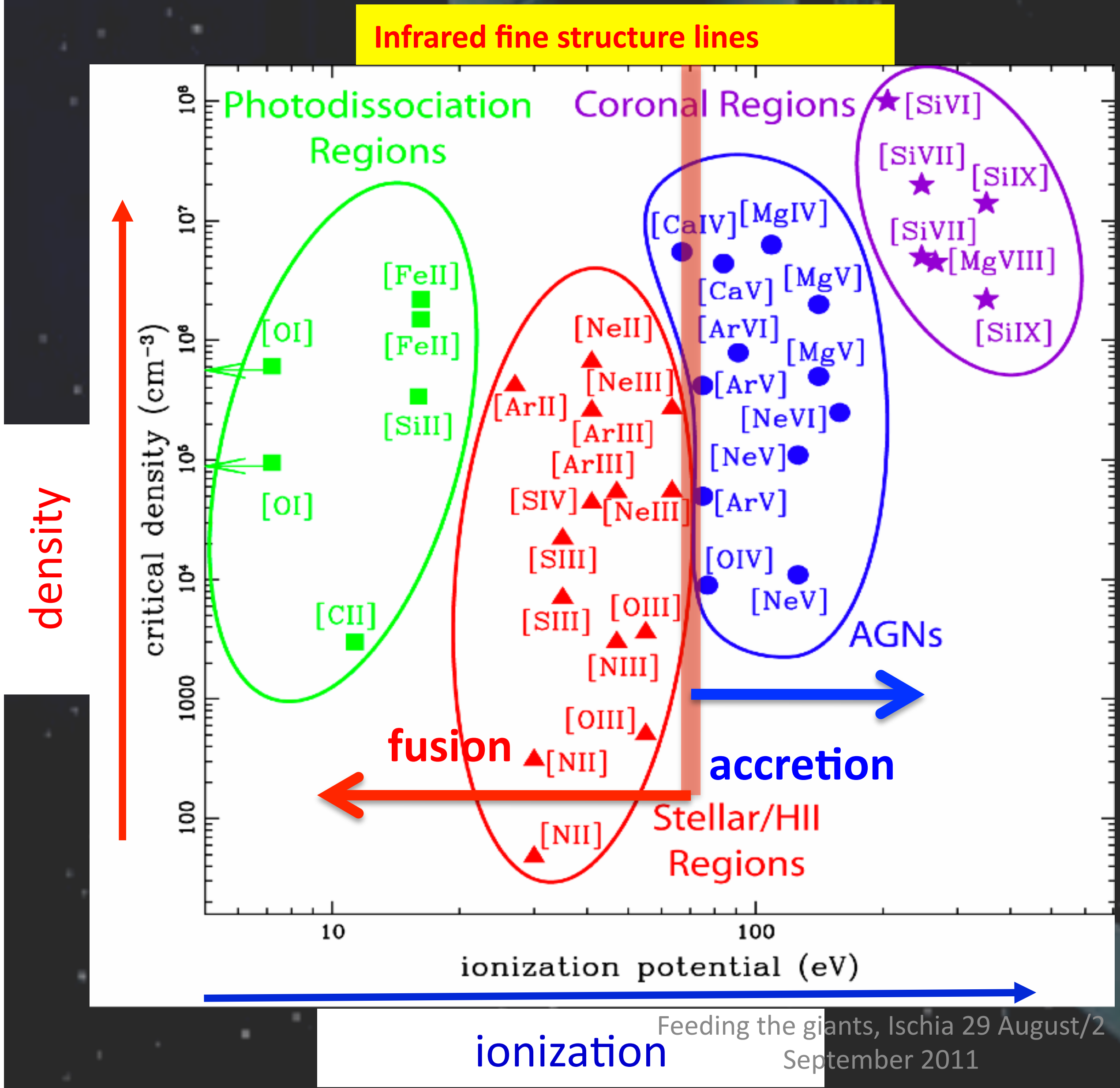
– Radio observations (EVLA, SKA) ➔ can detect AGN and SF to large z and can see through gas and dust, ➔measure morphology and spectral SED, detect polarization and variability, BUT not always redshifts can be measured. (at its highest frequencies SKA will measure redshifted molecular lines in the ISM of galaxies).

– mm/submm observations (e.g. ALMA, CCAT) ➔ spectra from SF (redshifted CO, CII, etc.), BUT no AGN tracers.

Rest-frame MIR/FIR imaging spectroscopy ➔ complete view of galaxy evolution and the role of BH and SF because it can (provided that large field of view and high sensitivity can be reached)

➔ trace simultaneously both SF and AGN,
➔ measure redshifts
➔ see through large amounts of dust.
➔ the most promising technique.

Why infrared spectroscopy is the best tool to isolate star formation and accretion?



IR fine structure lines:
- separate different physical mechanisms,
- cover the ionization-density parameter space
- do not suffer heavily from extinction

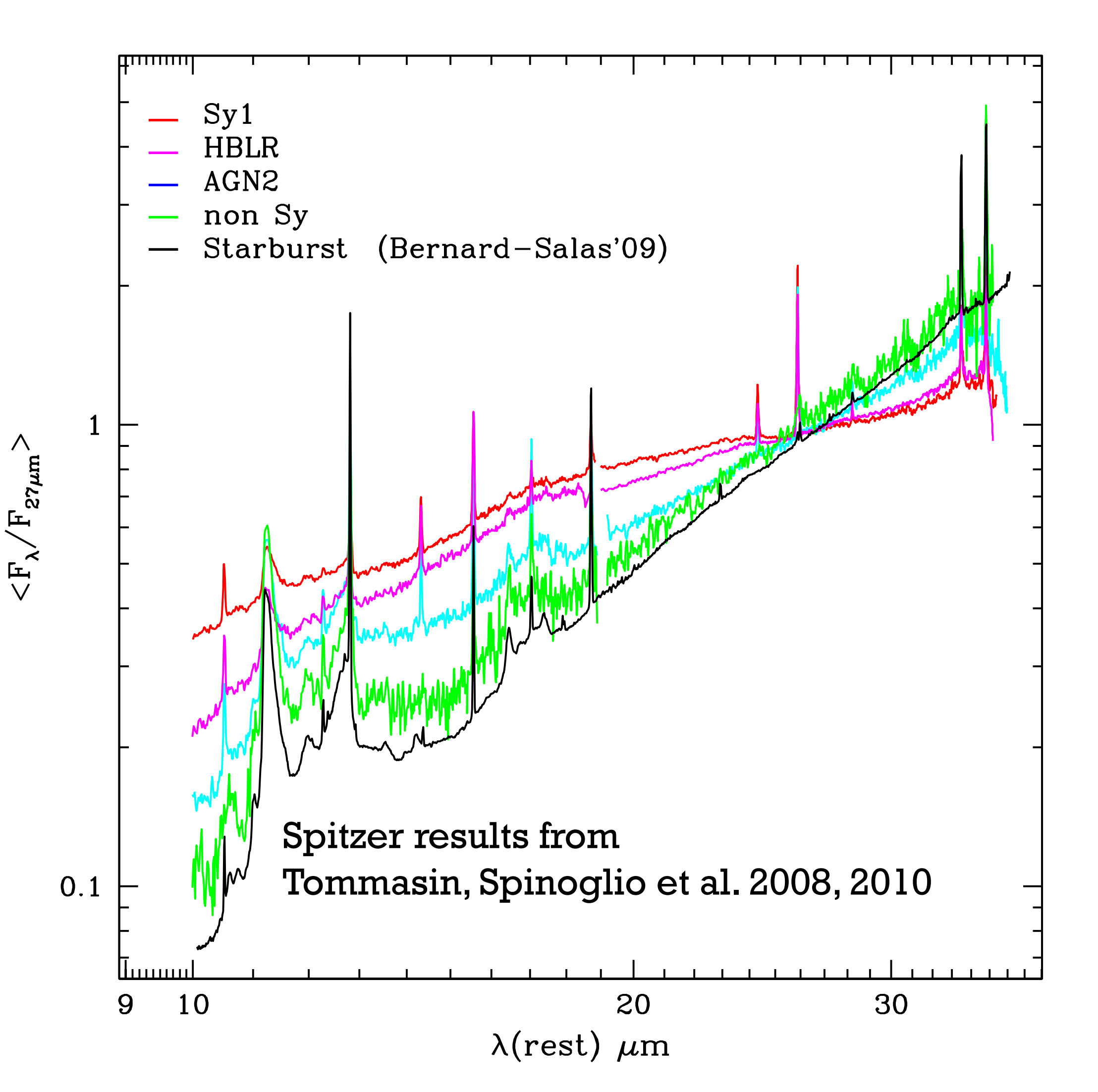
Spinoglio & Malkan (1992) predicted for the first time the line intensities of IR lines in active and starburst galaxies, before the launch of ISO.

Game Plan: IR Spectra of 'optical quality'

- Mid-IR spectroscopy provides a full suite of strong fine structure lines over wide range of ionization
- Spitzer/IRS spectra have huge SNR and good ***spectral resolution*** (R~600)
- From SB to Sy1:

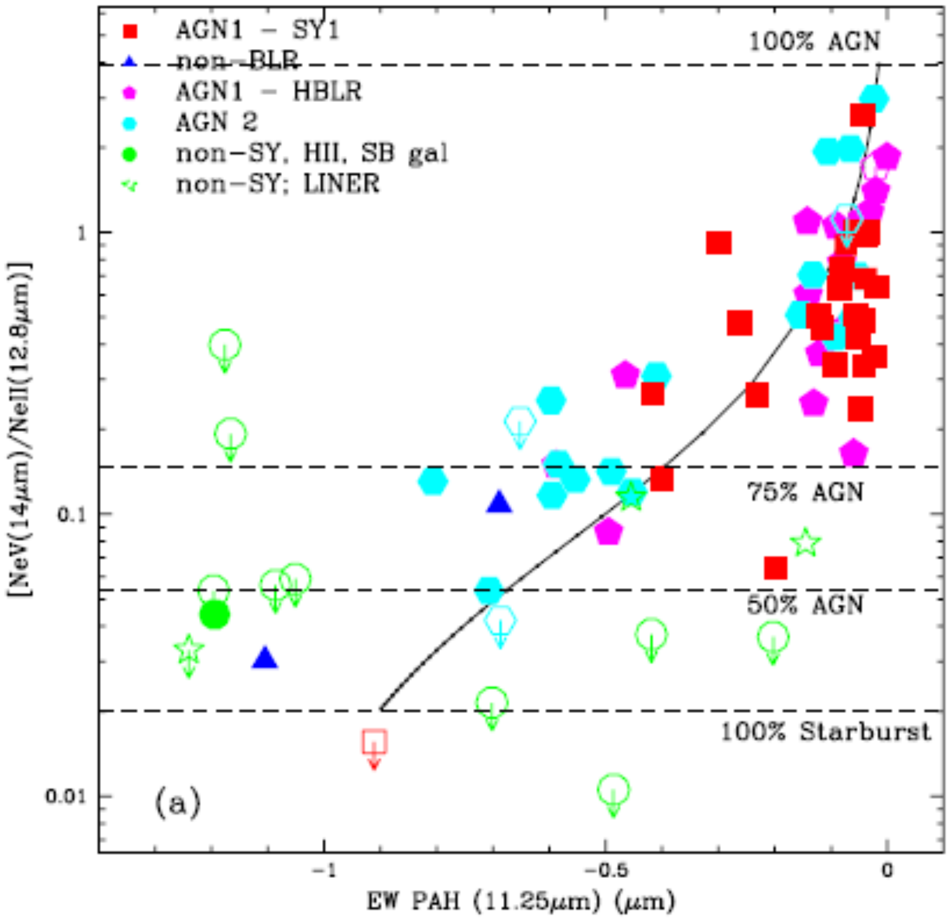
- Higher ionization lines decrease in flux and equivalent widths

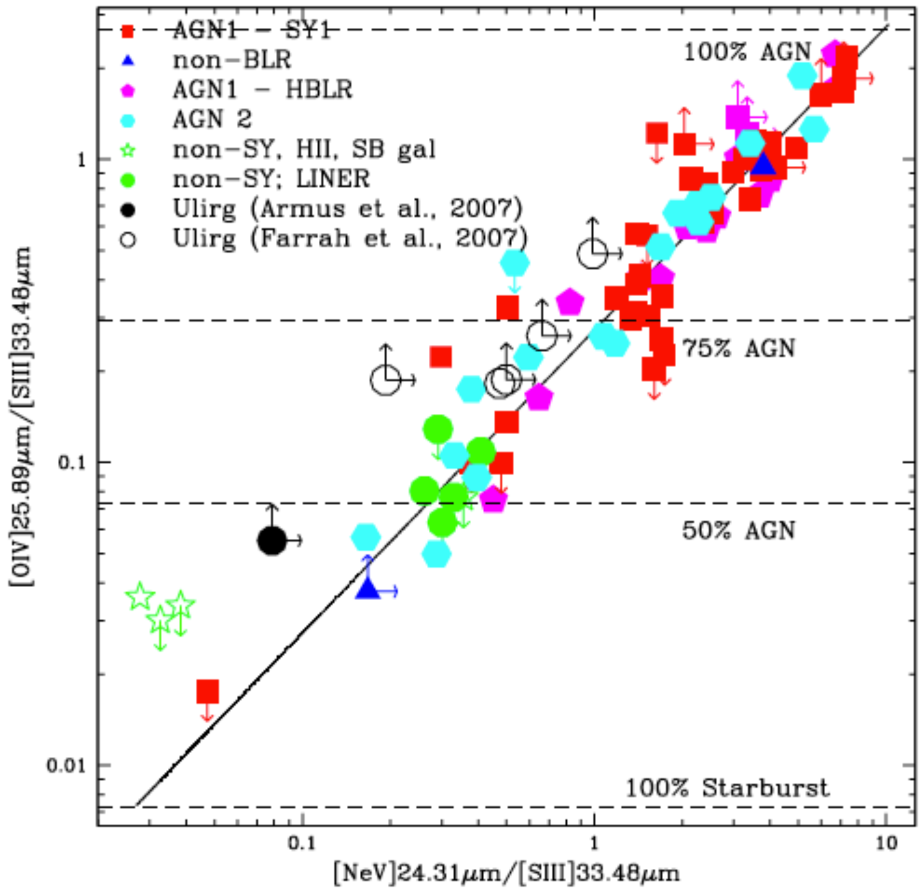
- PAH feature remains almost constant in flux, while its equivalent width decreases



Average IRS high resolution spectra of the 12μm active galaxies (Tommasin, Spinoglio, Malkan, Fazio 2010, ApJ) compared to the starburst spectra (Bernard-Salas+ 2009)

AGN/Starburst Mixing Diagrams with Lines





[OIV]/[NeII] and [NeV]/[NeII] ratios are very good indicators of AGN strength
EW(PAH@11.25μm) and EW([NeII]12.8μm) good SF indicators (Tommasin, LS +, 2010)

[OIV]/[SIII] and [NeV]/[SIII] ratios also very good indicators of AGN strength, [SIII] line at 33μm in SAFARI range at any detectable z

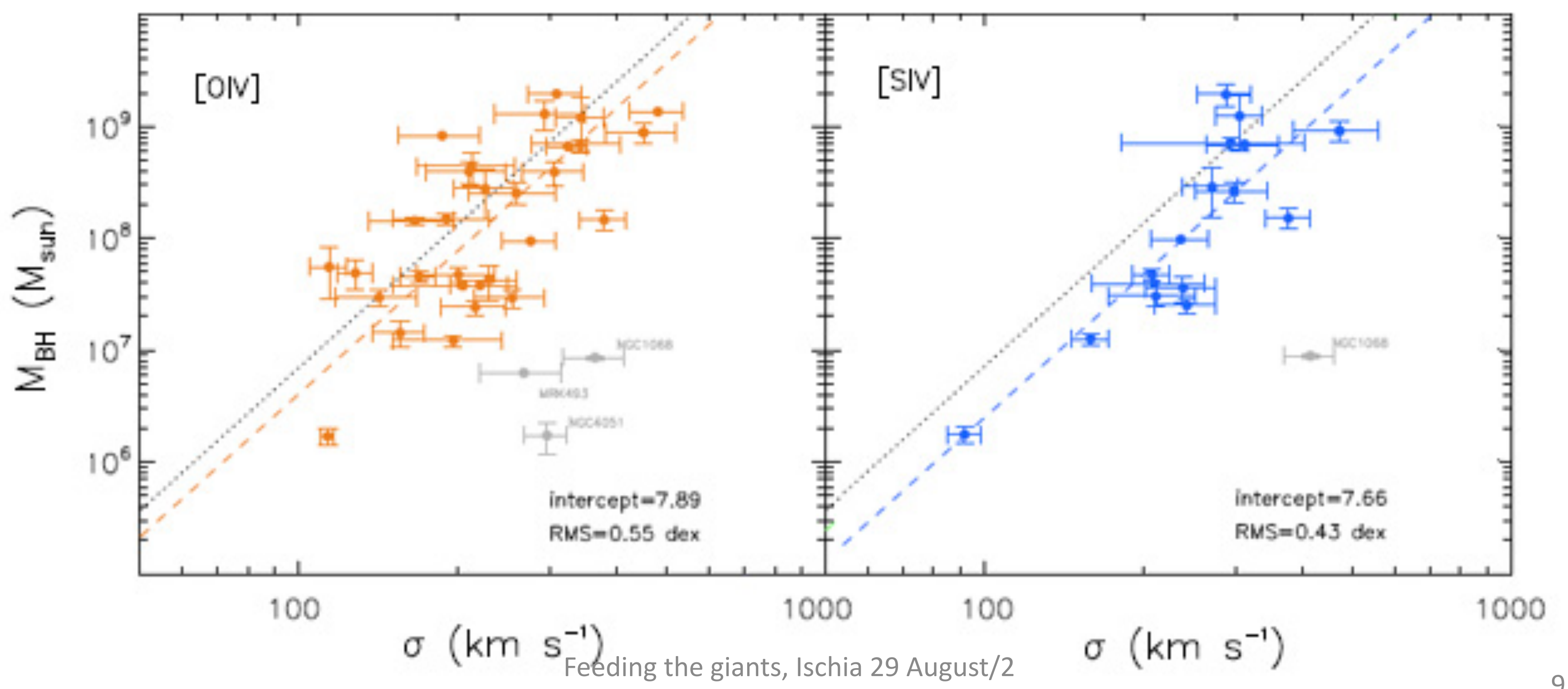
➔ MIR spectroscopy able to quantify AGN and SB components

IR fine-structure lines as black hole mass tracers

The width of the narrow lines can be used as a means of weighting M_{BH} as the velocity dispersion of the NLR gas σ_{NLR} scales with M_{BH}

(as known from optical wavelengths; Nelson 2000; Shields et al. 2003; Greene & Ho 2005; Gaskell 2009)

Dasyra et al. (2008; 2011)



The importance of AGN excited fine structure emission

Fine structure emission excited by the AGN allows simultaneous:

- identification of obscured AGN

+ characterization of accretion rate, M_{BH}, density of surrounding gas in systems in which

to be compared with SFR, stellar mass, SF compactness

An extremely useful tool for cosmological surveys…

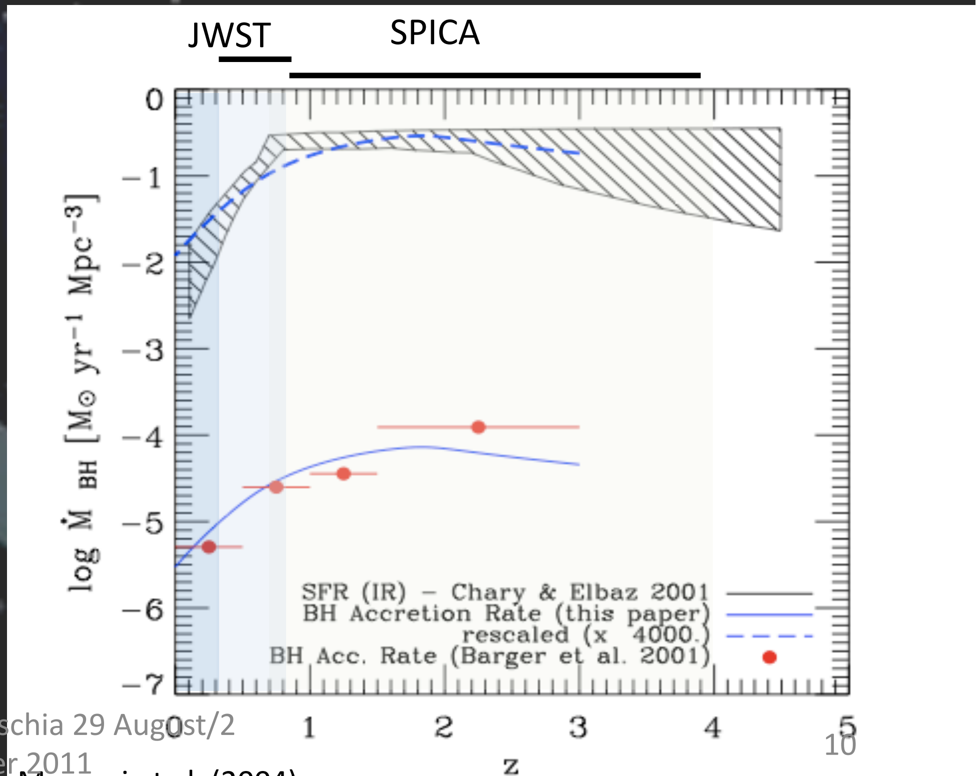
Spitzer: z<0.3 using [NeV] (due to sensitivity)

JWST: [NeV] up to z<0.8

SAFARI: will cover [OIV] in ULIRGs up to z~3-4:

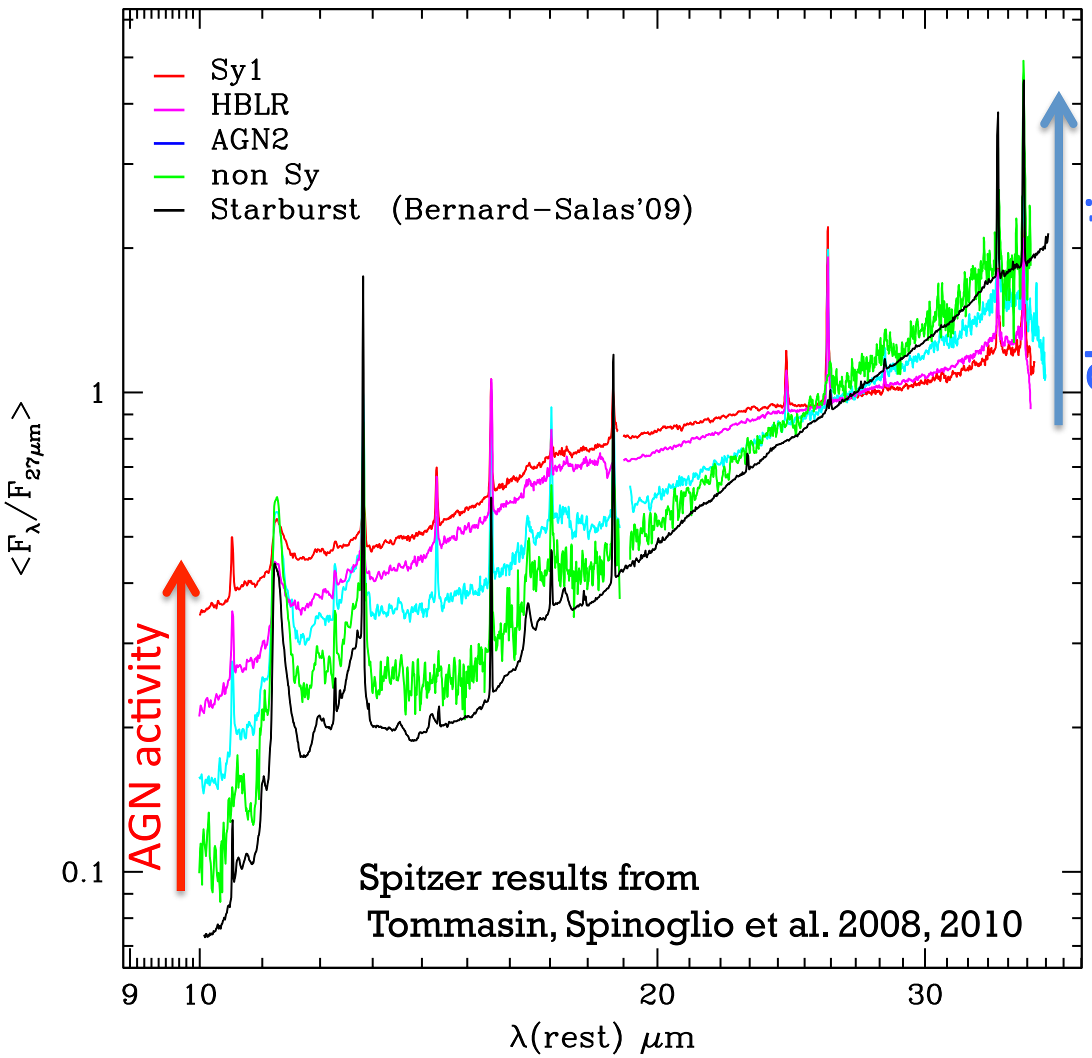
unique parameter space for large surveys

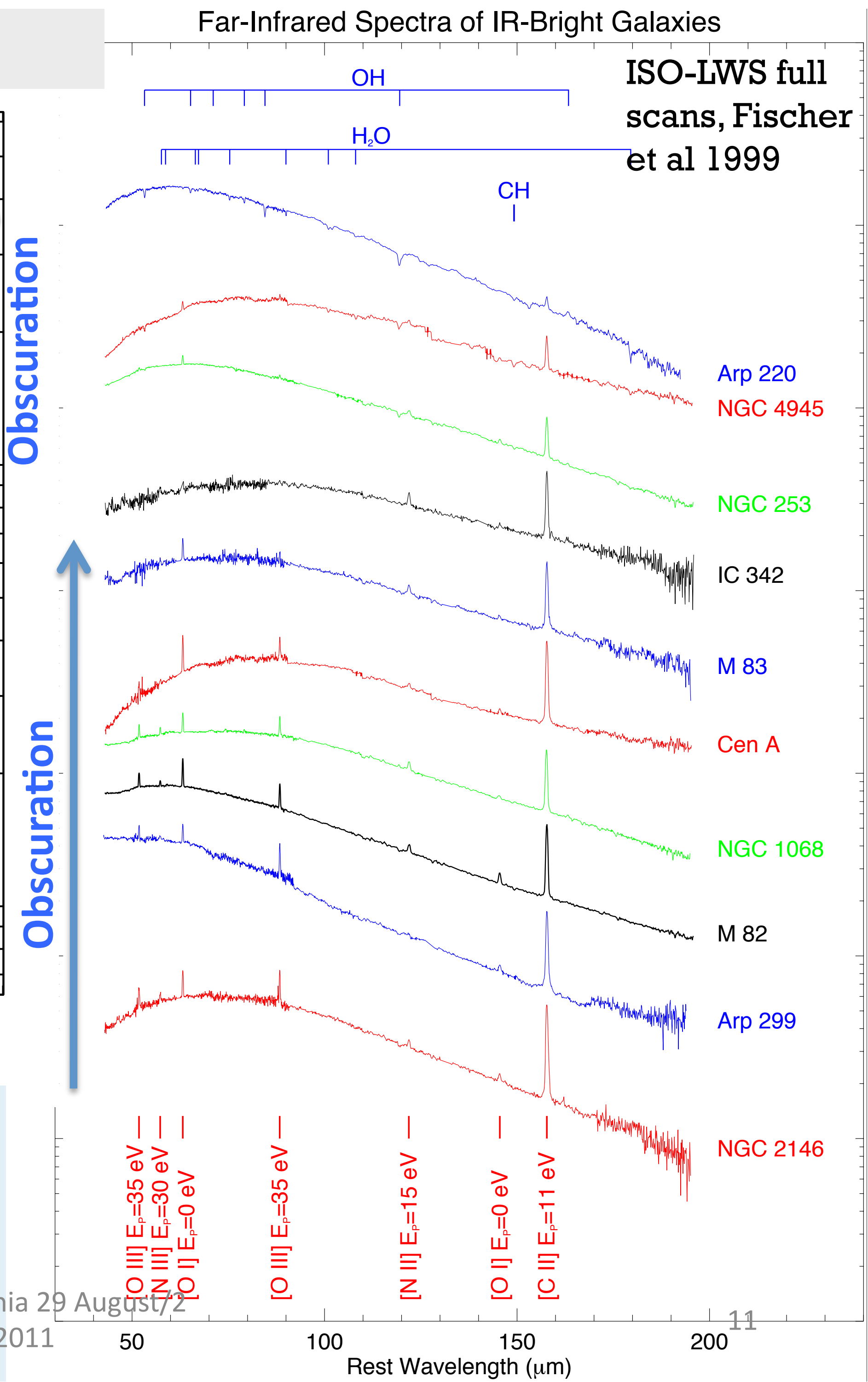
Dasyra et al. (2008; 2011)



Marconi et al. (2004)

MIR & FIR spectroscopy complementary





Links between **OBSCURATION**, **ACCRETION ACTIVITY** and **STAR FORMATION** in galaxies must be determined to understand **GALAXY EVOLUTION**

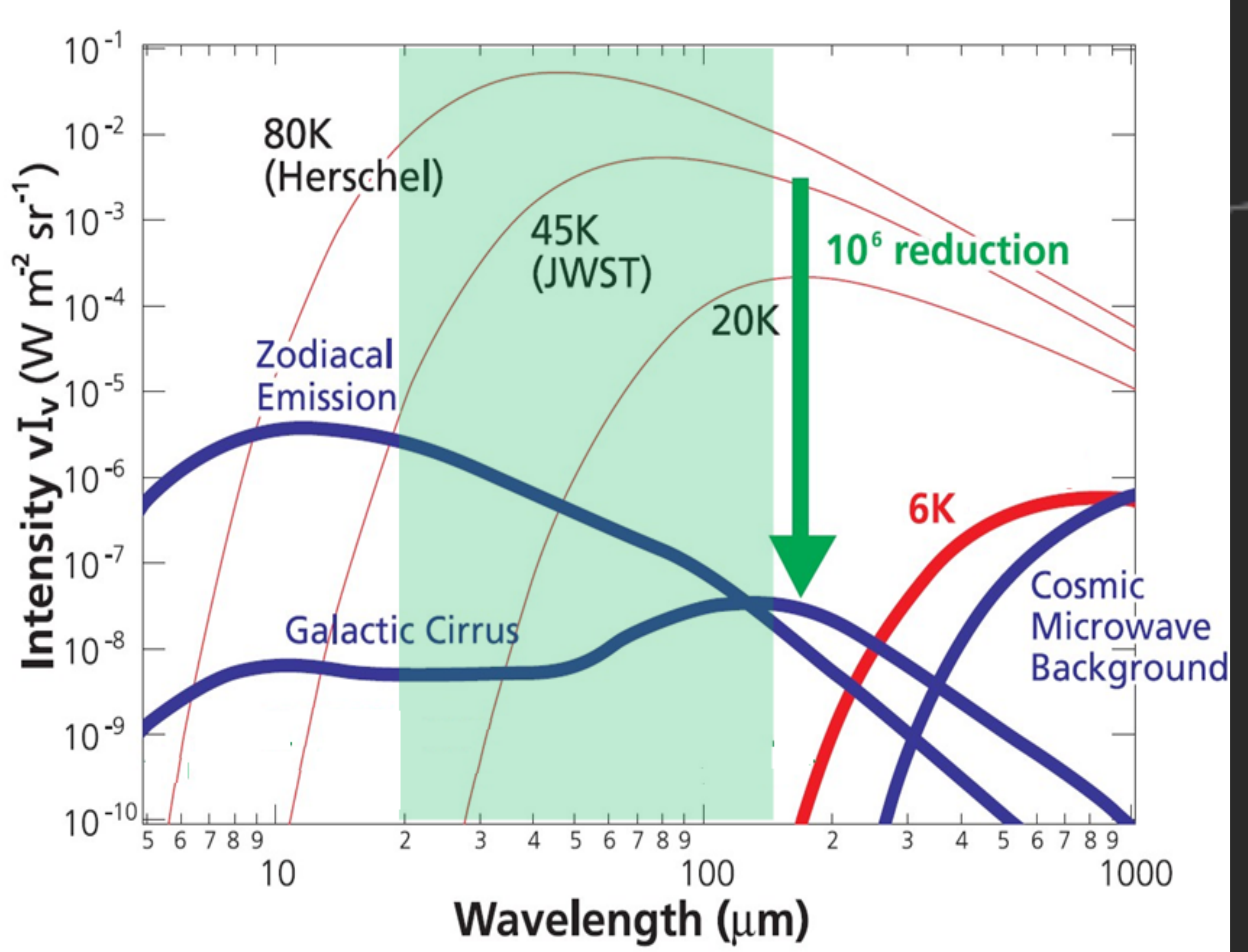
What is next: SPICA JAXA + ESA Cosmic Vision

3.2 m telescope
Cooled to < 6K

Instruments cover 5- 210 µm

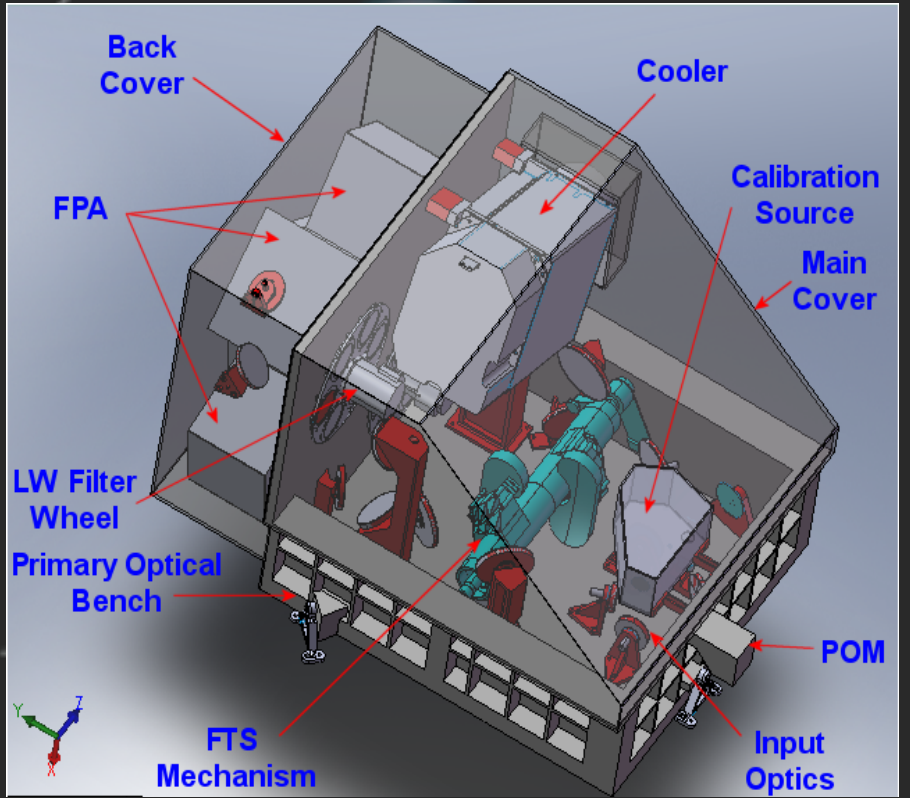
- -MIR spectro-photometer
- -**FIR imaging spectrometer.**
- -MIR Medium/High Resolution Spectrometer
- -MIR coronagraph
- -Focal Plane Camera dedicated to guidance
- -FIR and sub-mm spectrometer – optional

Thermal Backgrounds



SPICA-SAFARI

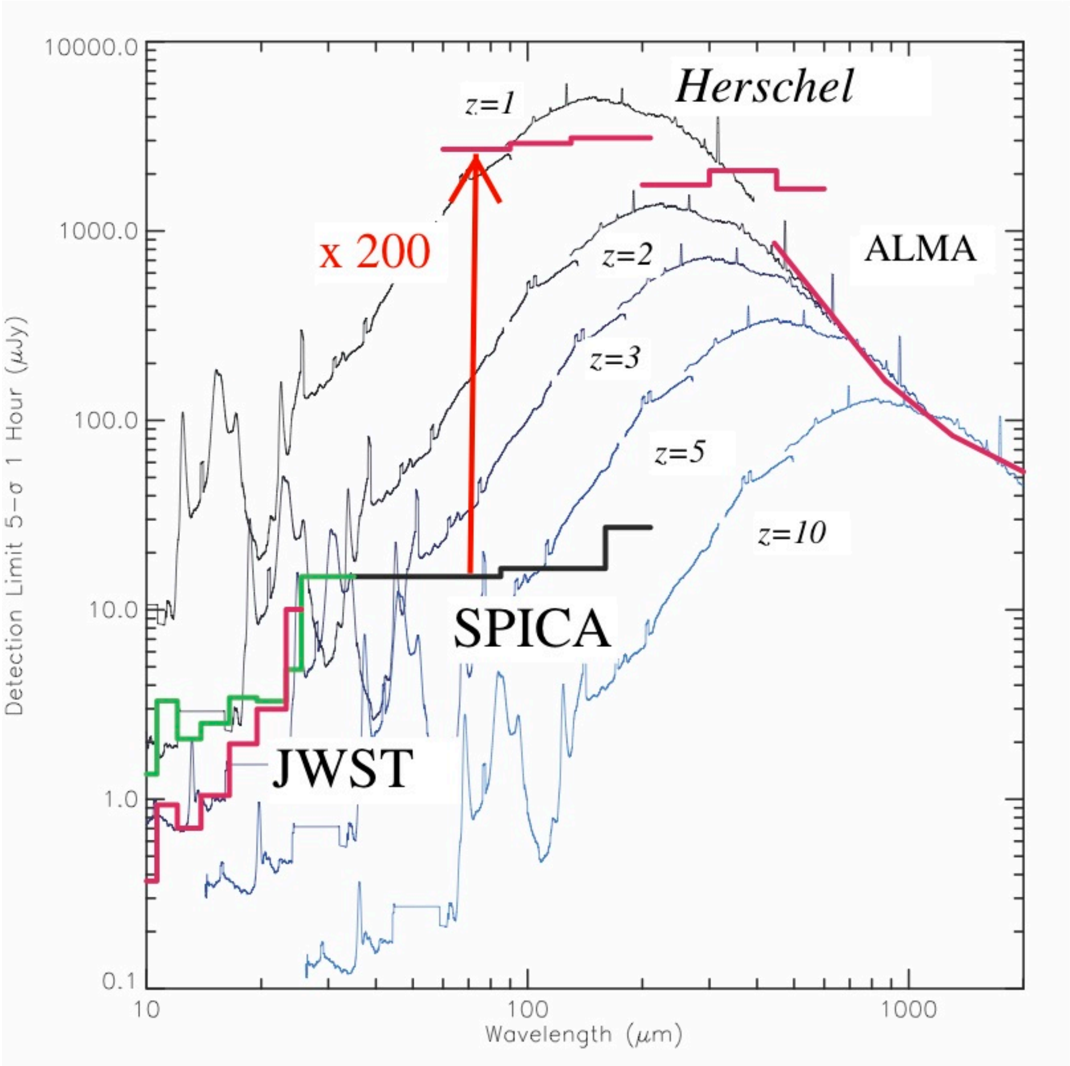
- FIR Camera and spectrometer
  - Imaging FTS
  - Based on SPIRE heritage
  - 35 – 210 μm
  - $\lambda/\Delta\lambda \sim 2000$
  - Field of view 2 x 2 arcmin

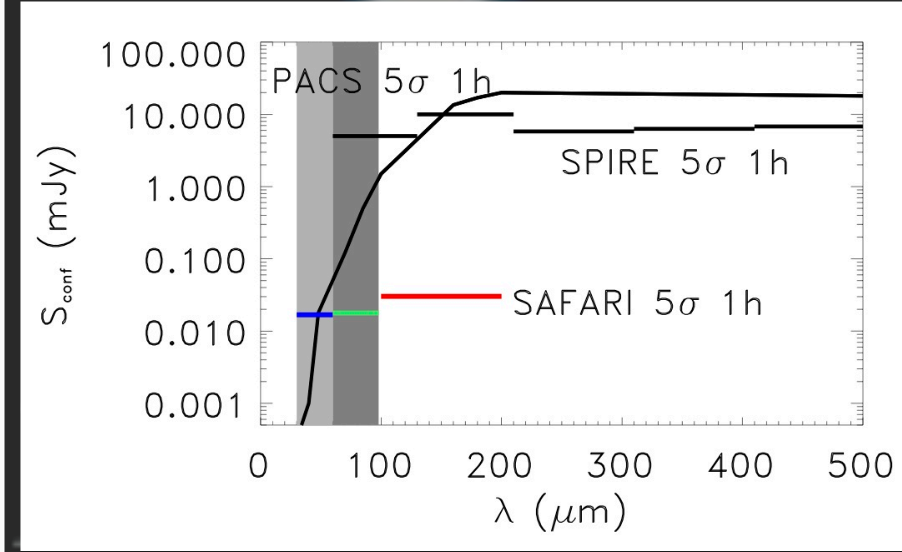


- Features
  - Instantaneous coverage of full band
  - Measurement of continuum and lines
  - Low background
  - Sensitive and linear detectors
    - Superconducting TES arrays
    - Target NEP = 2×10^{-19} W Hz$^{-1/2}$

→Huge increase in sensitivity and observing speed

SPICA Sensitivity - photometry

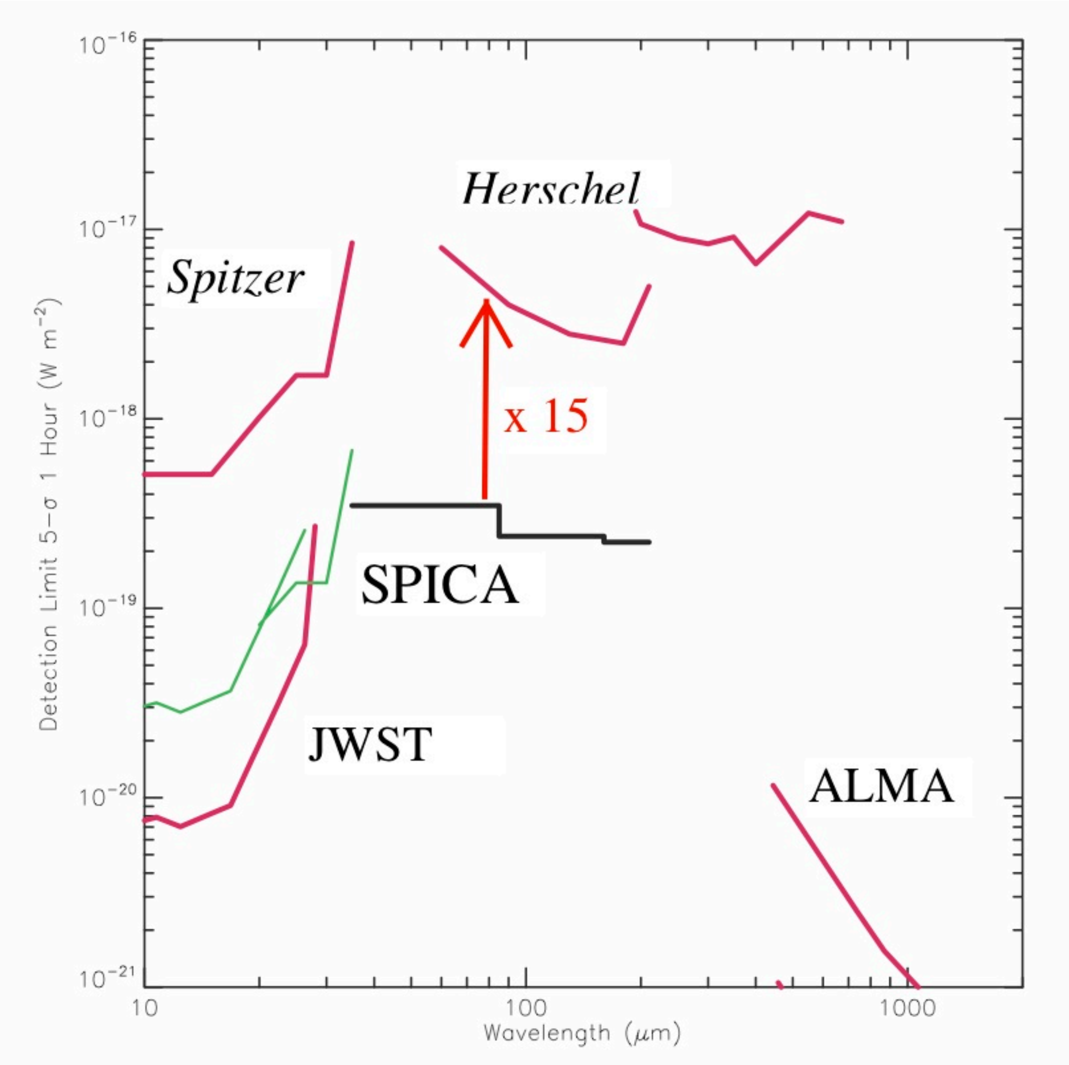




70 µm confusion limit 100 times better then Herschel 100µm confusion limit >10 times better than Herschel

200 times more sensitive than Herschel PACS

SPICA Sensitivity - spectroscopy

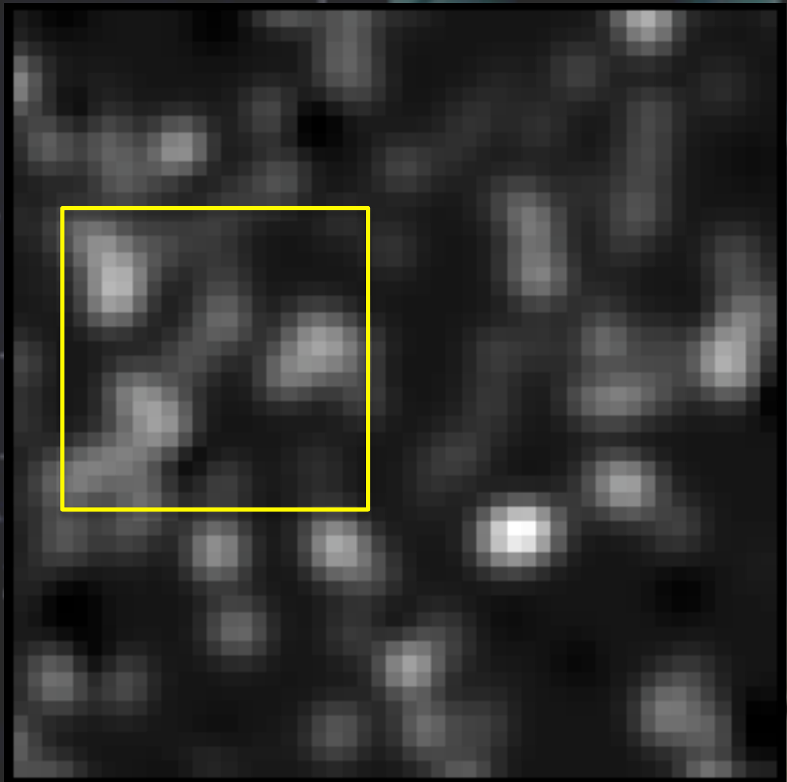


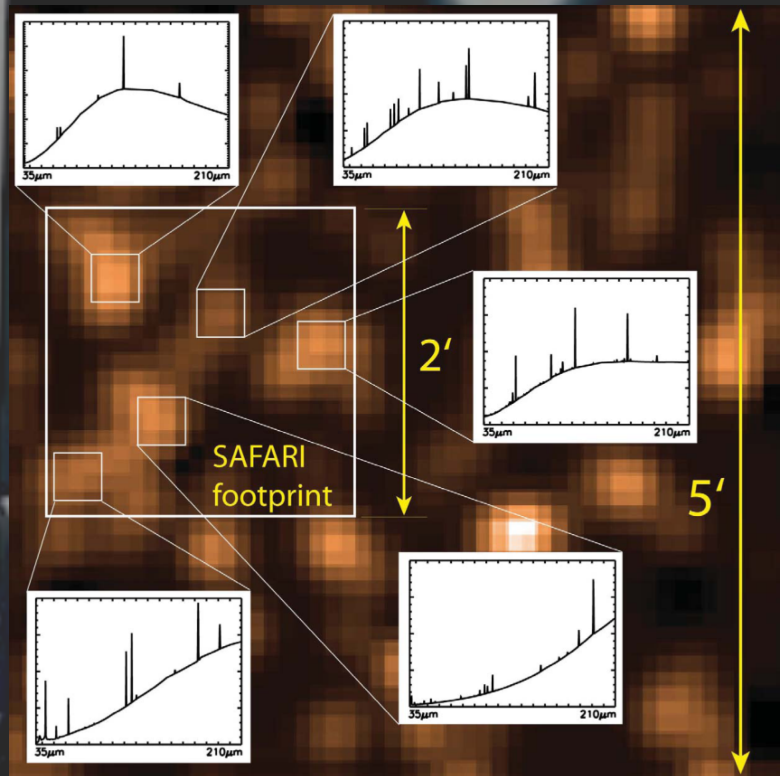
Single unresolved line in single object:
SAFARI sensitivity 15 times better than Herschel
+ huge multiplexing advantage

FTS > 100's times faster to cover multiple lines over large field of view

The Multiplex Advantage

Looking closer at the SPIRE background sources

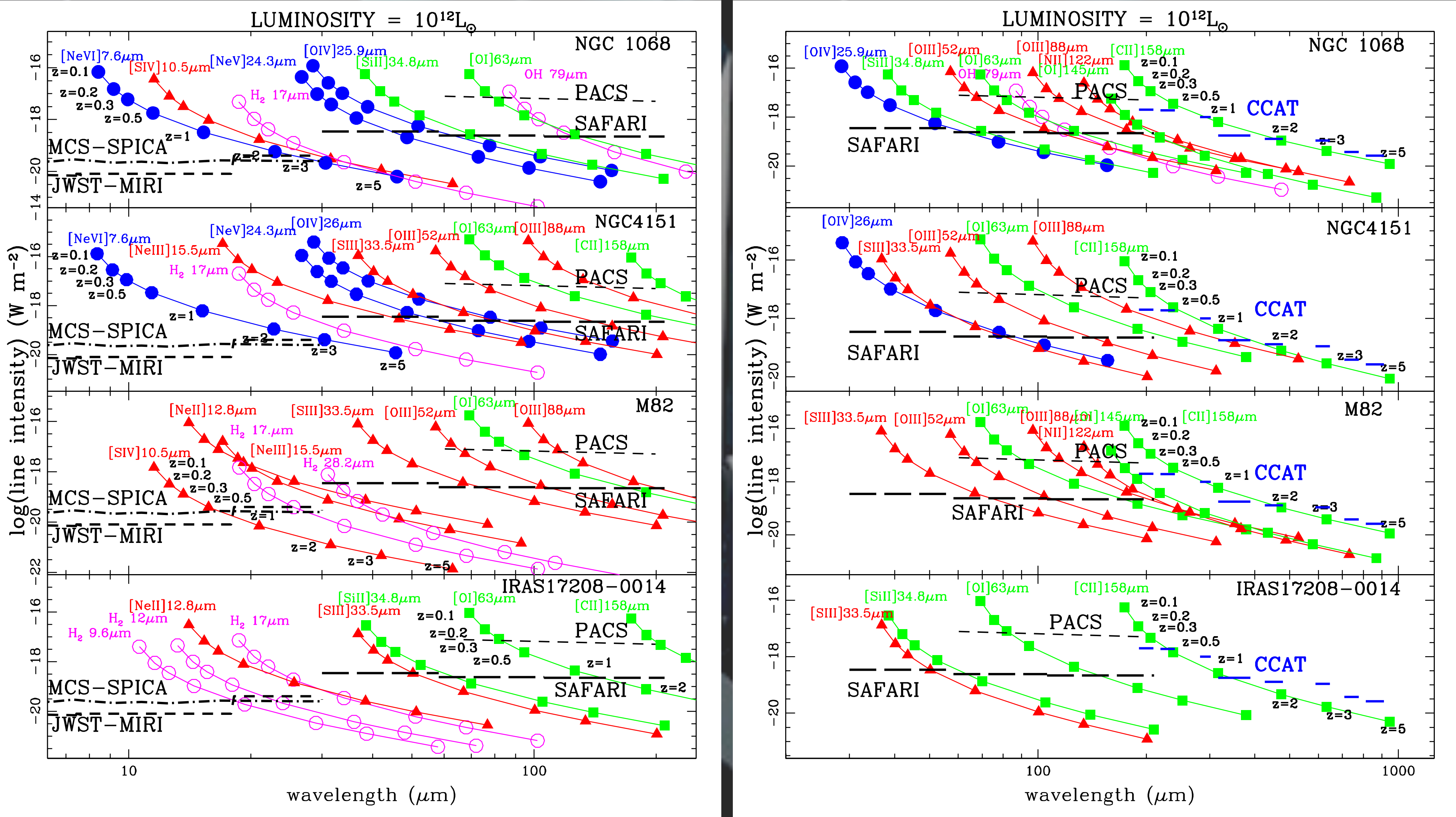




SPICA FIR FTS will take spectra of 7-10 sources/field

Images Rosenbloom, Oliver, Smith, Raab private communication

Four local templates: at what redshift can SAFARI (and CCAT) detect their lines ?



NGC1068, a prototypical Seyfert 2 AGN, NGC4151, a well studied type 1 AGN, the prototypical moderate luminosity starburst M82, and a starburst-dominated ULIRG, IRAS17208-0014.

Number of Starburst Galaxies and AGN at z=0 - 4 that FIR/submm spectroscopic surveys can detect

Method:

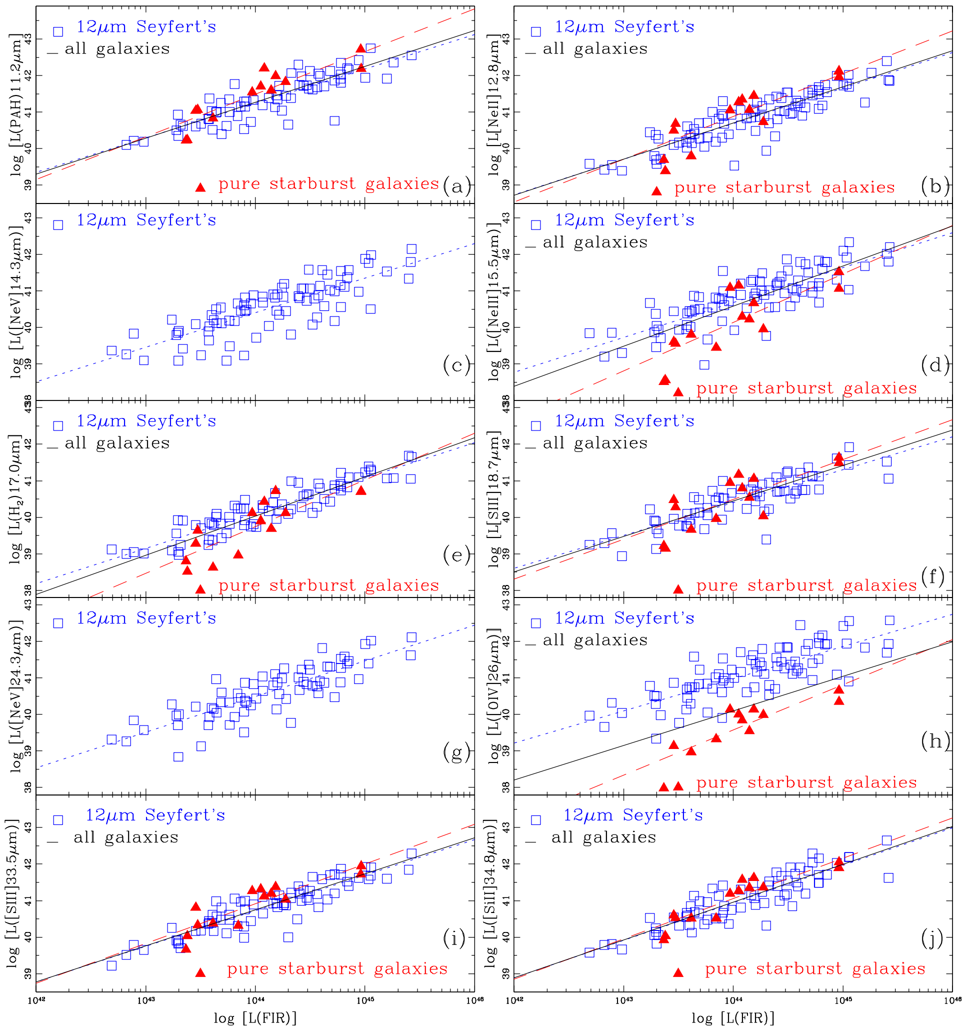
1) Use IR continuum Luminosity Functions (from observations and models).
2) Identify spectroscopic tracers of SF and AGN activity
3) Use correlations between line and IR continuum luminosity in Local Universe.
4) Transform continuum LF (z=0-4) in line LF

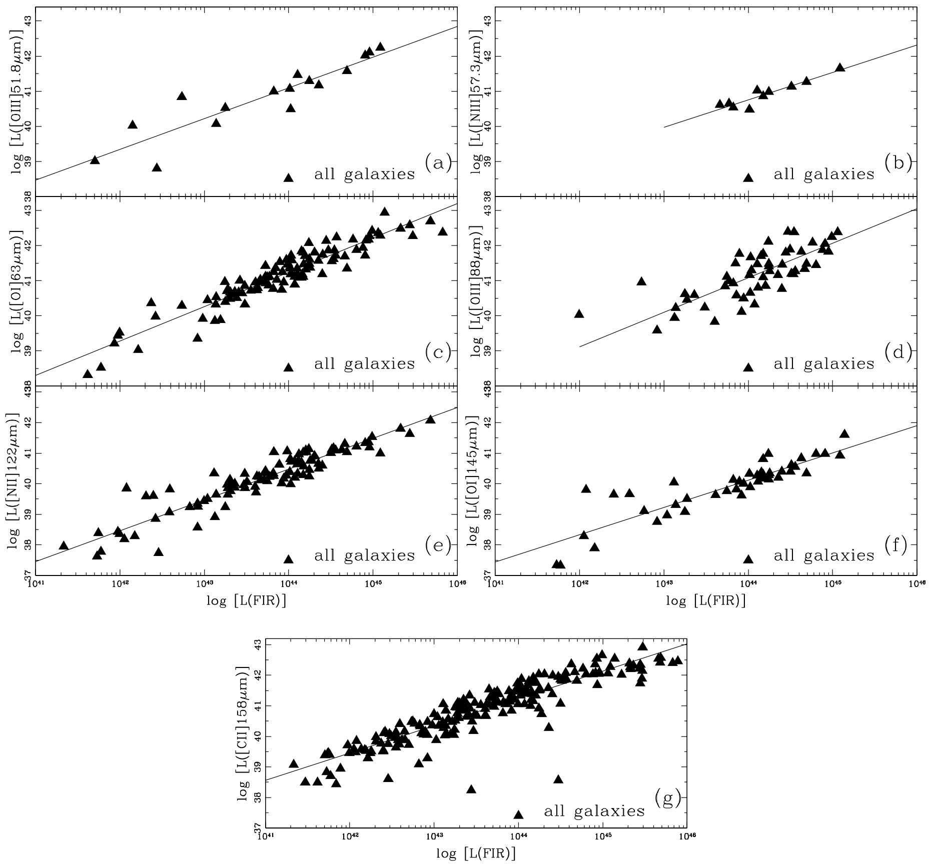
- 1st model by C. Gruppioni et al (2011, mnras) uses all available IR data to extrapolate continuum LFs at z=0 - 4. Contribution from SB and AGN disentangled. It reproduces the first Herschel results from PEP.

- 2nd model by Franceschini et al. (2010, A&A): Backward evolution model fitting all available data from Spitzer, ISO, COBE, SCUBA, etc. It reproduces the first Herschel results from Hermes. It includes direct determinations of multi-wavelength redshift-dependent luminosity functions from Spitzer. The model accounts in great detail not only of star forming Galaxies, but also for type-1 and type-2 AGNs.

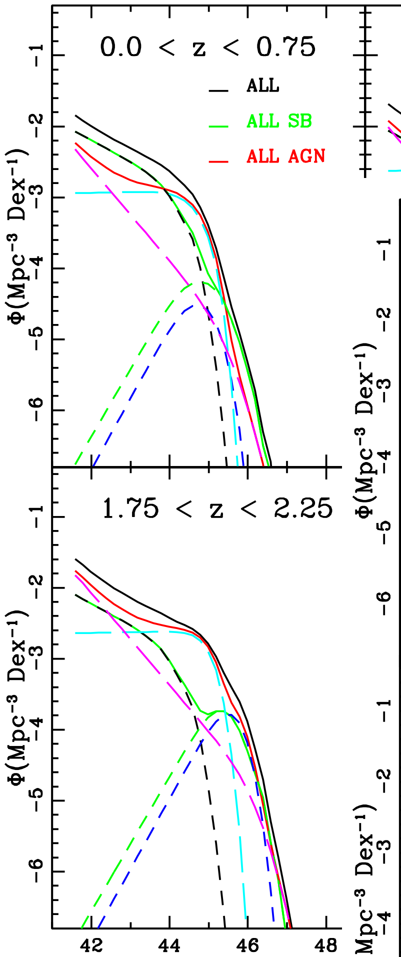
- 3rd model by Valiante et al (2009, ApJ): developed using Spitzer and SCUBA observations, it has been very successful in predicting Herschel results. It considers all infrared galaxies as a single population, assuming that starbursts and AGN coexist.

FIND CORRELATIONS BETWEEN LINE AND CONTINUUM LUMINOSITY IN THE LOCAL UNIVERSE

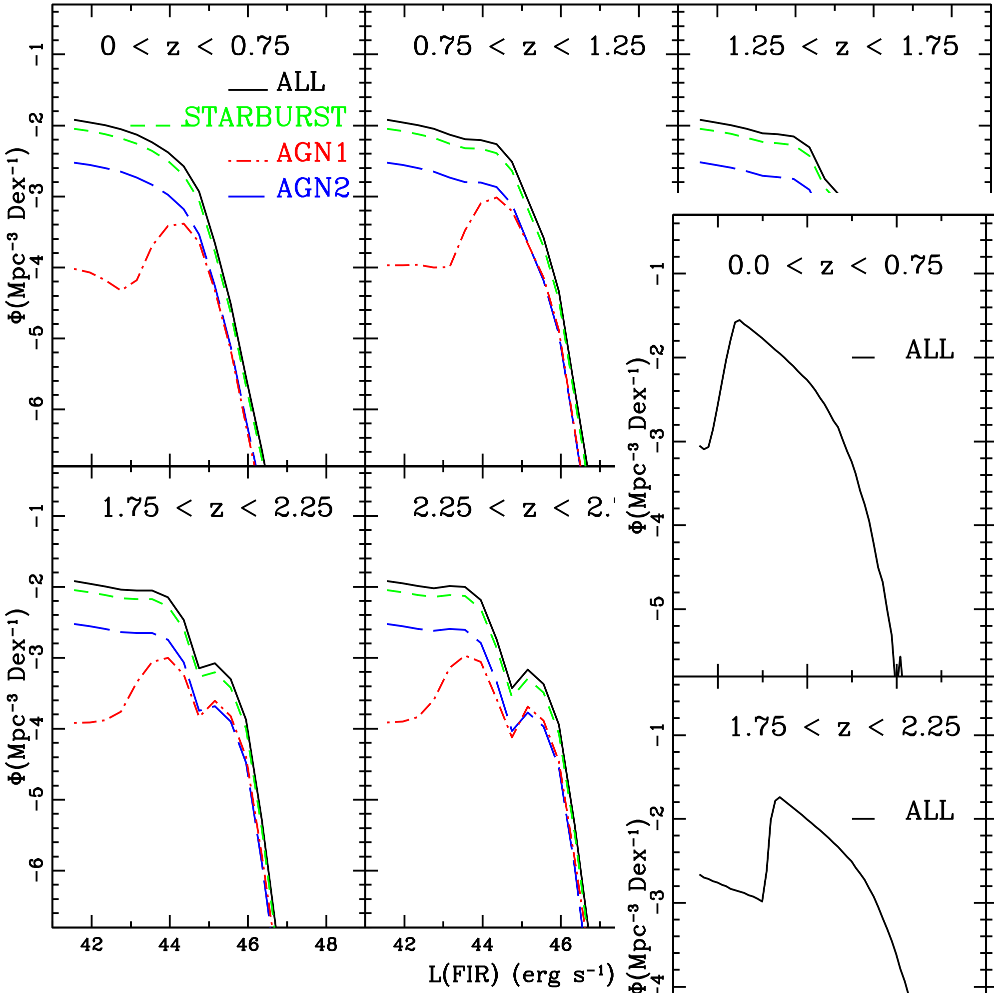




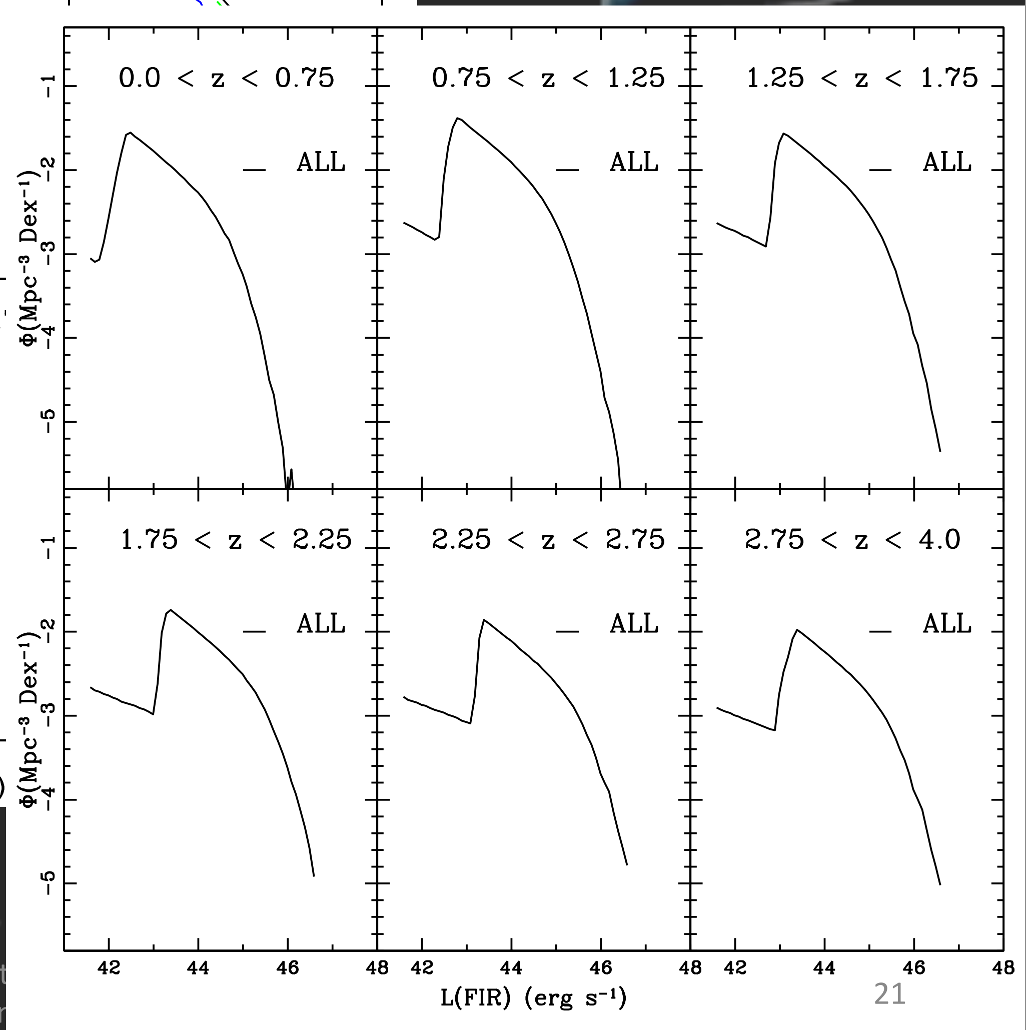
Least-squares fit to data



Gruppioni model

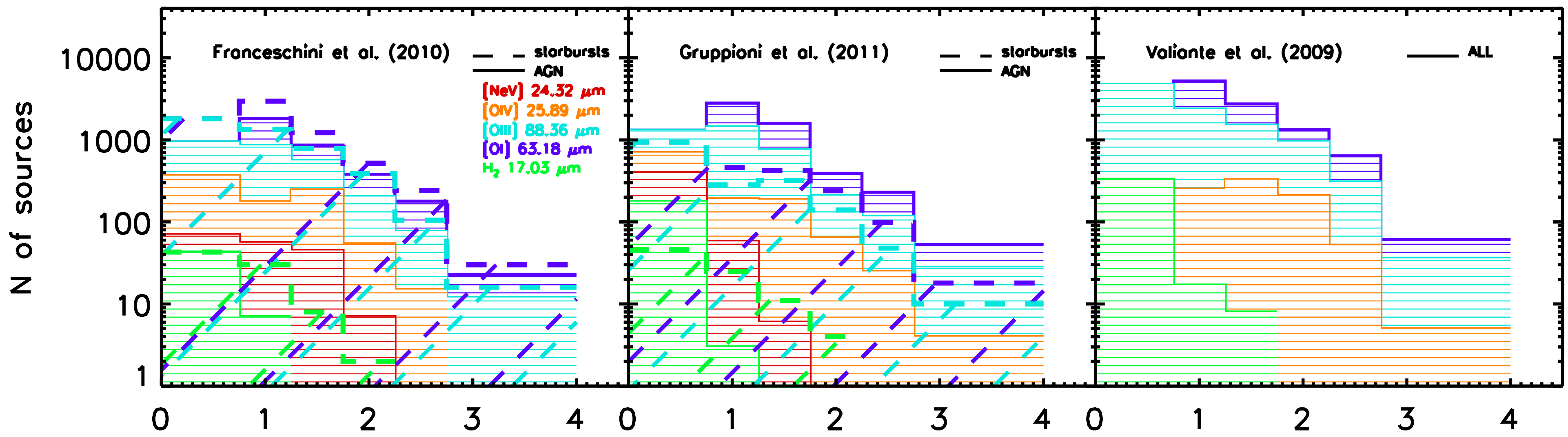


Franceschini et al (2010) model

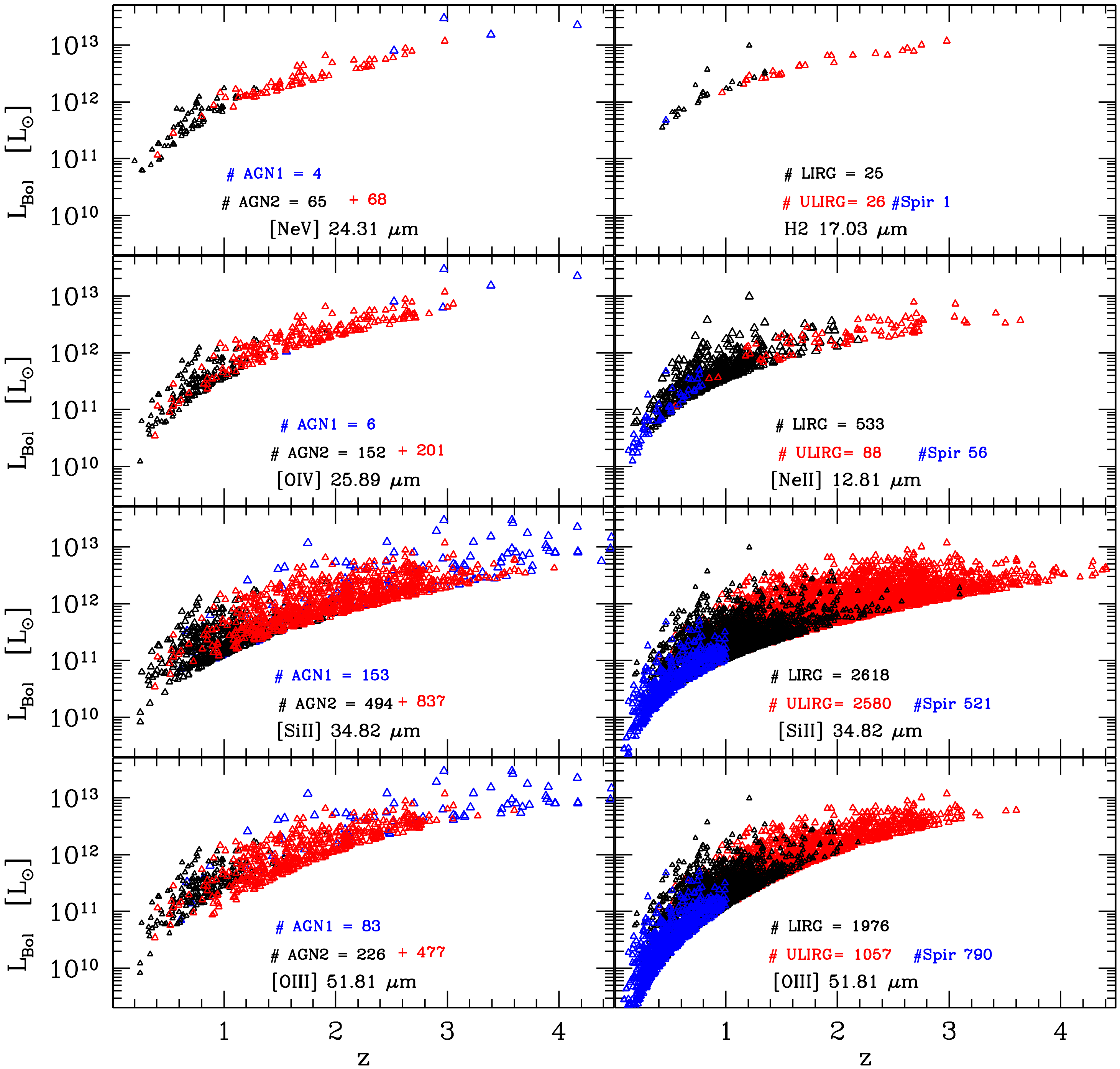


Valiante et al (2009) model

A basic result of this analysis is that the total number of detectable objects agrees to within a factor of 2–3 for most lines and z ranges, and that at least a thousand galaxies will be simultaneously detected in four lines at 5σ over a half square degree. A comparison of the output of the three models is visualized below. A survey of the given assumptions will lead to the detection of bright lines (e.g., [O I] and [O III]) and PAH features in thousands of galaxies at z>1. Hundreds of z>1 AGN will be detected in the [O IV] line, and several tens of z>1 sources will be detected in [Ne V] and H_2.



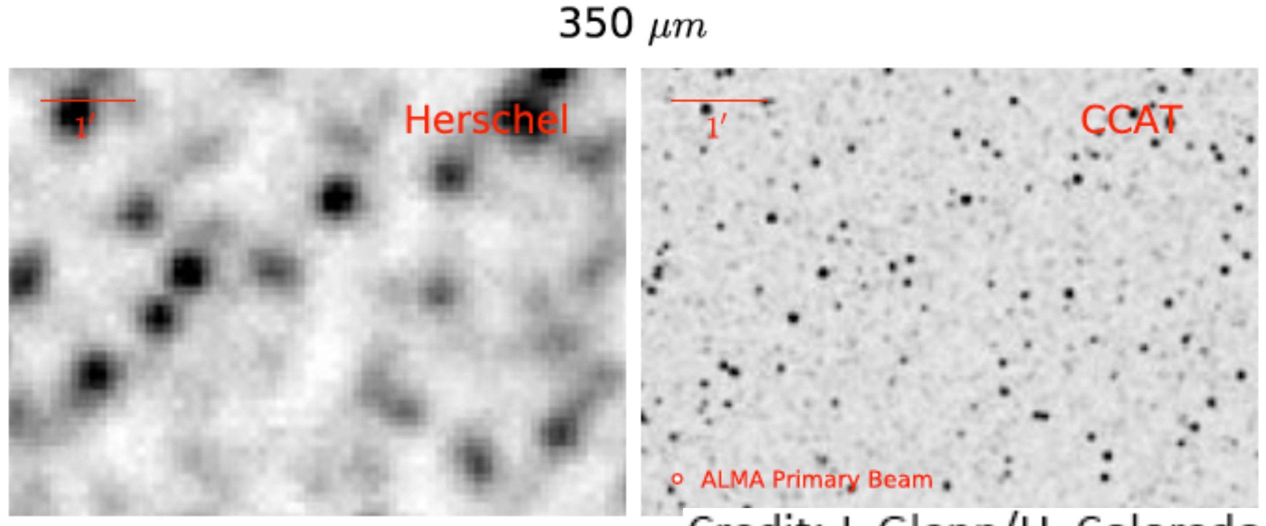
Number of objects detected per spectral line in 1 hour integration/FoV 0.5 deg2 survey with SAFARI.



Prediction of the number of sources of a 0.5 deg^2 spectroscopic survey with SAFARI (Franceschini+2010), giving the number of detectable starburst galaxies and AGN at the 3σ level. Left: AGN predictions, right: starburst predictions. As for the SB, the number of type 2 AGNs associated with the LIRG and the ULIRG populations are separately reported (in black and red, respectively).

CCAT = Cerro Chajnantor Atacama Telescope

25m diameter
20' to 1 degree FoV
12μm rms surface accuracy
0.2 – 2.0 mm wavelength range
Cerro Chajnantor, Chile (5600m)



Credit: J. Glenn/U. Colorado

- CCAT is designed for submm surveys
  - Wide field of view
  - High sensitivity (25 m, excellent site)
  - Good angular resolution (3".5 at 350 μm)
  - Broad wavelength coverage
- Leading-edge instruments
  - Wide-field cameras
  - Multi-object or integral-field spectrometers
- Aiming for completion by 2018
- See www.submm.org

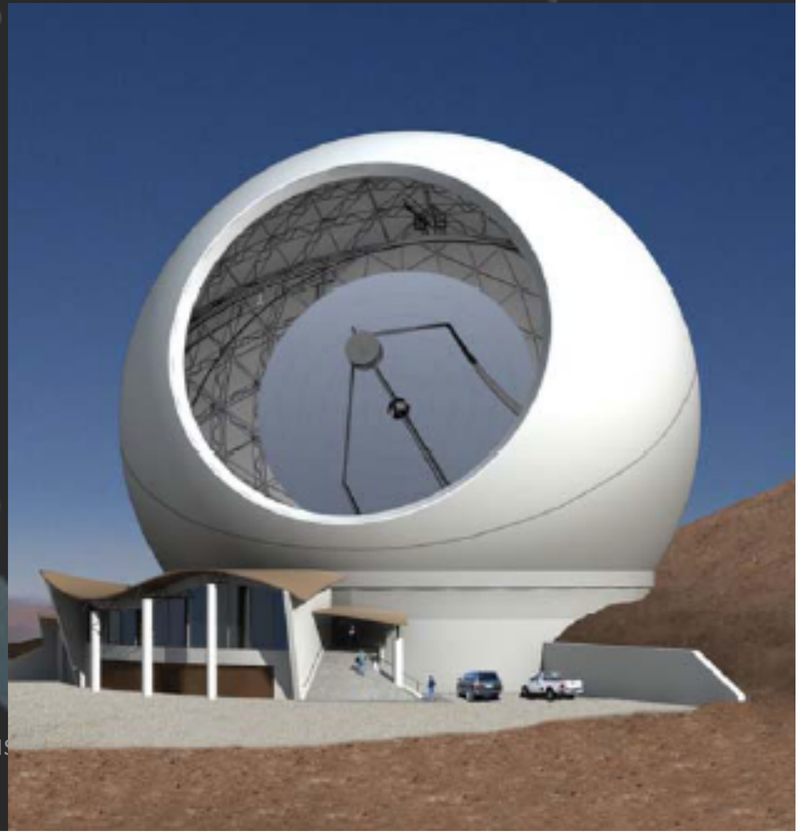
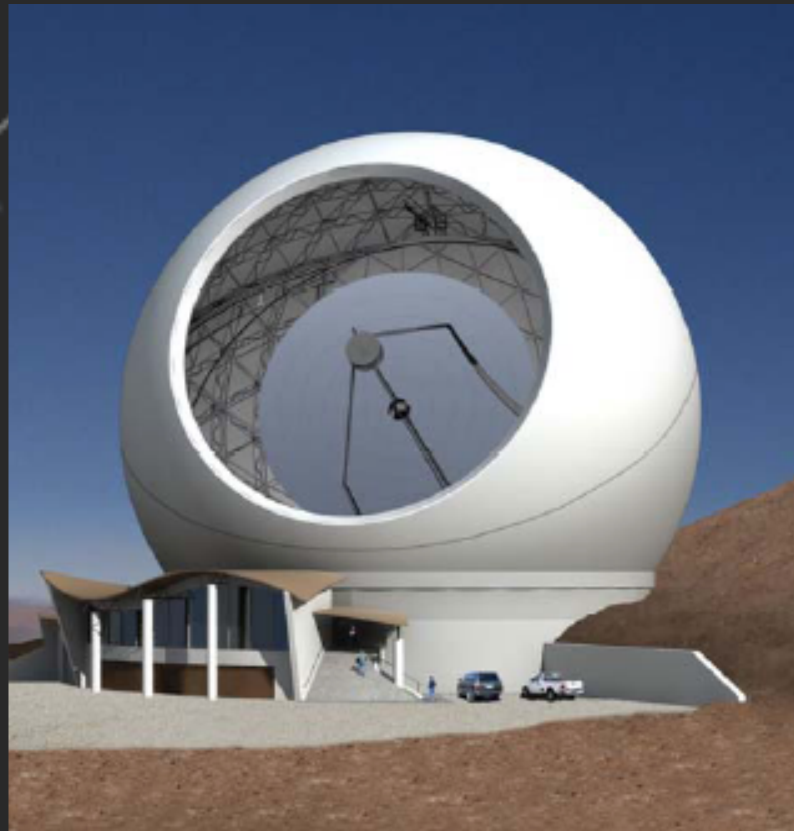


Table 4.4 CCAT Line Sensitivity*

λ (μm)	Freq (GHz)	PWV (mm)	NEFD (mJy)	Line Flux (W/m²)
200	1500	0.3	1627.0	2.44×10^{-17}
228	1317	0.3	1760.3	2.32×10^{-17}
291	1030	0.3	1182.5	1.22×10^{-17}
350	857	0.4	253.4	2.17×10^{-18}
450	667	0.5	231.7	1.54×10^{-18}
620	484	0.5	272.4	1.32×10^{-18}
740	406	0.7	111.1	4.50×10^{-19}
865	347	1.0	91.1	3.16×10^{-19}
1100	272	1.0	61.4	1.67×10^{-19}
1180	254	1.0	62.1	1.58×10^{-19}
1400	214	1.5	62.3	1.33×10^{-19}
2000	150	1.5	58.4	8.34×10^{-20}
3300	91	1.5	64.6	5.87×10^{-20}

*R = Δν/ν = 1000 spectroscopic sensitivity for CCAT. Continuum (NEFD) and Line fluxes are for 1-sigma in 1-second assuming a transmission equal to the band average. The sensitivity calculated on the basis of the appropriate PWV for that wavelength.

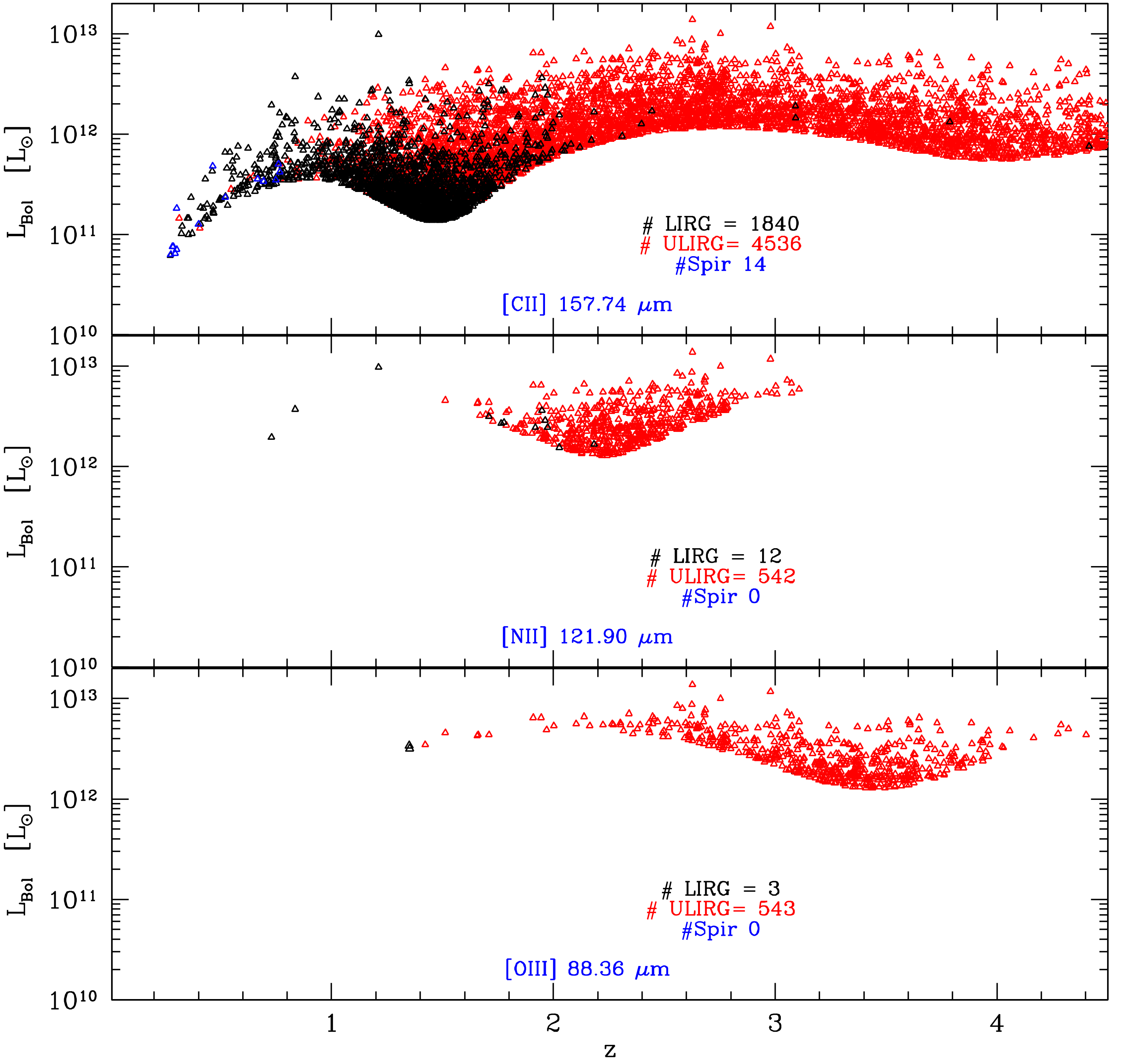


(from: CCAT feasibility/concept design study 2006)

NUMBER OF GALAXIES DETECTABLE IN A CCAT SURVEY OF 0.5 SQ. DEG. IN IR LINES AS A FUNCTION OF REDSHIFT AT 5σ (3σ) IN 1 HR. INTEGRATION PER FoV, FOLLOWING FRANCESCHINI ET AL. (2010)

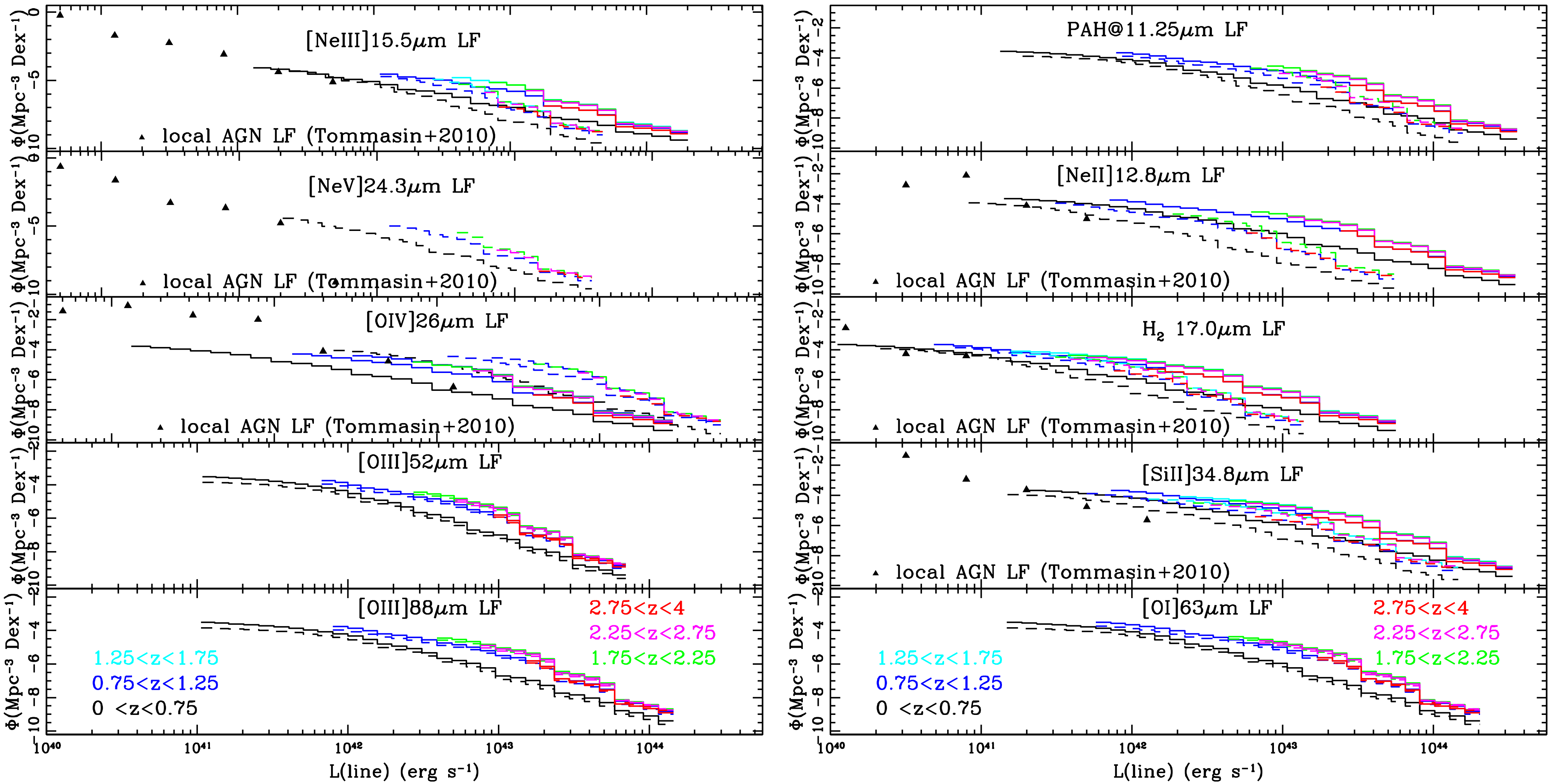
line/redshift	0<z<0.75	0.75<z<1.25	1.25<z<1.75	1.75<z<2.25	2.25<z<2.75	2.75<z<4
[*OI*] 63.18μm	··· (···)	··· (···)	··· (···)	0.27 (3.60) ⋄	··· (0.27) †	··· (0.22) ‡
[*OIII*] 88.35μm	··· (···)	22.2 (67.5) ⋄	1.80 (25.8) †	2.07 (12.1) ‡	86.0 (219.) #	21.1 (67.0) $
[*NII*] 121.90μm	13.5 (39.0) †	0.22 (0.85) †	0.27 (1.80) ‡	12.1 (59.0) #	3.15 (27.0) $	0.22 (1.53) §
[*OI*] 145.52μm	0.45 (1.35) †	··· (0.09) ‡	0.86 (3.02) #	··· (0.25) $	··· (···) §	··· (0.72) ¶
[*CII*] 157.74μm	235. (643.) †	1786. (3951.) #	1314. (1998.) $	517. (1116.) $	219. (603.) §	350. (603.) ¶

*Notes: ⋄: at 200μm band; †: at 230μm band; ‡: at 291μm band; #: at 350μm band; $: at 450μm band; §: at 620μm band; ¶:at 740μm band



Prediction of the number of sources of a 0.5 deg^2 spectroscopic survey based on Franceschini et al. (2010), giving the number of detectable galaxies at the 3σ level with CCAT.

Predictions of the line luminosity functions with z and comparison with those measured in the local universe



Conclusions

- After 30 years of efforts… we are close to having reliable IR measures of STAR FORMATION RATE and AGN ACCRETION POWER, through IR/FIR SPECTROSCOPIC SURVEYS, completely unaffected by dust, allowing us to study the evolution of galaxies in terms of stellar fusion and gravity powers
- Accurately measuring the fusion-power and gravity-power is the first step towards understanding galaxy evolution over the history of the Universe
- We learned how to measure these in local galaxies through mid/far-IR spectroscopy
- Blind FIR spectroscopic surveys with SAFARI-SPICA will be the way to "physically" measure galaxy evolution
- Given the expected sensitivity of SAFARI-SPICA ~2.5x10^-19 (5σ,1 hr.) thousands of sources will be detected in more than 4 lines in typical 0.5 sq.deg. Surveys (total t=450 hours).
- Complementary to SAFARI, CCAT will detect several tens to hundreds of galaxies at R~1000 in a 0.5 sq.deg. survey in 4.5 hours in the [OIII]88μm line and thousands of galaxies in the [CII]158μm line