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 (reddening versus obscuration)

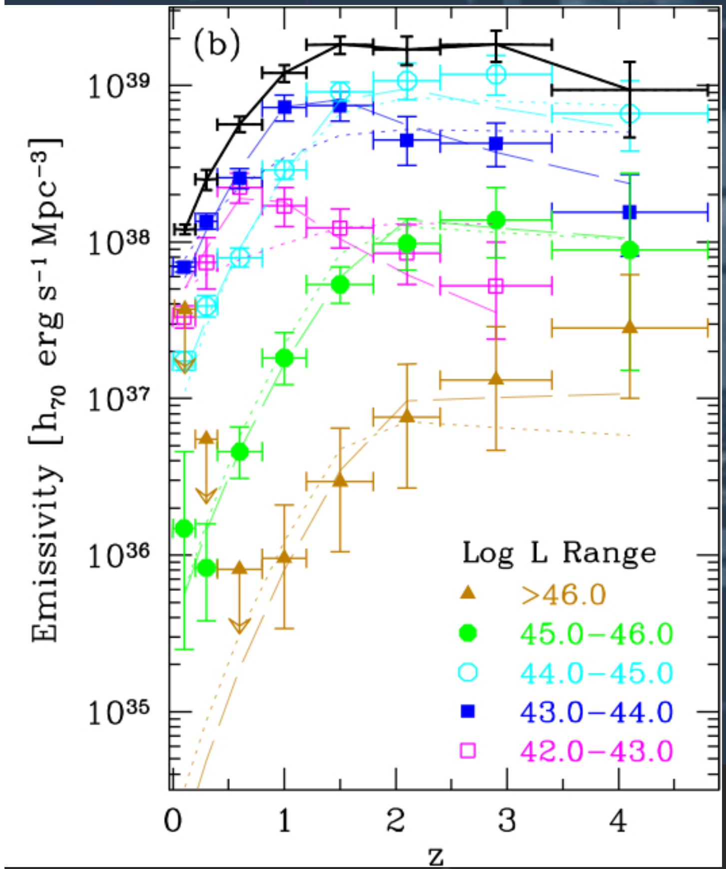
- 4) Seek cosmic connections between a galaxy's stars and its massive Black Hole: understand the how and why of these systems

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)

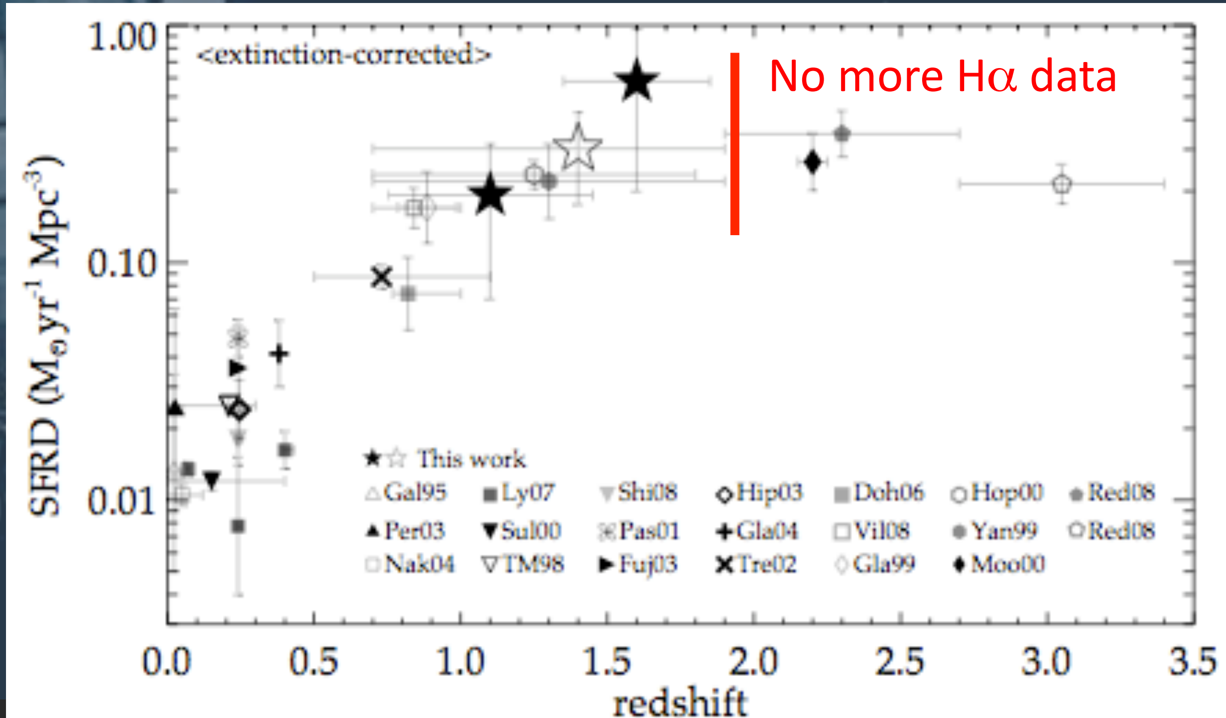
Hasinger et al 2005

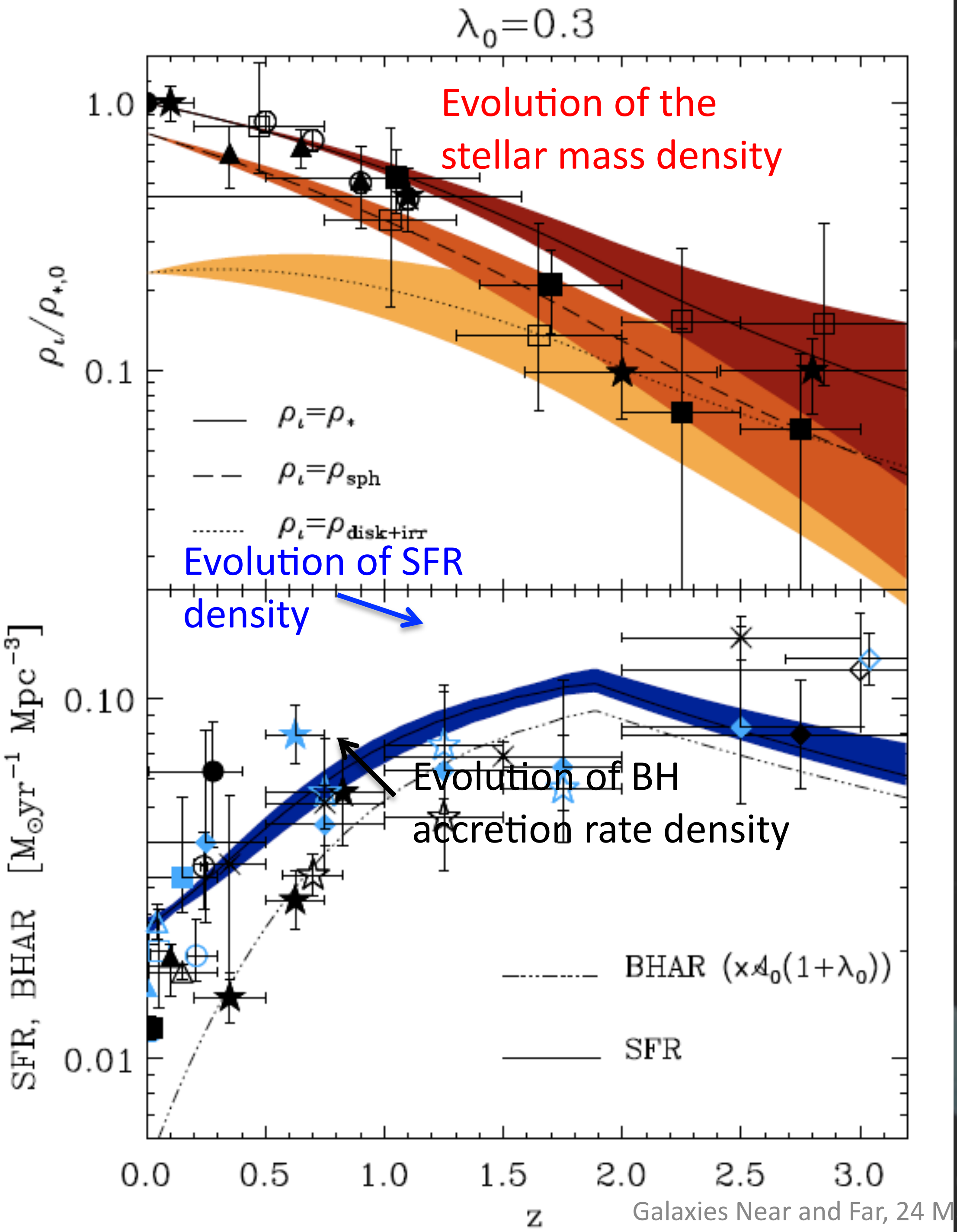


Young Star Power,

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 the different techniques:

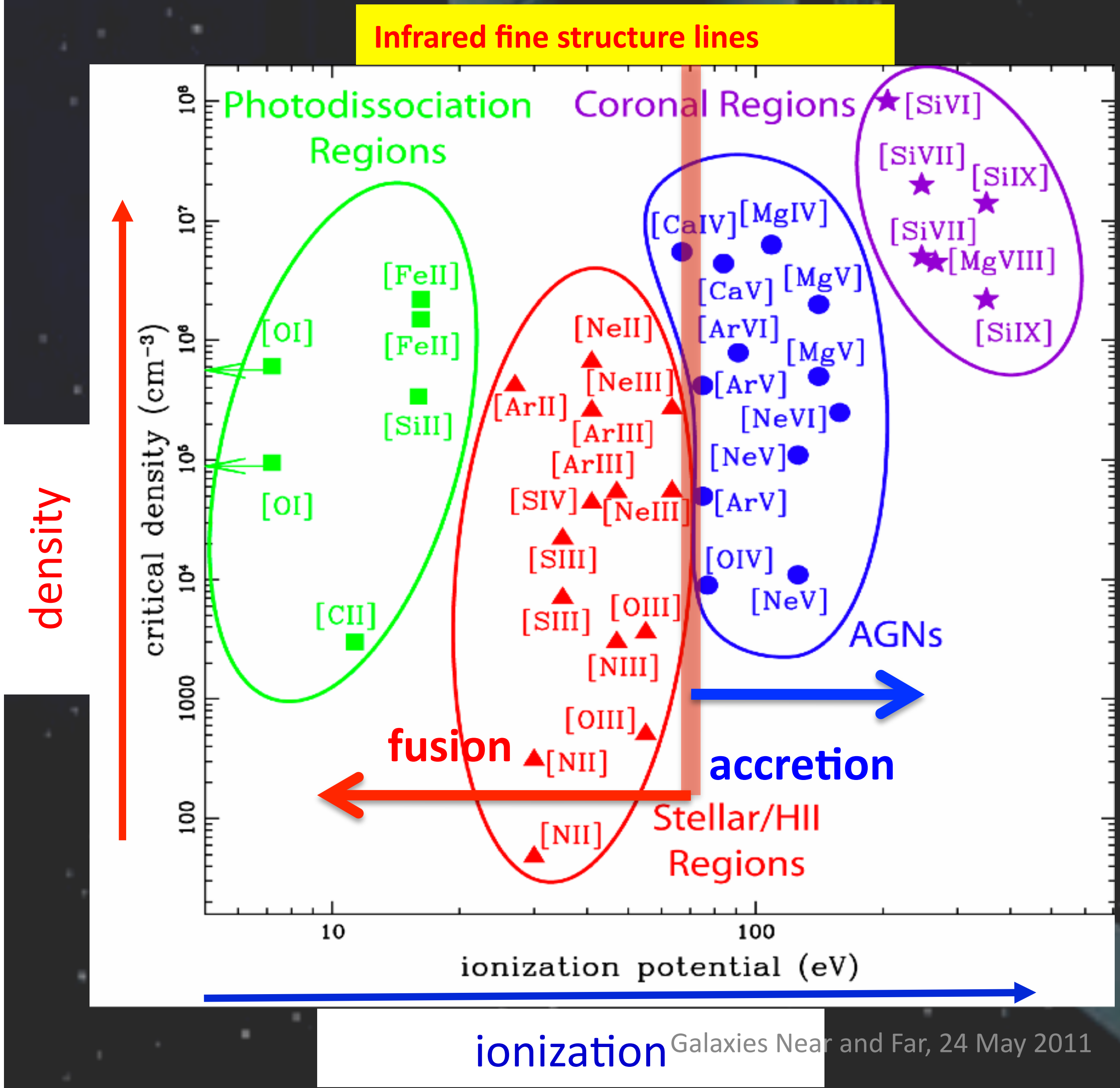
– UV/Optical/NIR observations ➔galaxy morphology and spectra,
BUT they seriously suffer from dust obscuration

– 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, ➔ can reveal morphology and obtain spectral SED, detect polarization and variability,
BUT not always redshifts can be measured .
(Using its highest frequencies SKA will be able to measure redshifted molecular lines in the interstellar medium of galaxies).

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

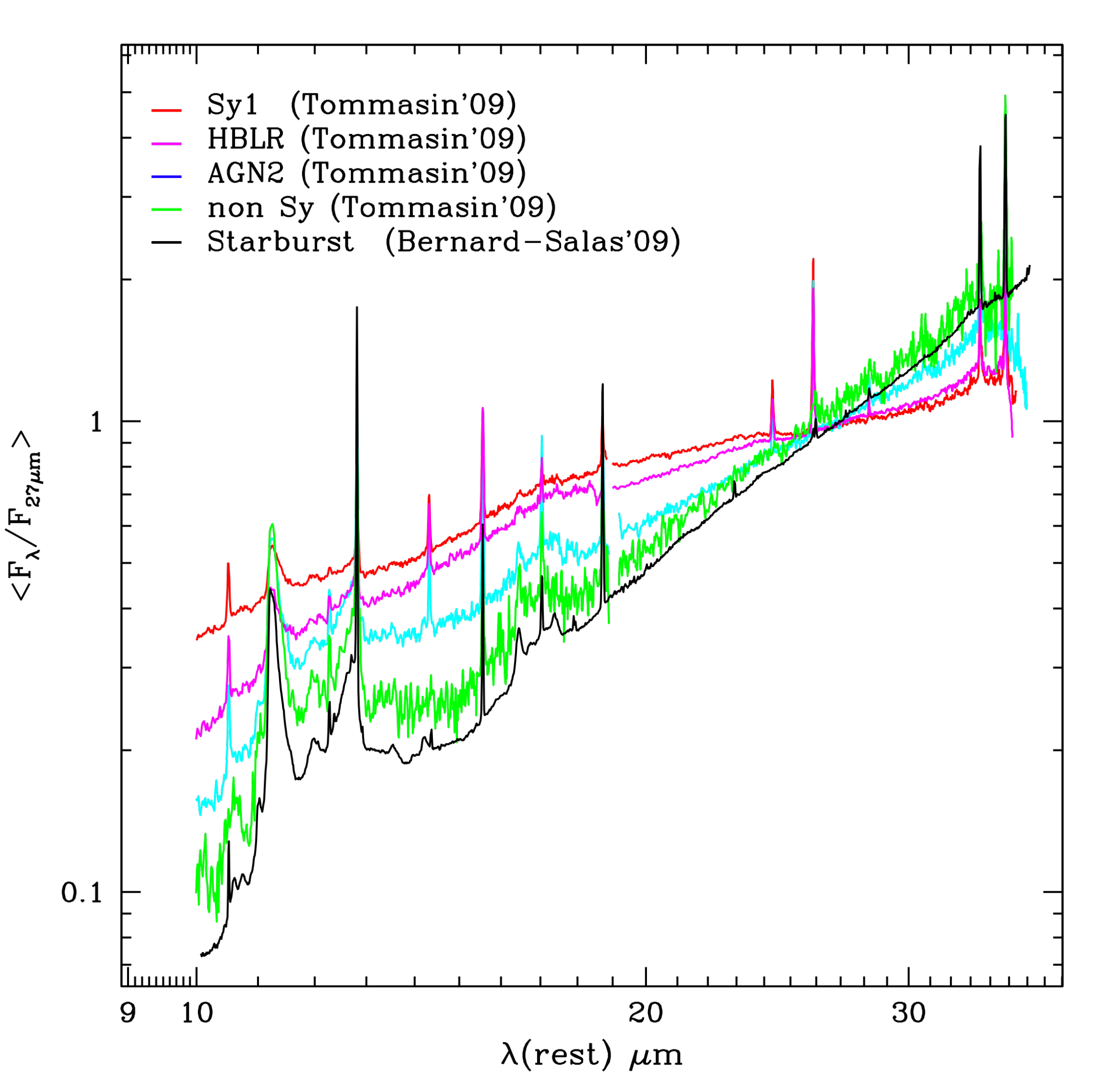
Spinoglio & Malkan (1992) predicted for the first time the line intensities of IR lines in active and starburst galaxies, before the launch of ISO.

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:

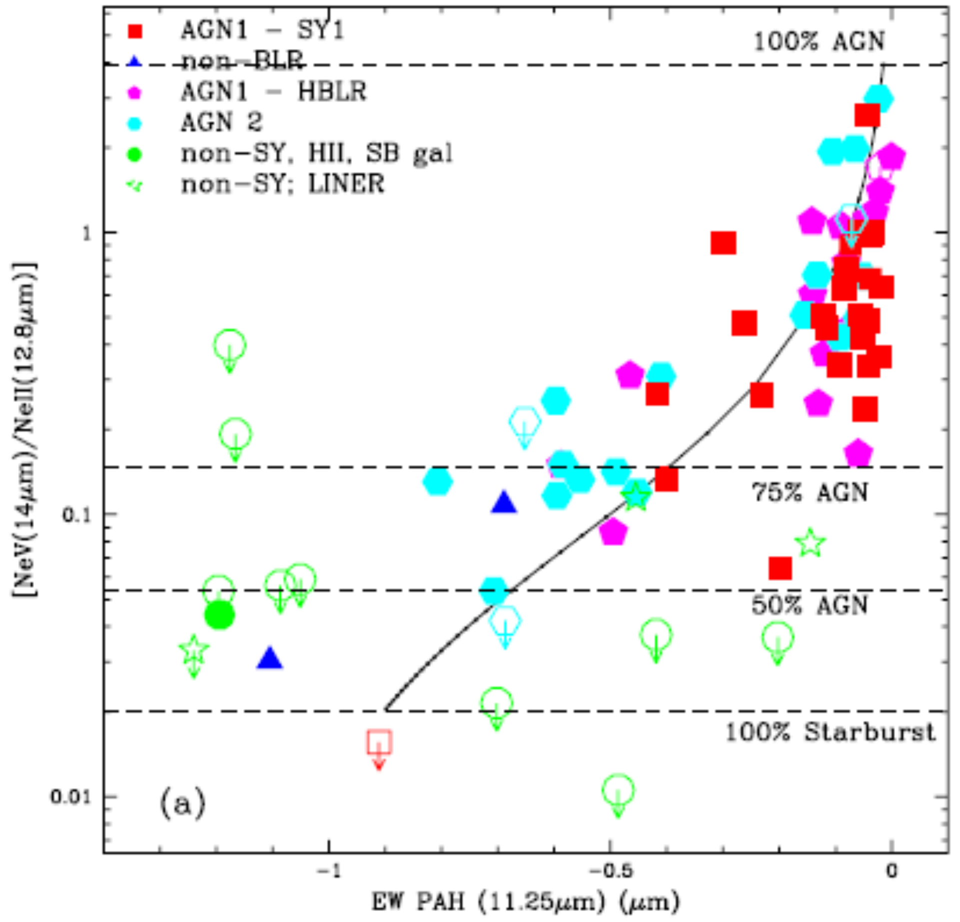
- Higher ionization lines decrease in flux and equivalent widths

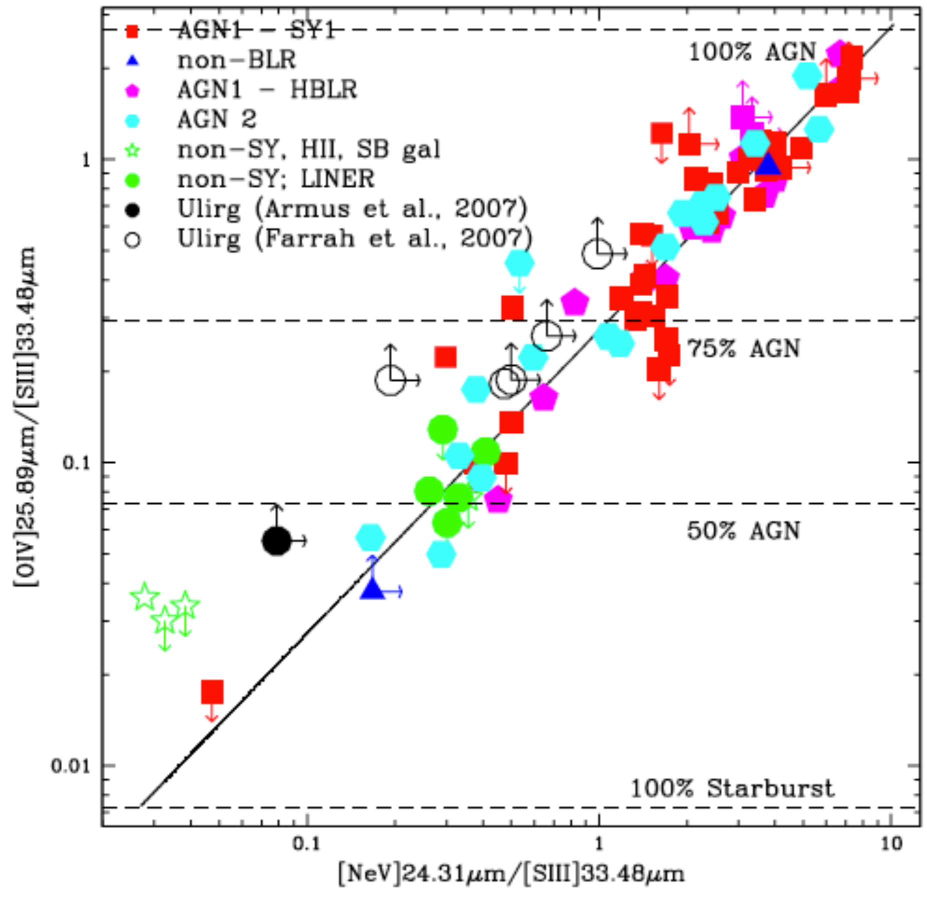
- PAH feature remains almost constant in flux, while its equivalent width decreases



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



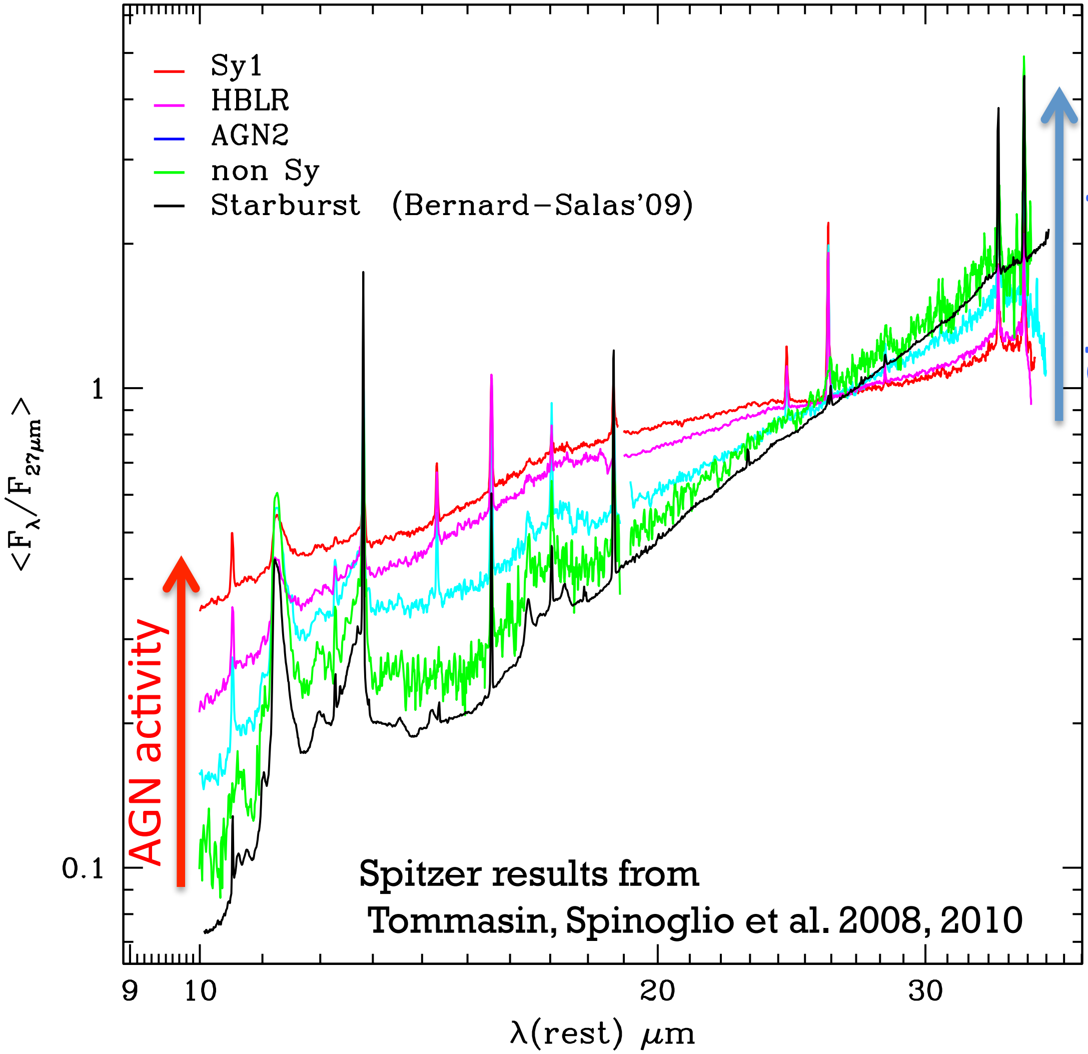


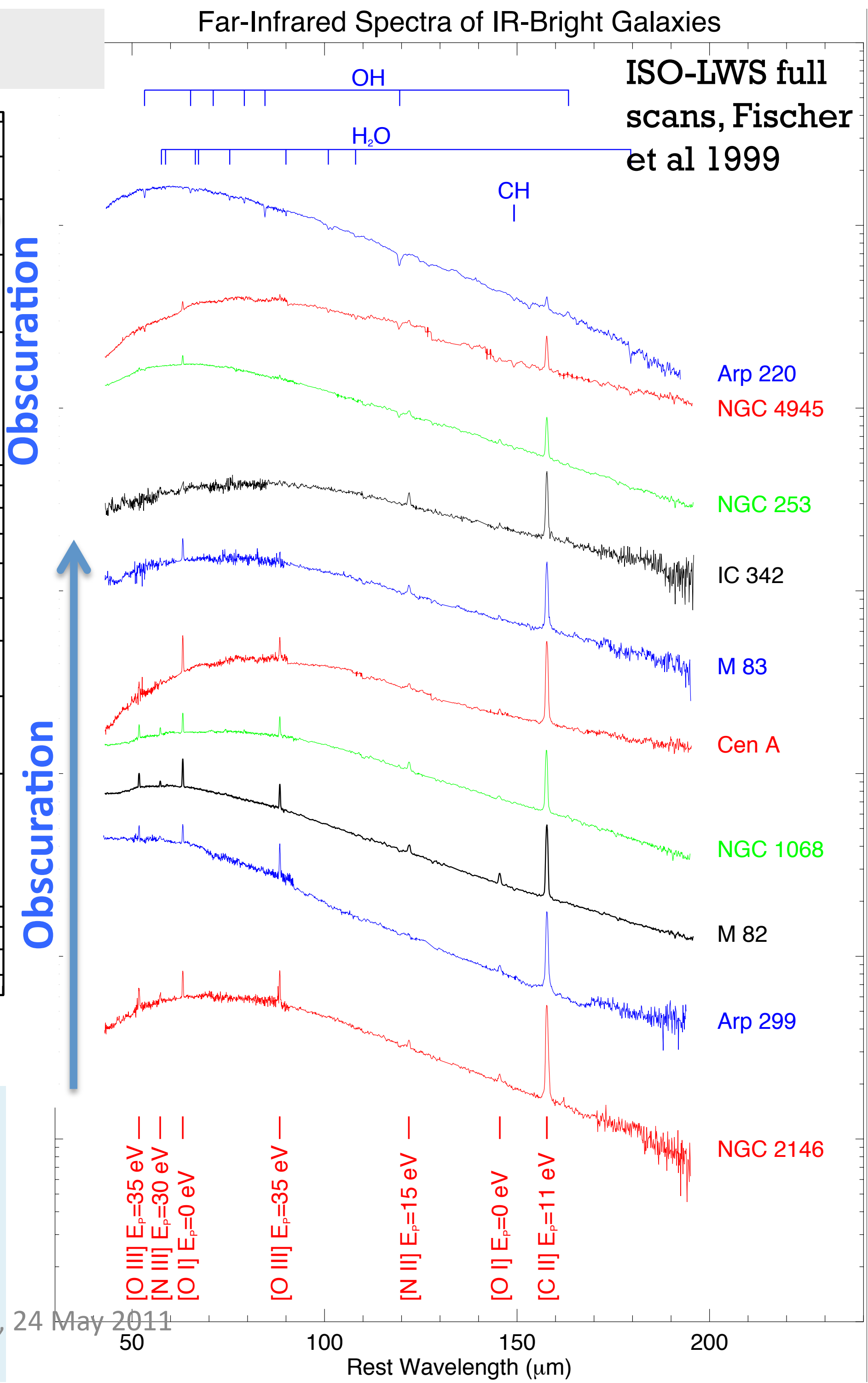
[OIV]/[NeII] and [NeV]/[NeII] ratios are very good indicators of AGN strength EW(PAH@11.25μm) and EW([NeII]12.8μm) good SF indicators (Tommasin, LS +, 2010)

[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

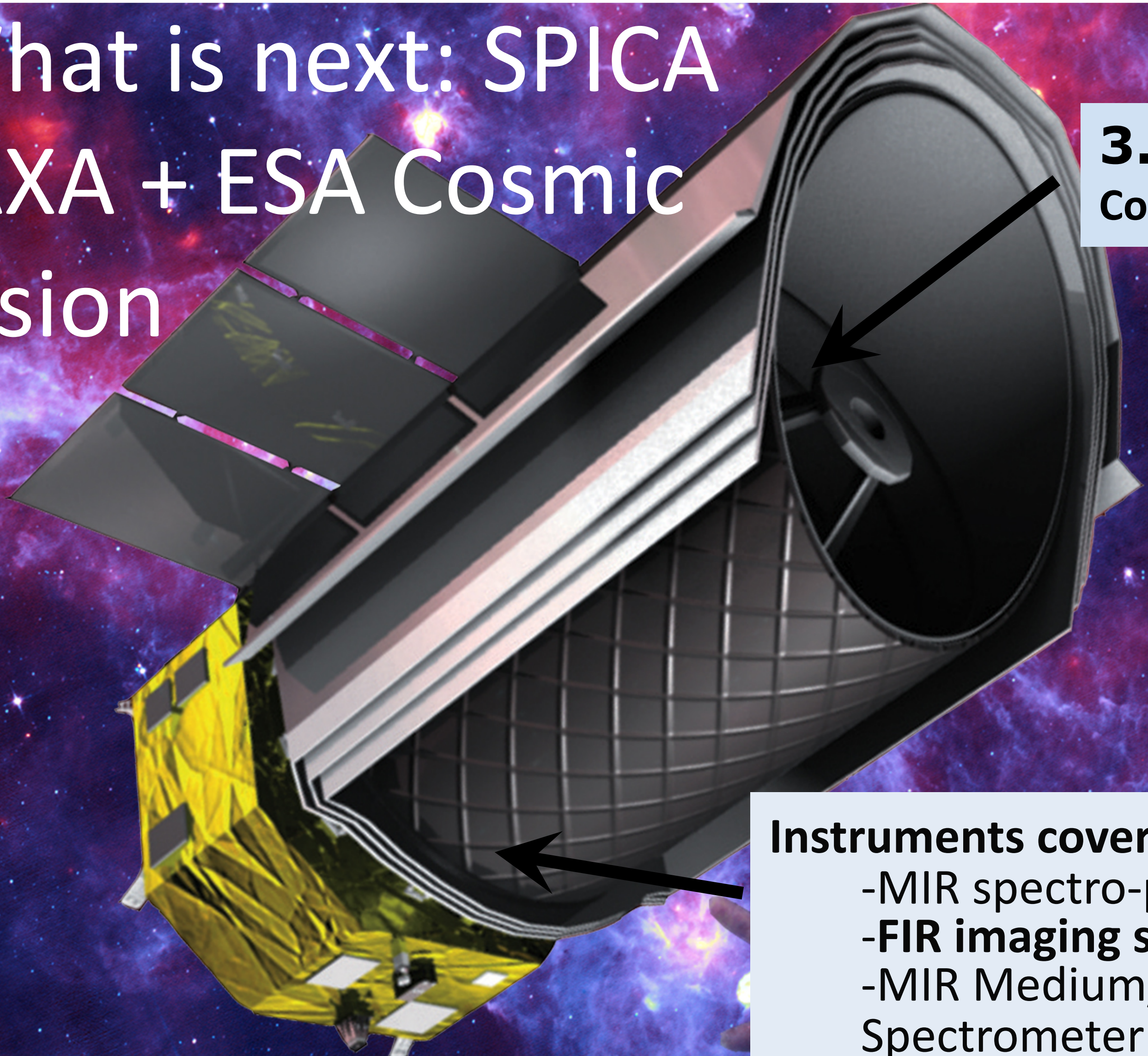
MIR & FIR spectroscopy complementary





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

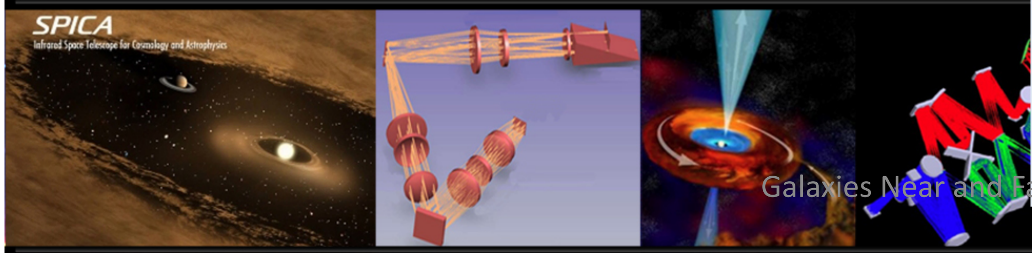
What is next: SPICA JAXA + ESA Cosmic Vision



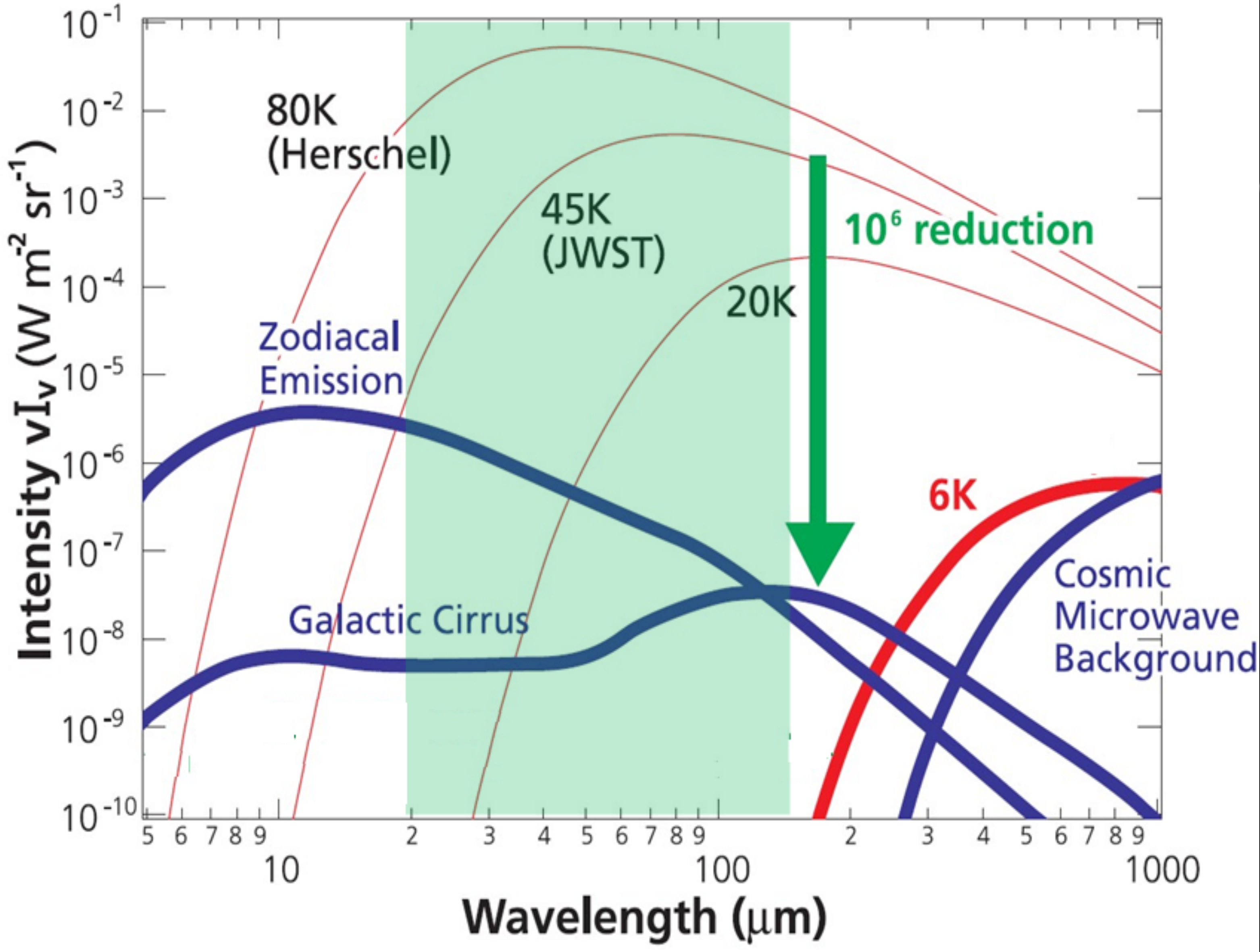
3.2 m telescope
Cooled to < 6K

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

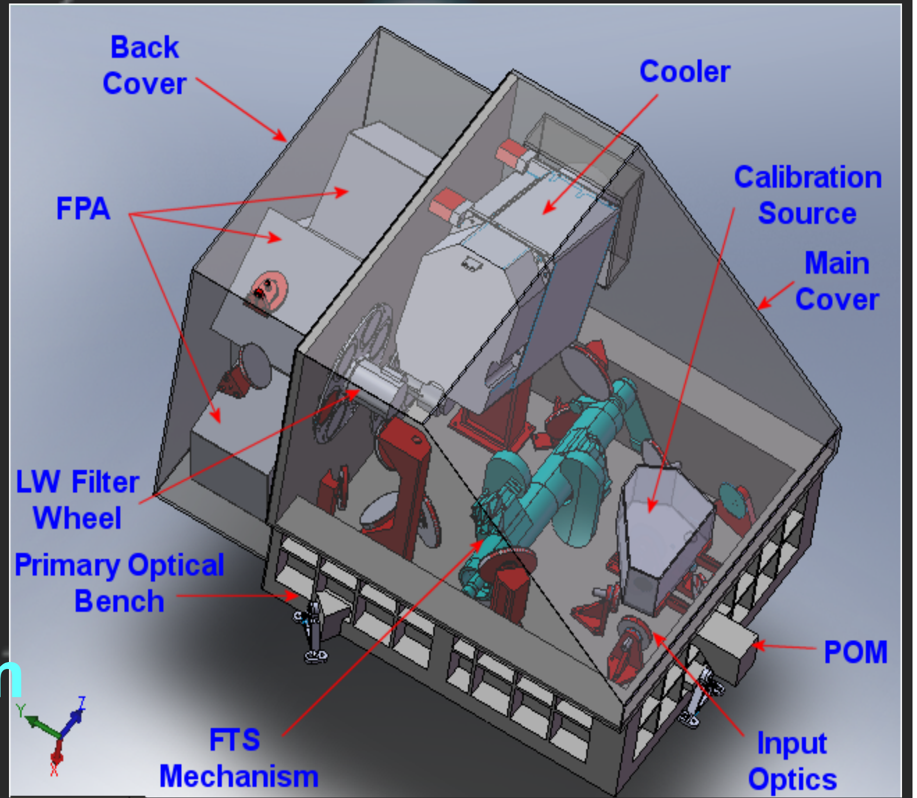


Thermal Backgrounds



SPICA-SAFARI

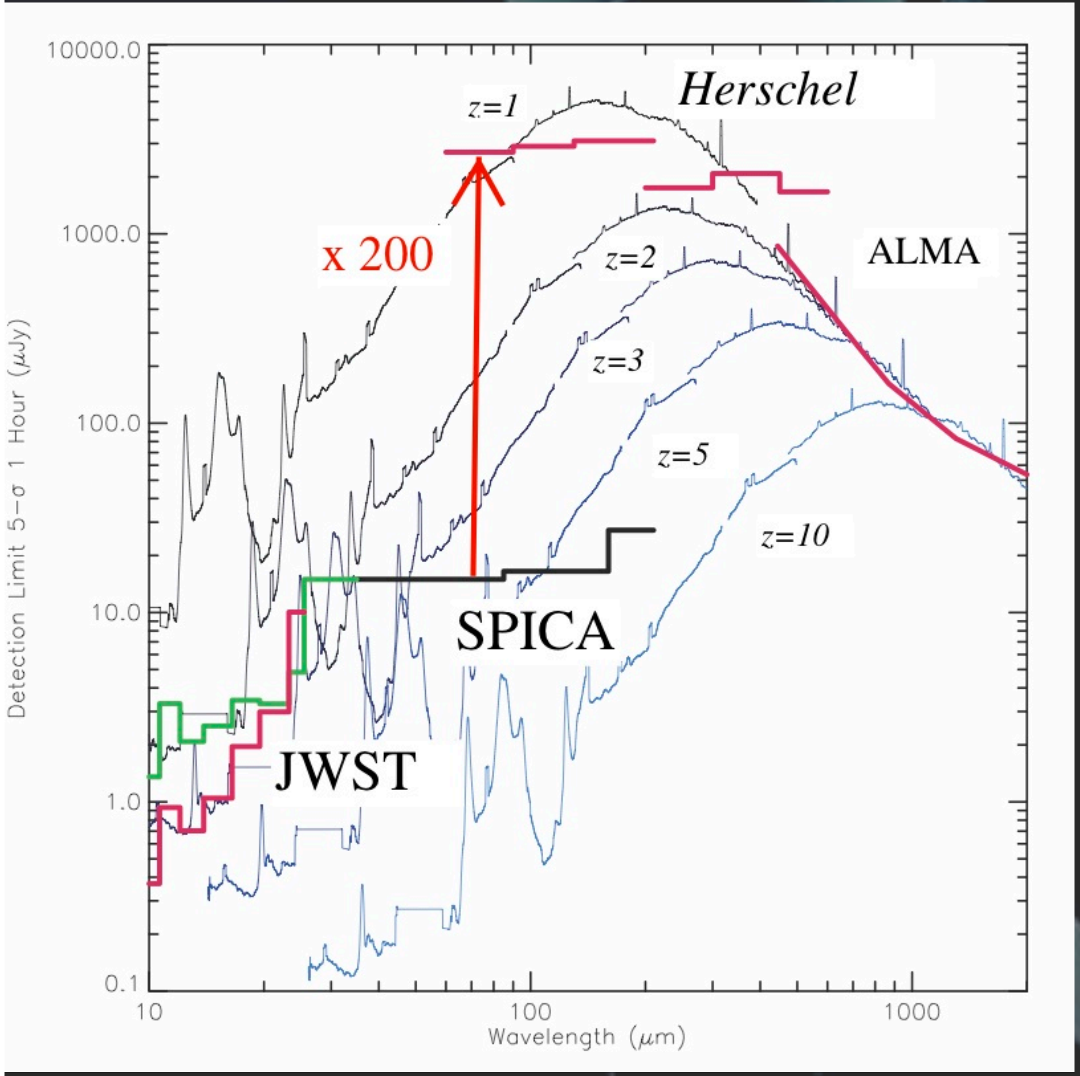
- FIR Camera and spectrometer
  - Imaging FTS
  - Based on SPIRE heritage
  - 35 – 210 μm
  - $\lambda/\Delta\lambda \sim 2000$
  - Field of view 2 x 2 arcmin

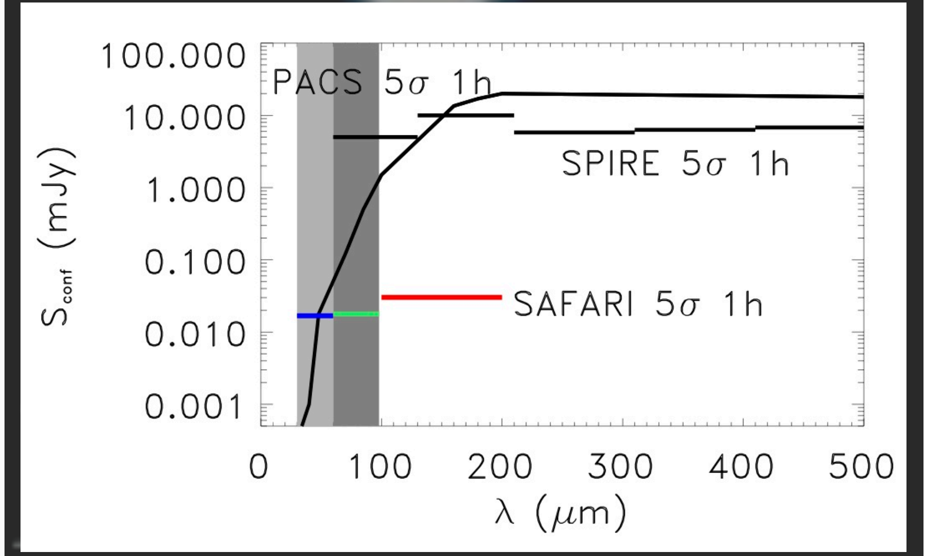


- Features
  - Instantaneous coverage of full band
  - Measurement of continuum and lines
  - Low background
  - Sensitive and linear detectors
    - Superconducting TES arrays
    - Target NEP = 2 x 10^{-19} W $Hz^{-1/2}$

→ Huge increase in sensitivity and observing speed

SPICA Sensitivity - photometry

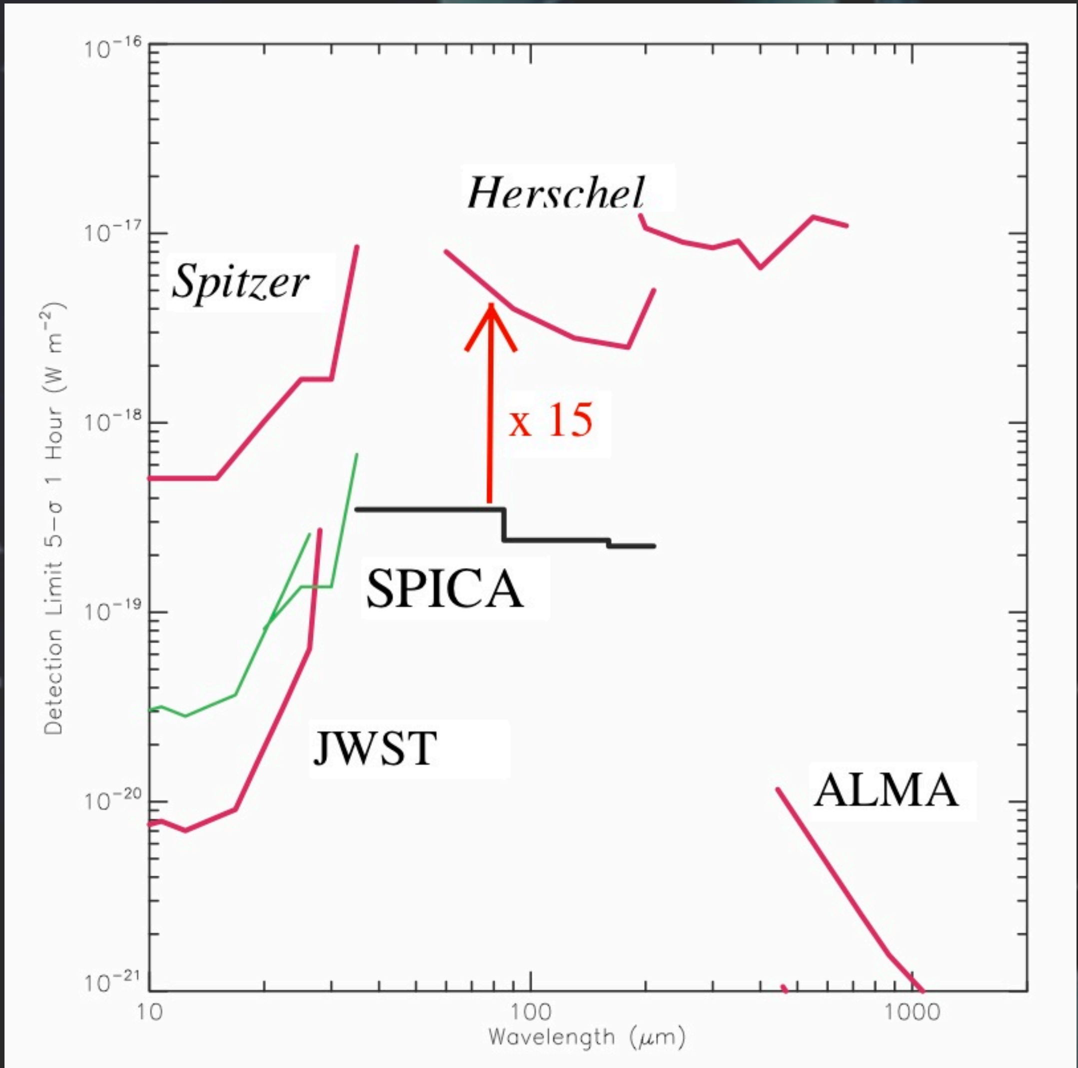




70 µm confusion limit 100 times better then Herschel 100µm confusion limit >10 times better than Herschel

200 times more sensitive than Herschel PACS

SPICA Sensitivity - spectroscopy

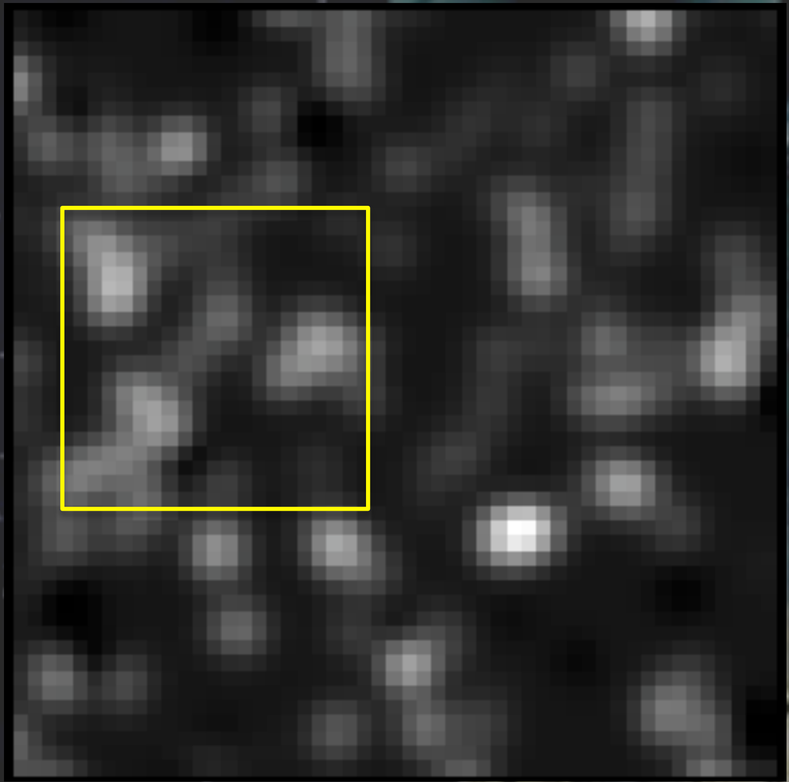


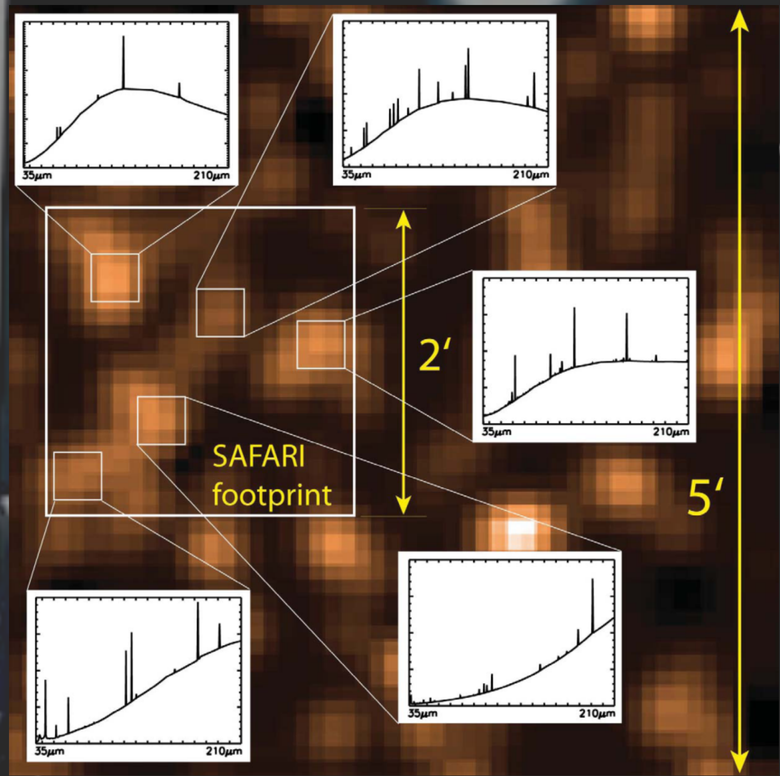
Single unresolved line in single object:
SAFARI sensitivity 15 times better than Herschel
+ huge multiplexing advantage

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

SPICA/SAFARI 900 hour spectral survey

5 sigma flux limit: (line, 1 hour per position)
2 × 10—19 W/m^2

Spectroscopically detected over the entire range (34-210μm) all galaxies down to L (IR)>10^11 Lsun at z=1
L(IR)>10^12 Lsun at z=2

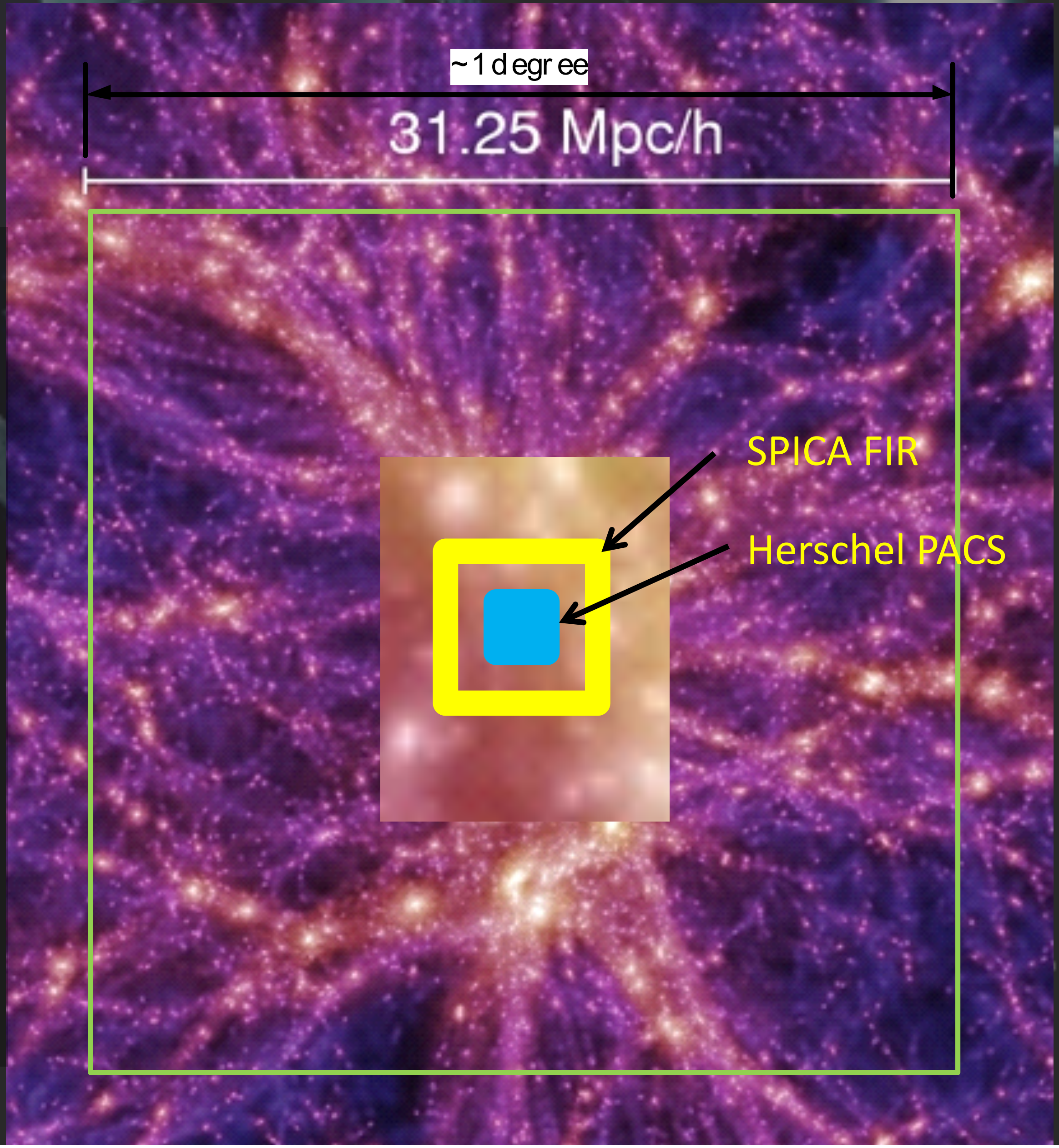
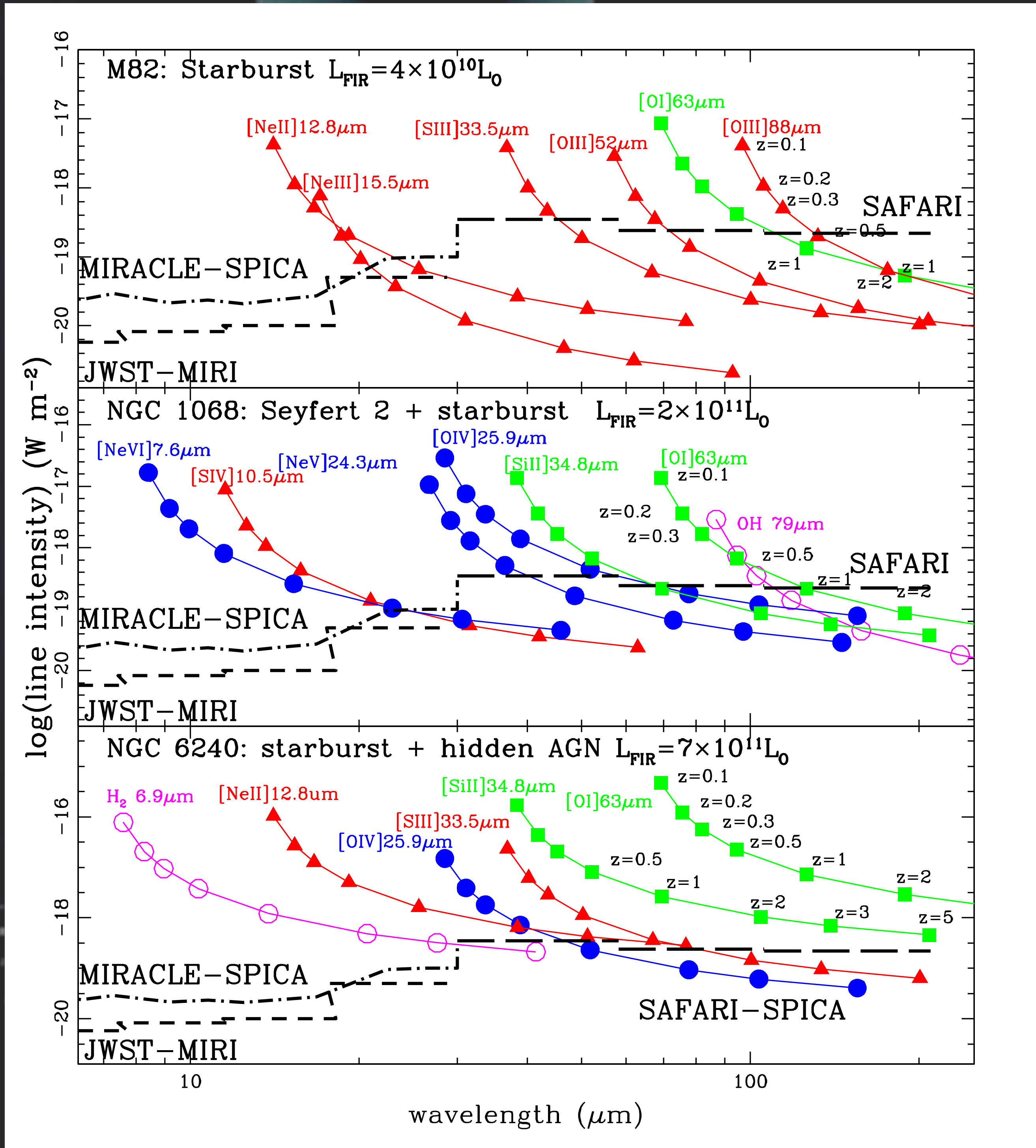
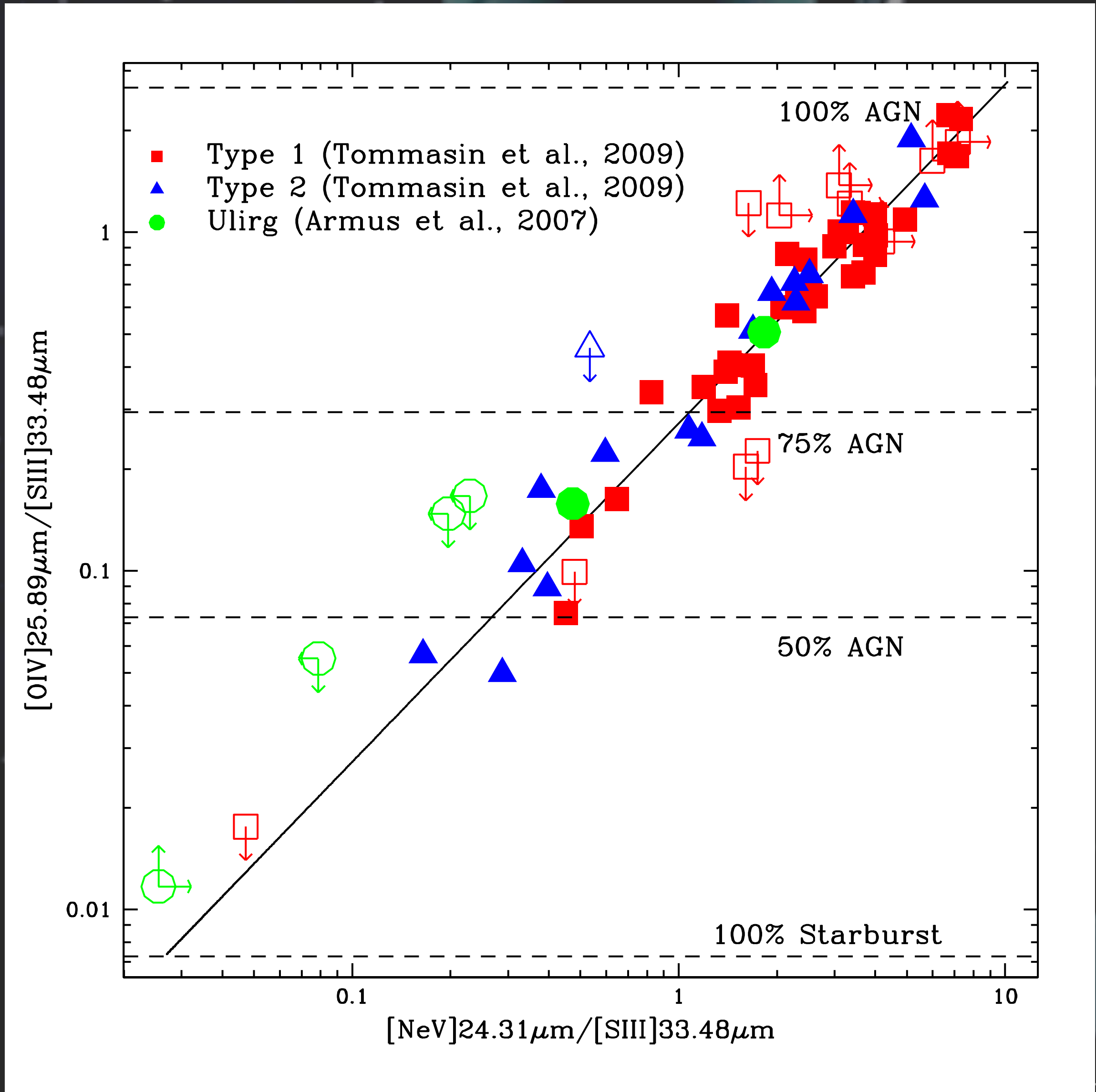


Image Springel et al. 2006



Three local templates: at what redshift can SAFARI detect their lines ?

Black hole accretion vs star formation: address AGN/starburst co-evolution with redshift

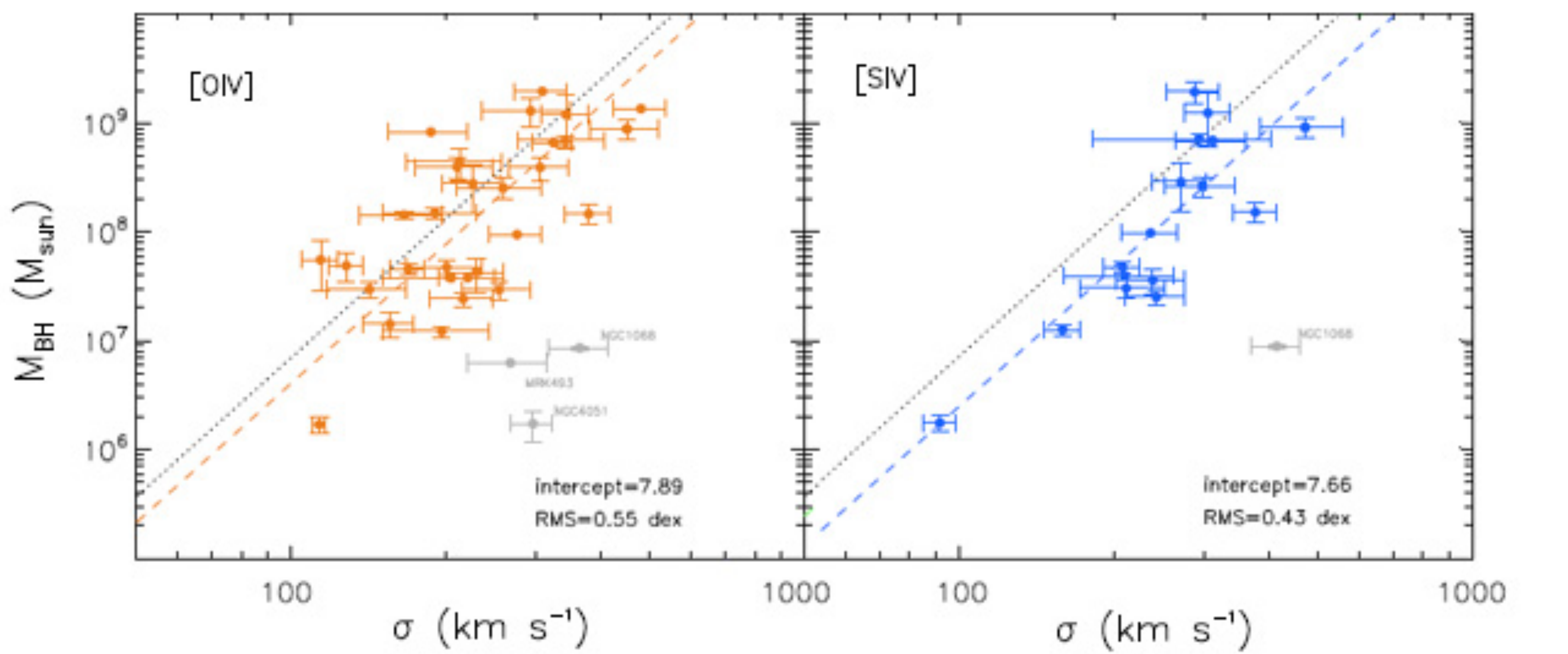


IR fine-structure lines as black hole mass tracers

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…

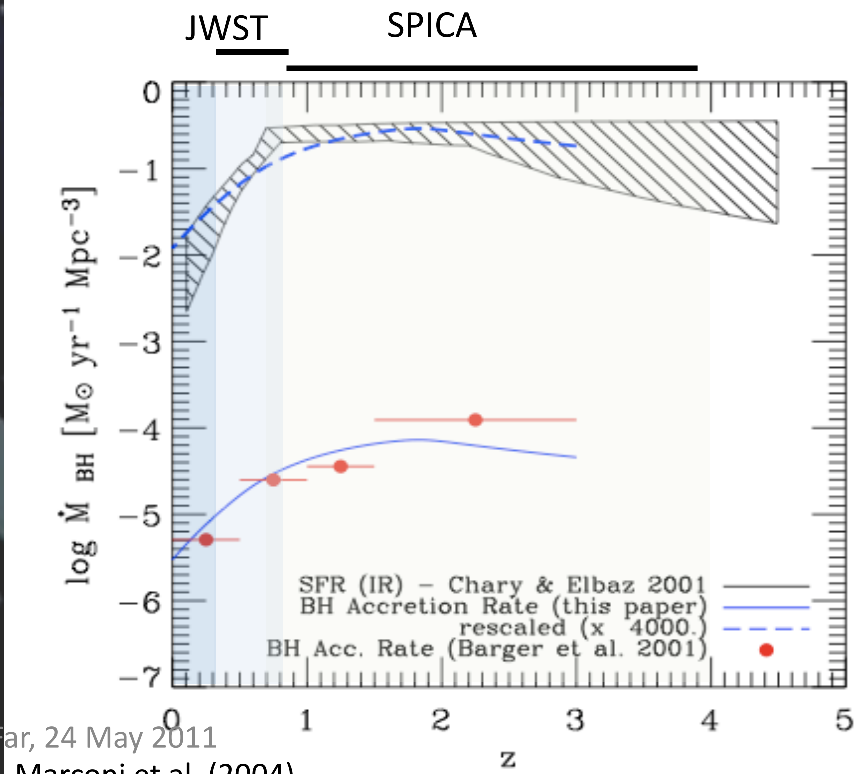
Spitzer: z<0.3 using [NeV] (due to sensitivity)

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)

The first FIR spectroscopic cosmological surveys: What has been done in the local Universe with Spitzer will be done up to z~2 with SPICA:

In a single shot: redshift and nature of the detected sources to study the co-evolution of stars and black holes on a cosmological scale.

- Evolution of the massive, dusty distant galaxy population
- What is shaping the mass and luminosity functions of galaxies?
- How do star formation rate and AGN activity vary with environment and cosmological epoch?

Number of Star Forming Galaxies and AGNs from z=0 to z=4 to be spectroscopically detected by SPICA/SAFARI

Method:

1) Use IR continuum LF (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

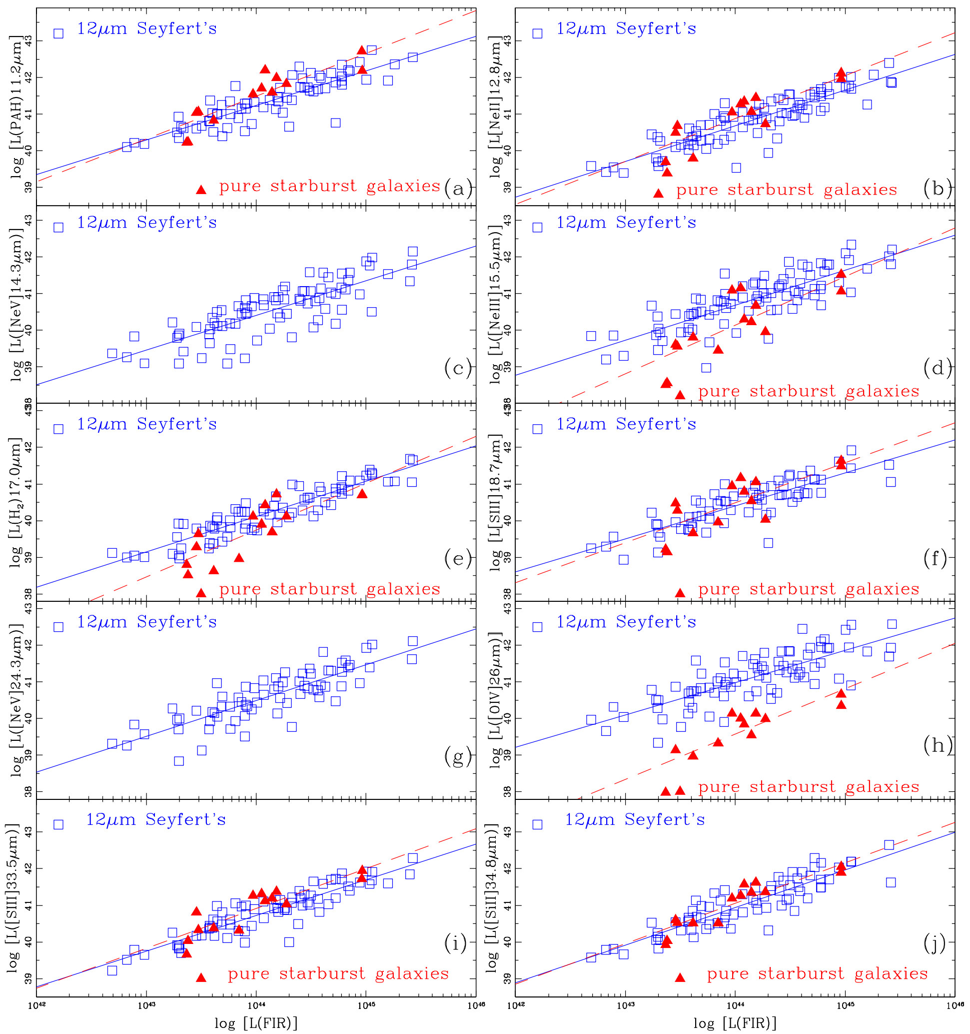
- 1st model.

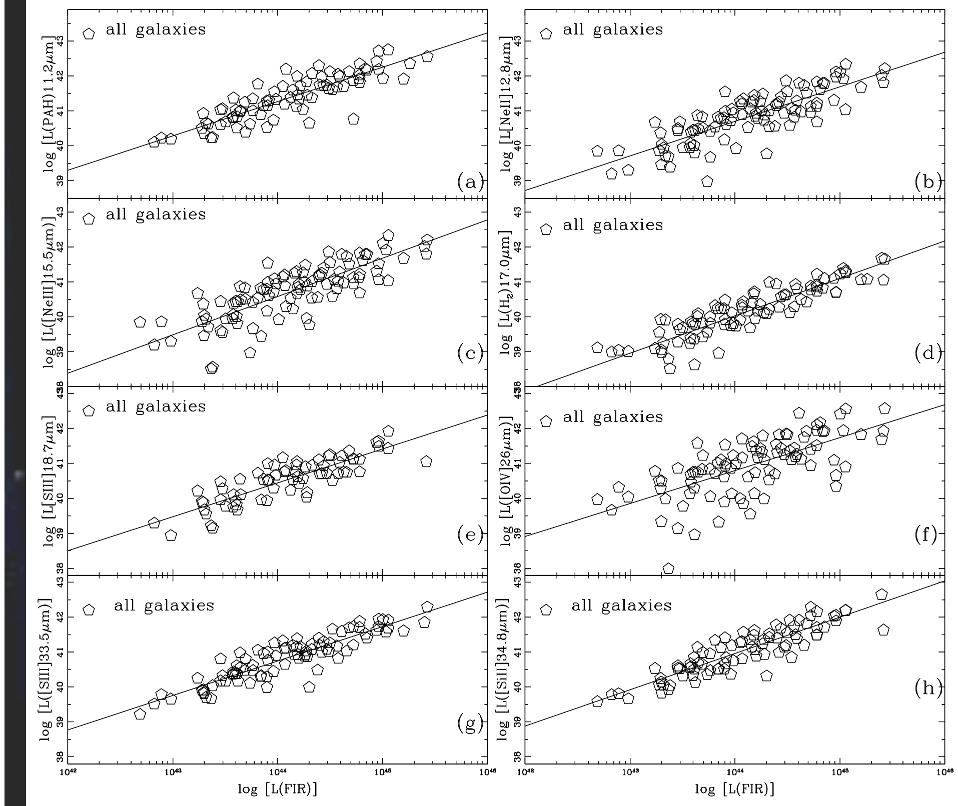
by C. Gruppioni & Pozzi (INAF, OaBo, Italy) uses all available IR data to extrapolate continuum LFs at z=0 - 4. Contribution from SB and AGN disentangled. It reproduces the first Herschel results from PEP.

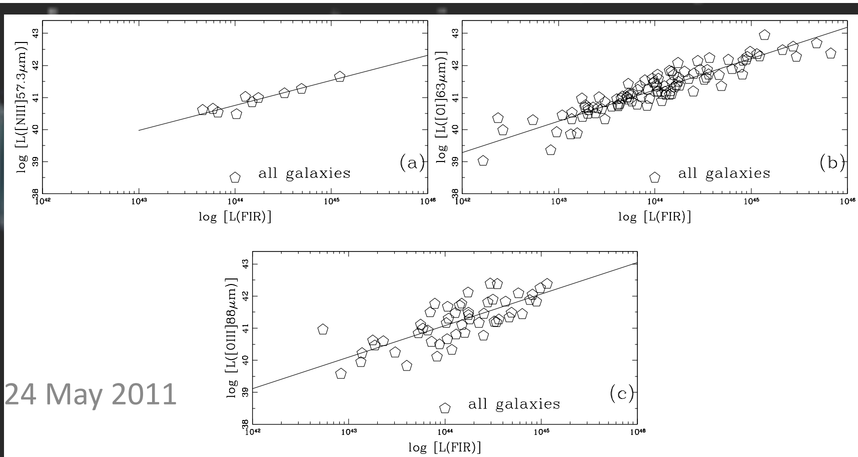
-- 2nd model.

by Franceschini et al. (Padova Univ., Italy) 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.

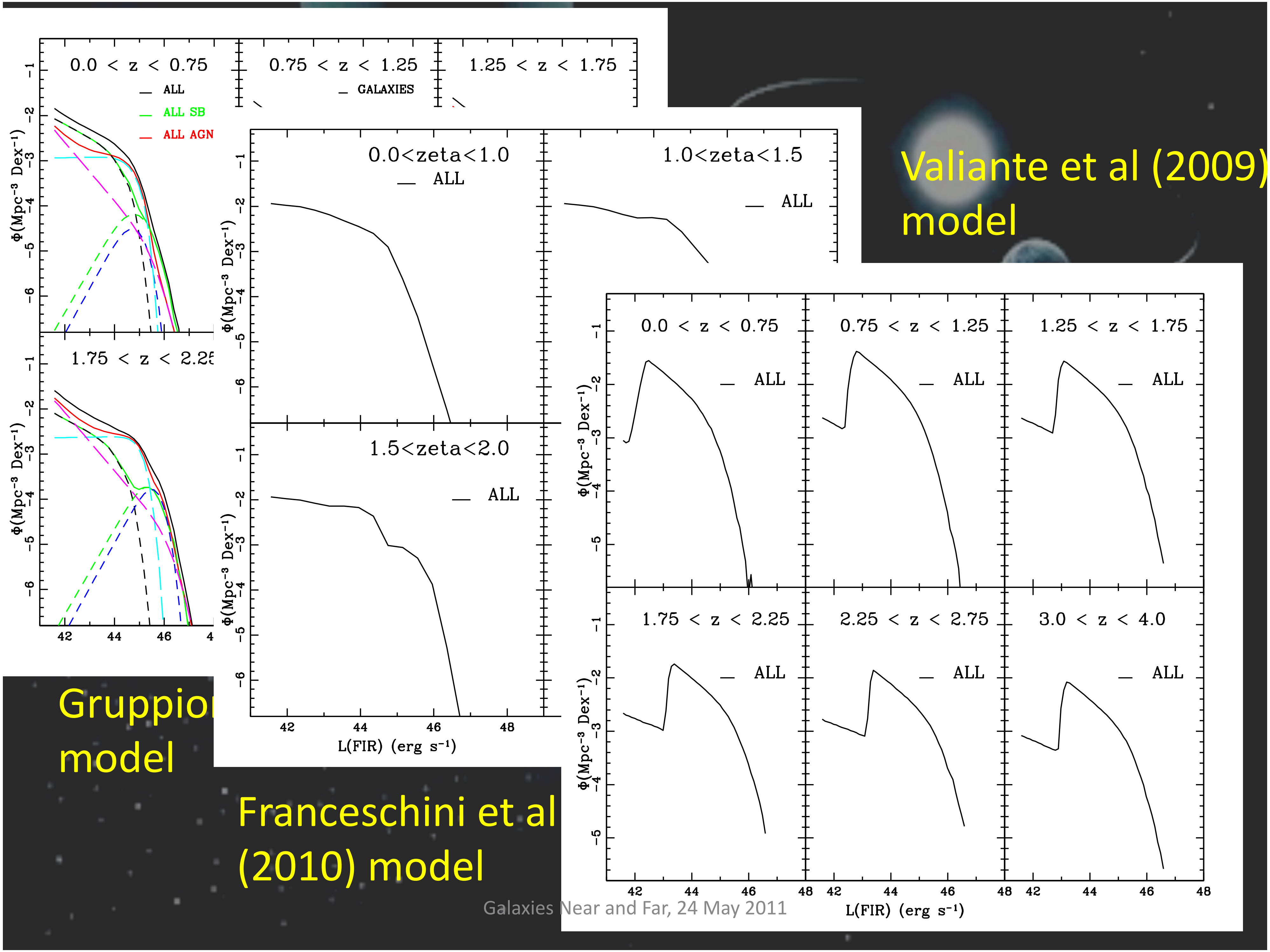
FIND CORRELATIONS BETWEEN LINE AND CONTINUUM LUMINOSITY IN THE LOCAL UNIVERSE







Least-squares fit to data



0.0 < z < 0.75
ALL
ALL SB
ALL AGN
0.75 < z < 1.25
GALAXIES
1.25 < z < 1.75
1.75 < z < 2.25
Φ(Mpc⁻³ Dex⁻¹)
Gruppioni model
0.0<zeta<1.0
ALL
1.0<zeta<1.5
ALL
1.5<zeta<2.0
ALL
L(FIR) (erg s⁻¹)
Franceschini et al (2010) model
Valiante et al (2009) model
0.0 < z < 0.75
0.75 < z < 1.25
1.25 < z < 1.75
1.75 < z < 2.25
2.25 < z < 2.75
3.0 < z < 4.0
ALL
L(FIR) (erg s⁻¹)
Galaxies Near and Far, 24 May 2011

Simulated spectroscopic survey: Total number of galaxies detectable in a 0.5 sq. deg. survey in MIR/FIR lines and features at 5σ *(3σ) in a total observing time of 450 hr*

Line/Model	Gruppioni et al (2011)	Franceschini et al (2010)	Valiante et al (2009)
PAH(11.25μm)	170 (375)	715 (1277)	1491 (3747)
[NeII] 12.81μm	162 (397)	228 (507)	42.3 (201)
[NeV] 14.32 μm	....	60.7 (207)	....
[NeIII] 15.55μm	121 (245)	113 (423)	179 (507)
[SIII] 18.71μm	67.0 (152)	55.8 (177)	6.3 (26.5)
[NeV] 24.32μm	143 (318)	37.8 (177)	....
[OIV] 25.89μm	638 (1208)	232 (631)	933 (1961)
[SIII] 33.48μm	850 (2061)	1753 (3307)	1104 (2553)
[SiII] 34.81μm	2224 (4159)	2713 (4738)	3037 (5836)
[OIII] 51.81μm	1929 (3962)	2983 (5076)	3883 (8100)
[NIII] 57.32μm	625 (1461)	567 (1613)	973 (2351)
[OI] 63.18μm	5422 (8496)	5611 (8905)	8896 (14679)
[OIII] 88.35μm	3028 (5062)	4274 (6682)	5121 (9490)

Same, as a function of redshift

Line/Model	Gruppioni et al (2011)			Franceschini et al (2010)		Valiante et al (2009)		
	0<z<1.3	1.3<z<2.3	2.3<z<4	0<z<1.5	1.5<z<2.5	0<z<1.3	1.3<z<2.3	2.3<z<4
PAH(11.25μm)	....	135 (288)	35 (128)	....	715 (1277)	....	1395 (3419)	96 (327)
[NeII]12.81μm	....	190 (362)	13 (36)	....	228 (507)	....	40 (185)	1.8 (16)
[NeV]14.32μm	....	1 (6.3)	....	61 (207)	....	....	....	....
[NeIII]15.55μm	69 (159)	61 (152)	2.7 (10)	87 (320)	26 (103)	94 (251)	78 (221)	7.2 (34)
[SIII]18.71μm	47 (77)	27 (67)	2.2 (7.6)	46 (131)	9.5 (46)	5 (17)	1.3 (77)	.... (1.8)
[NeV]24.32μm	130 (273)	14 (41)	.... (3.6)	37 (99)	1 (16)	....	....	....
[OIV]25.89μm	561 (918)	74 (265)	3.6 (25)	216 (551)	16 (80)	732 (1366)	185 (539)	16 (57)
[SIII]33.48μm	731 (1388)	284 (571)	41 (103)	1394 (2564)	360 (734)	890 (1933)	321 (539)	29 (147)
[SiII]34.81μm	1505 (2517)	596 (1308)	124 (334)	2068 (3520)	645 (1217)	1993 (3571)	827 (1750)	217 (513)
[OIII]51.81μm	1600 (2724)	319 (1173)	11 (66)	2679 (4144)	305 (932)	3137 (5771)	716 (2188)	29 (142)
[NIII]57.32μm	636 (1341)	29 (120)	....	564 (1583)	3.1 (30)	944 (2203)	29 (148)	....
[OI]63.18μm	3886 (5519)	1429 (2646)	107 (329)	4770 (7018)	840 (1886)	6502 (9972)	2188 (4069)	240 (640)
[OIII]88.35μm	2668 (3982)	539 (1080)	....	4365 (6009)	359 (675)	4617 (7144)	505 (1512)	....

Gruppioni+(2011) and Franceschini+(2010) models predict about 5 sources to be spectroscopically detected at 3 sigma in 5 spectral lines ([SiII]34.8μm, [OIV]26μm, [SIII]33.5μm, [OIII]52μm and [OI] 63μm) and ~9 sources in the 3 brightest lines, down to the expected flux limits of SPICA in a 1 hour pointing (FOV 2'x2').
Predictions from Valiante+(2009) model are higher by a factor of 1.5-2.

-with a "small" program (100h) -> 500-900 sources
(covering a 20'x20' field)
- with a large program (400h) -> 2000-3600 sources
(covering a 40'x40' field)

SPICA-SAFARI is excellent at detecting high-z sources and at assessing in a direct way their nature (e.g. whether AGN- or SF-powered) thanks to blind spectroscopy.
Complementary to SAFARI, MIRACLE will detect several tens to hundreds of galaxies at R~200 in a FoV=5'x5' in 1 hour up to z~1

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 will be the way to "physically" measure galaxy evolution
- The sensitivity of ~2x10^-19 W/m2 (3σ, 1 hour) [i.e. ~2.5x10^-19 at 5σ] must be reached to make these surveys.
- Complementary to SAFARI, MIRACLE will detect several tens to hundreds of galaxies at R~200 in a FoV=5'x5' in 1 hour up to z~1