Cosmological Studies with SPICA/SAFARI after the Herschel Mission, in the JWST & ALMA Era

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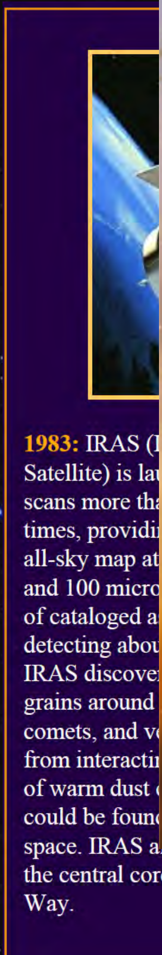
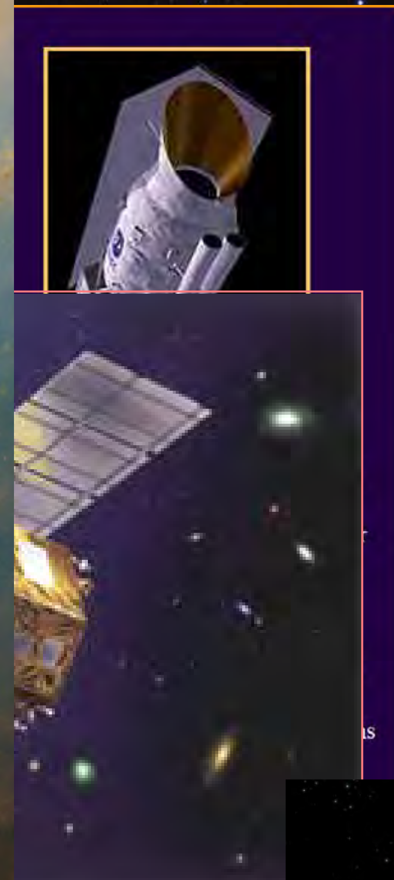
The last of the series: the Herschel Observatory





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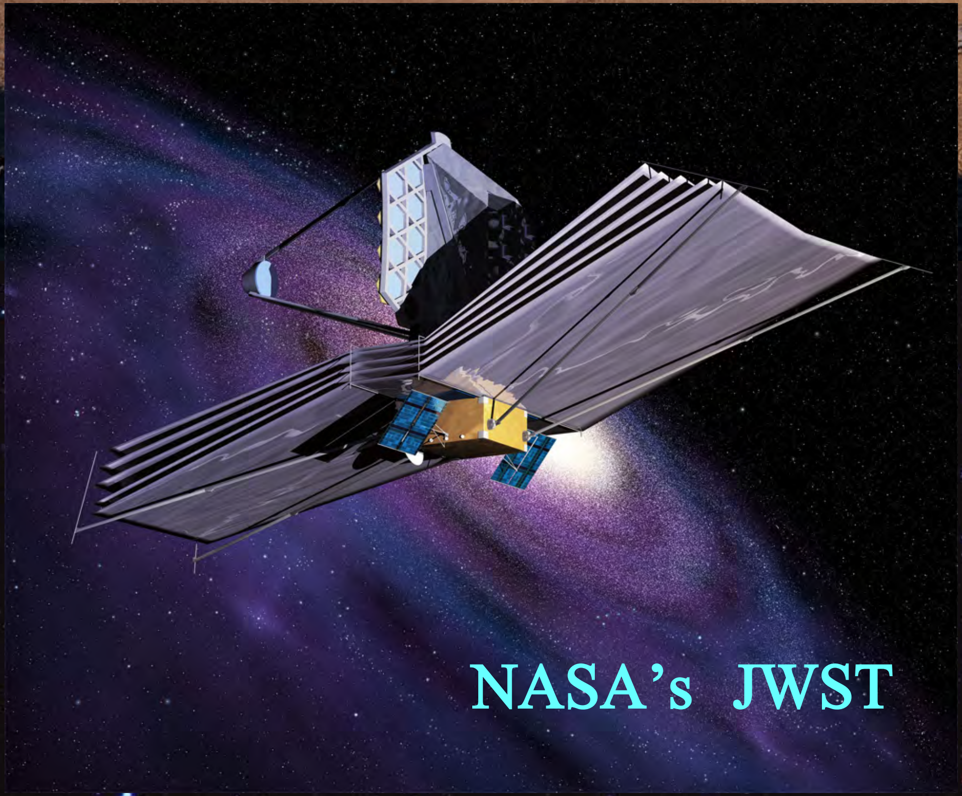
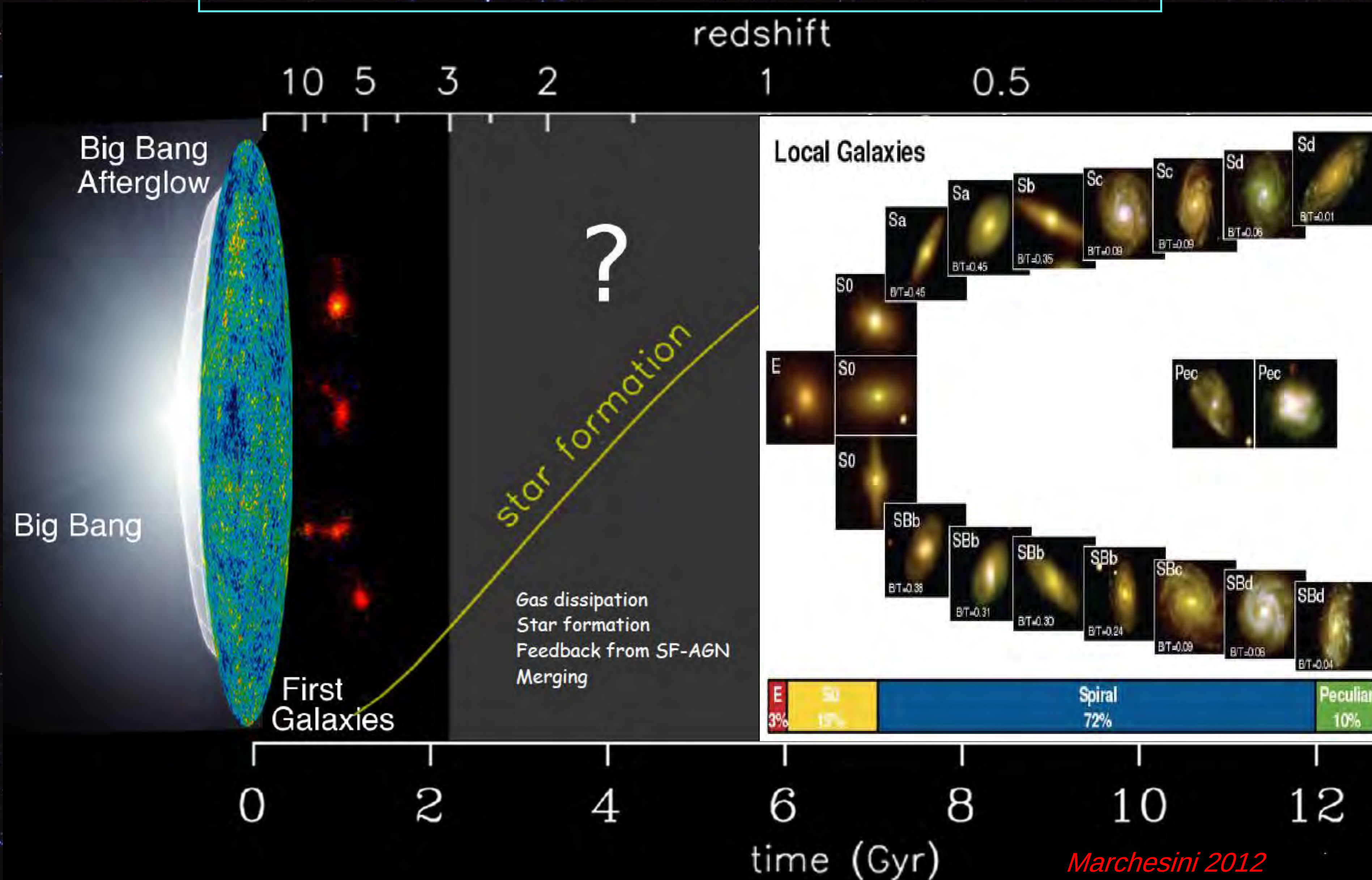
– +3 years warm


ALMA 19 antennas

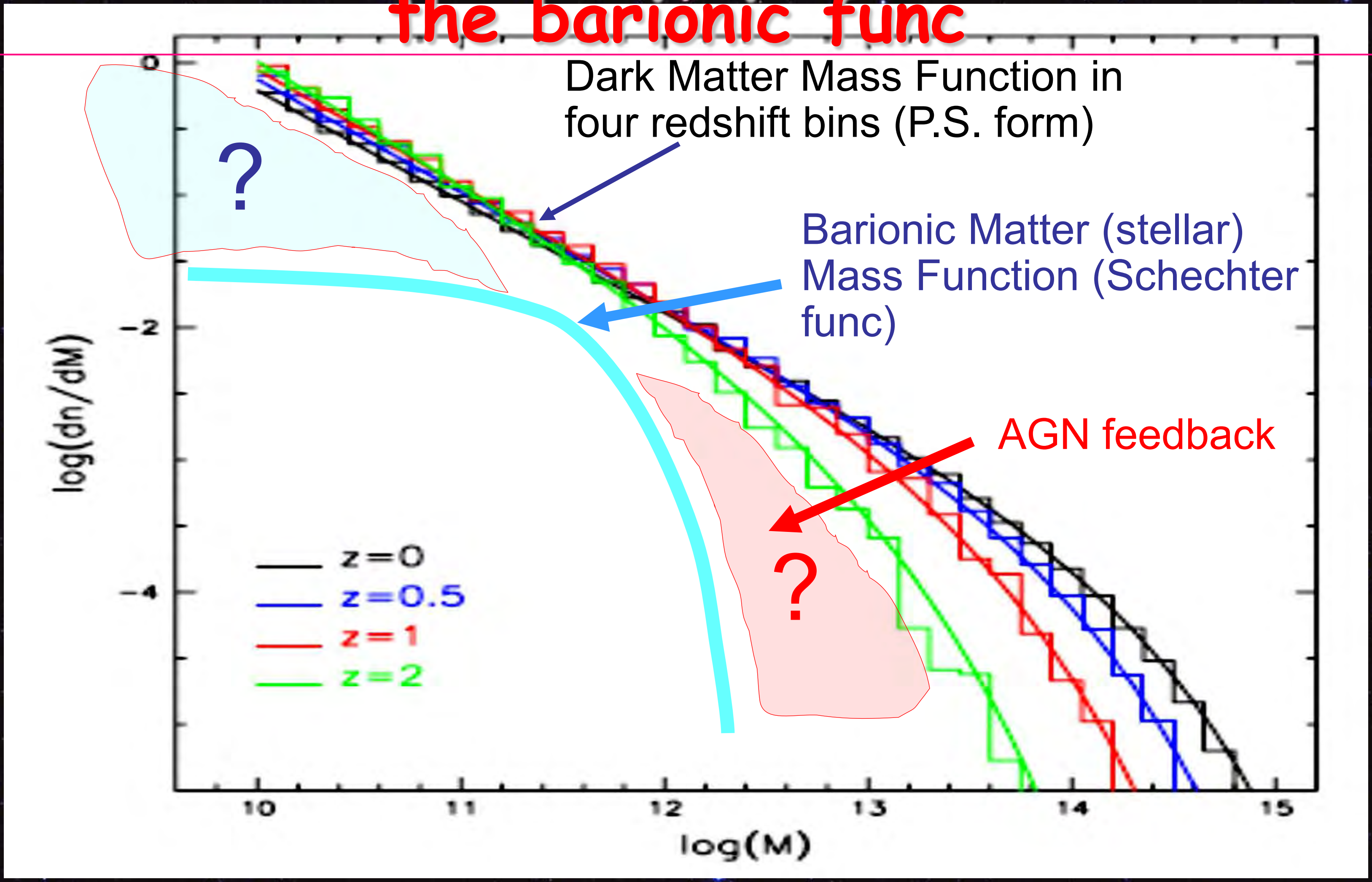

JCMT


NASA's JWST

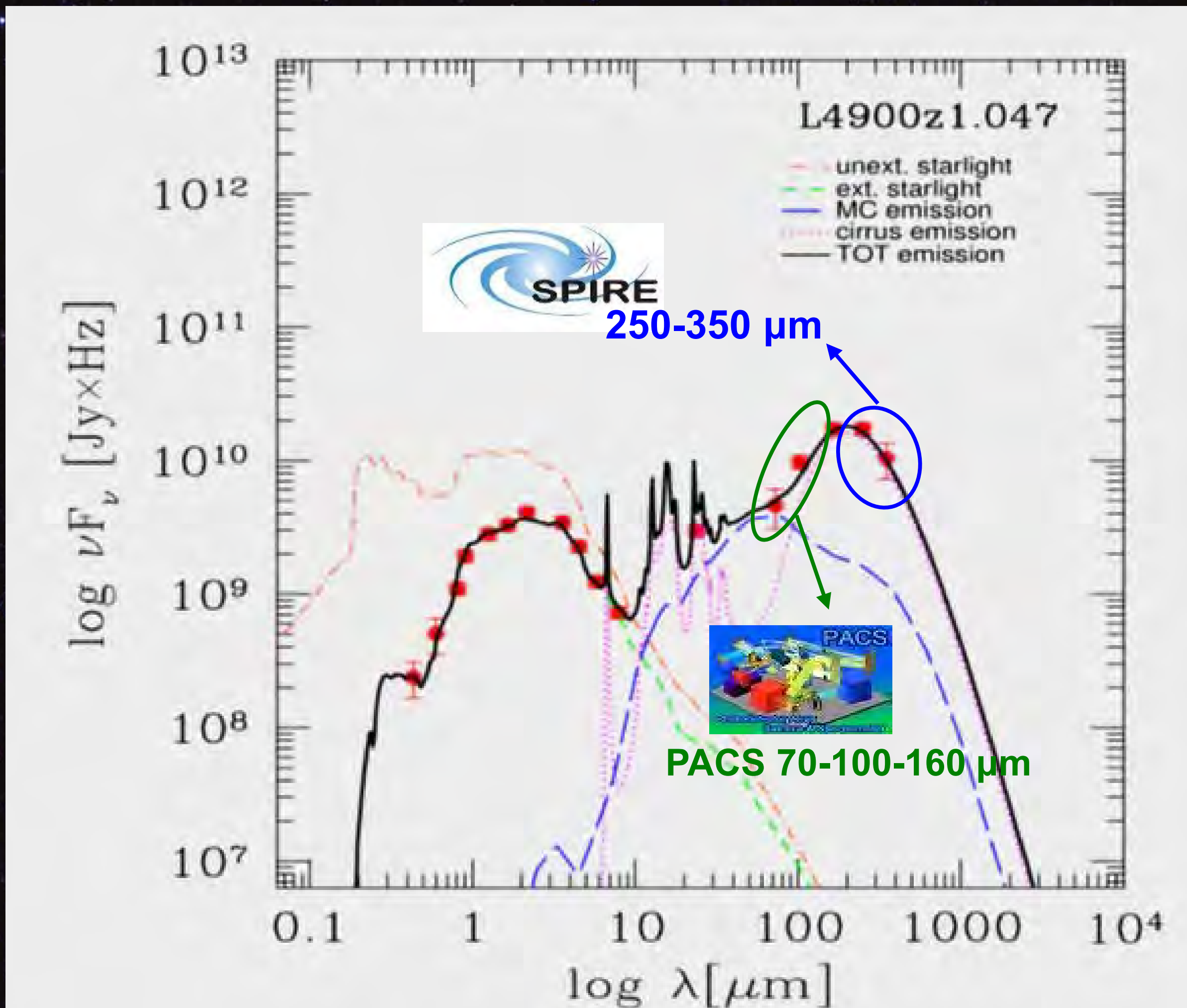
The Context

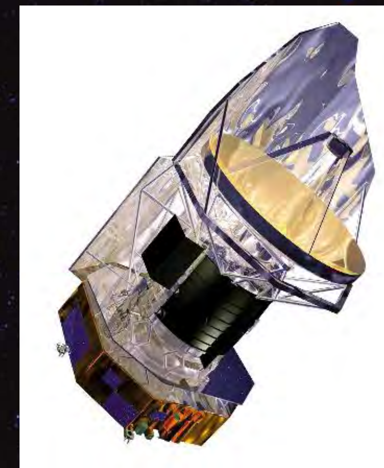

redshift
10
5
3
2
1
0.5
Big Bang Afterglow
Big Bang
First Galaxies
?
star formation
Gas dissipation
Star formation
Feedback from SF-AGN
Merging
Local Galaxies
E
S0
S0
S0
Sa
Sa
Sb
Sc
Sc
Sd
Sd
Pec
Pec
SBb
SBb
SBb
SBb
SBc
SBd
SBd
E 3%
S0 15%
Spiral 72%
Peculiar 10%
0
2
4
6
8
10
12
time (Gyr)
Marchesini 2012

The fundamental problem for our understanding of the origin of the cosmic structure (galaxies): how DM mapped into the barionic func



THE HERSCHEL MISSION FOR COSMOLOGY

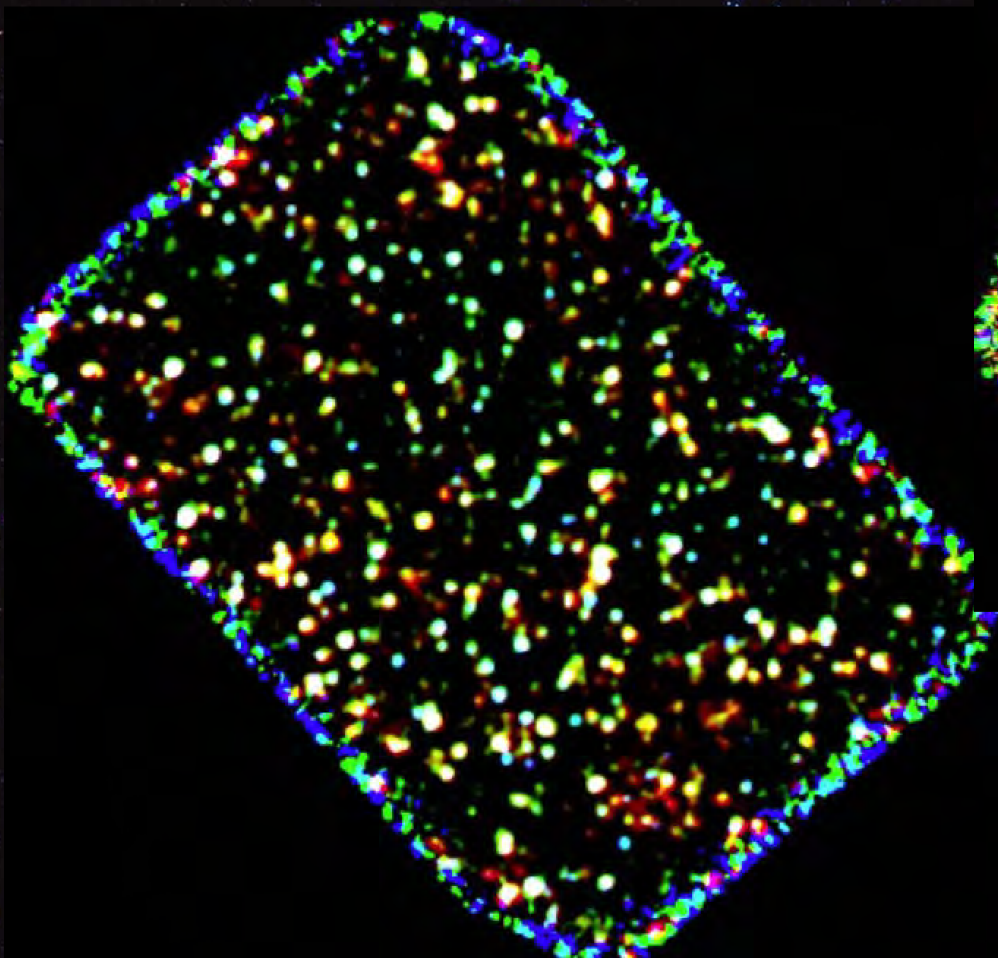


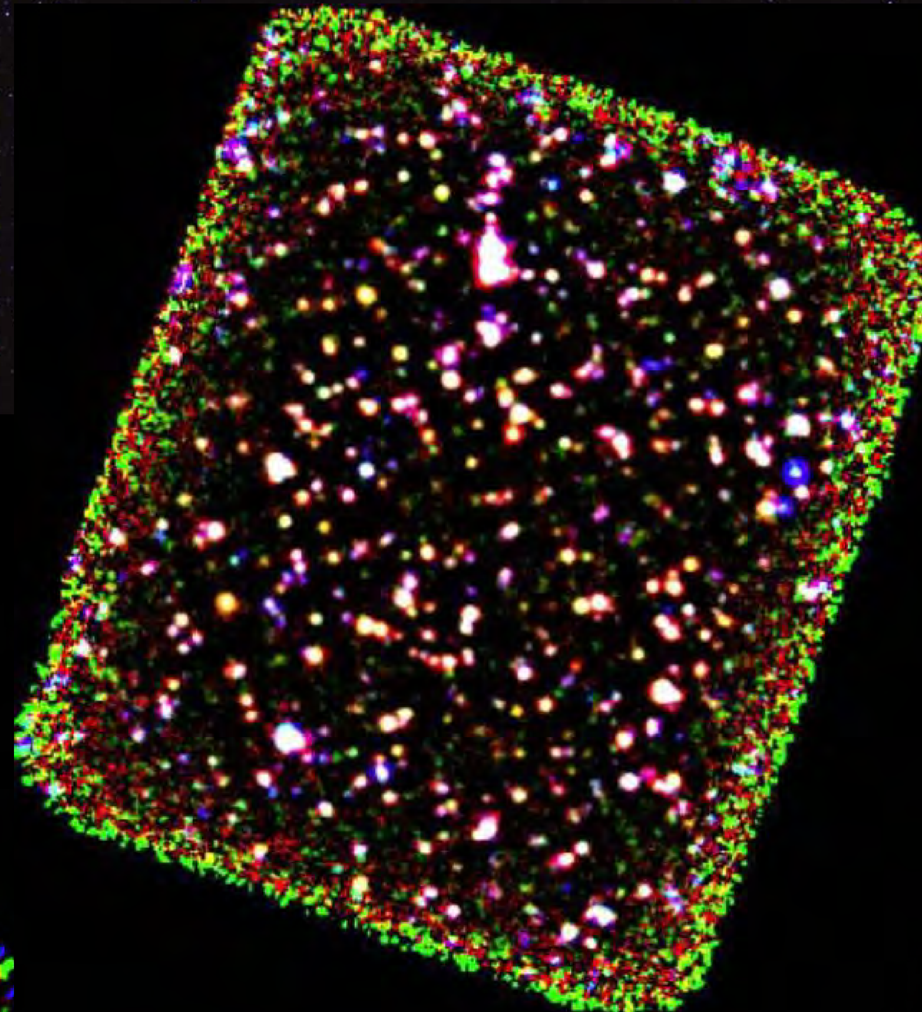


The Herschel SPIRE and PACS imagers/spectrometers

- unique probe of the bolometric emissions of cosmic sources during the main formation epochs
- characterization of the molecular and dusty ISM

GOODS–north field (10′×15′) at 100 μm (blue), 160 μm (green) and 250 μm (red)



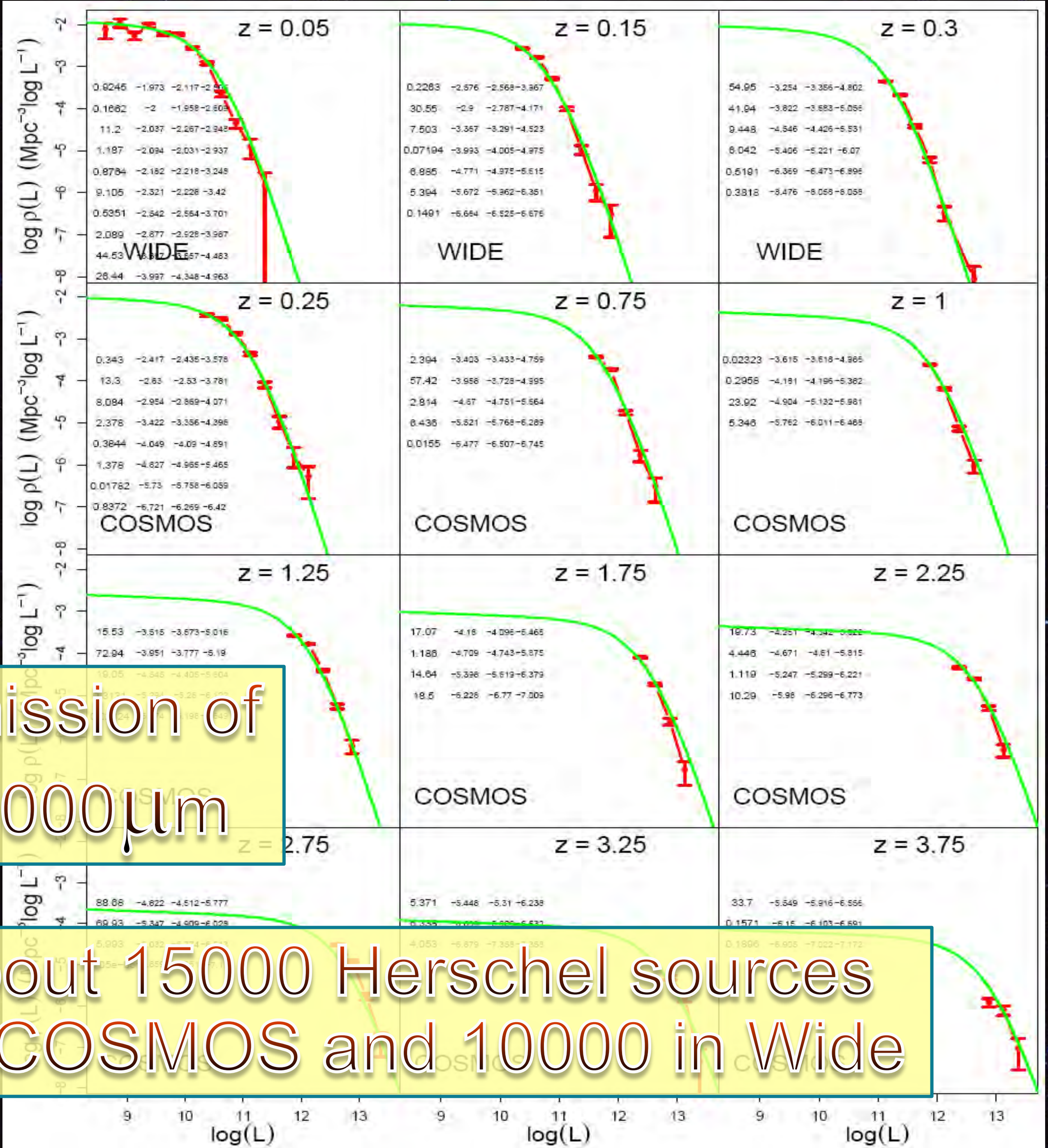


GOODS–south (10′×10′) at 24 μm (blue), 100 μm (green) and 160 μm (red)

Elbaz et al. 2011

Galaxy Population analyses

The Evolution of the IR Bolometric Luminosity Function (COSMOS + Wide-Area Flds)



Bolometric emission of sources at 8-1000μm

About 15000 Herschel sources in COSMOS and 10000 in Wide

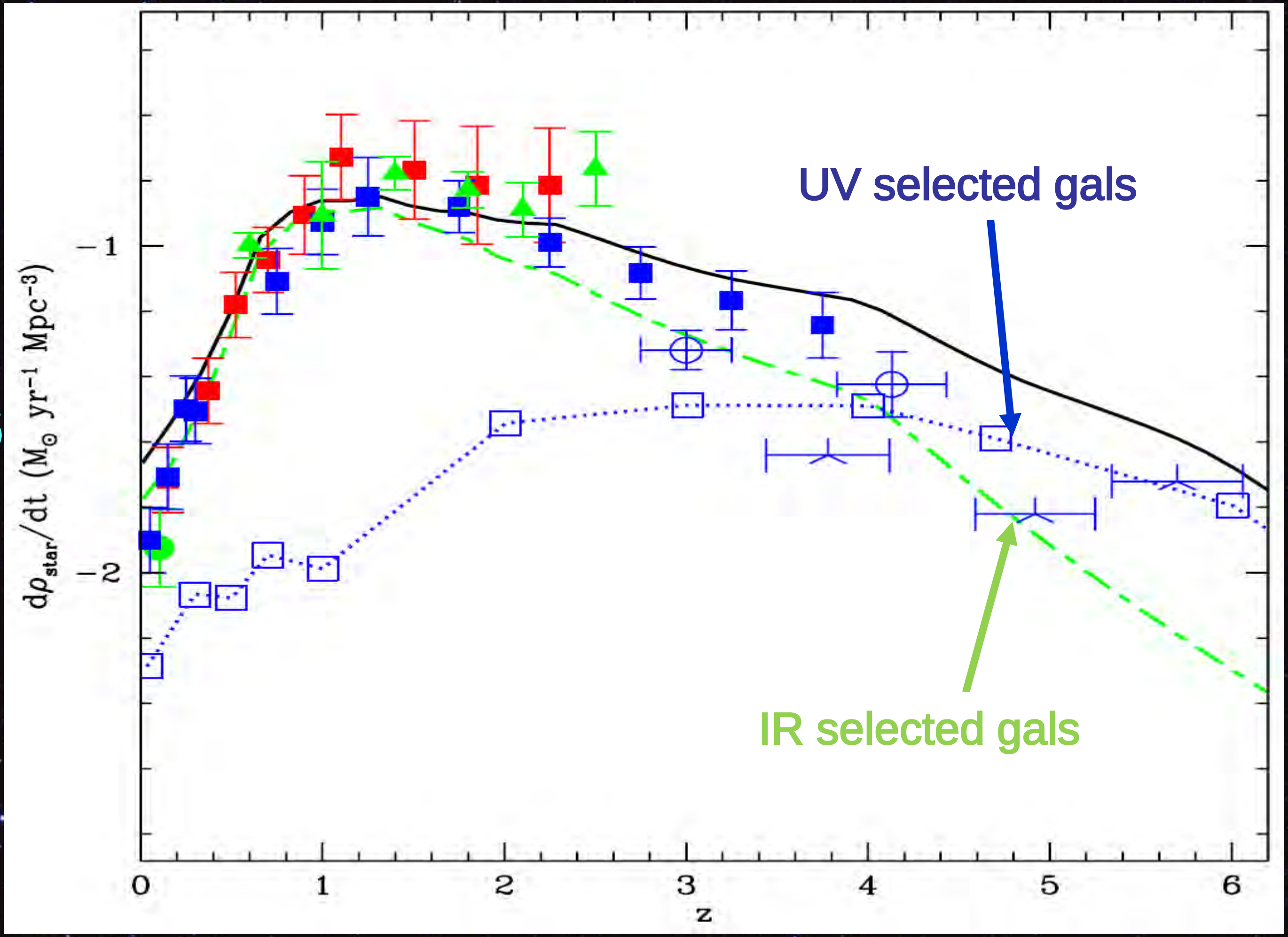
Vaccari et al. 2013
Marchetti et al. 2013

IR & UV SFR estimates ...

From integrations of 1500° LFs by:

Arnouts et al 2005
Schiminovic + 2005
Wyder + 2005
(@ low z)

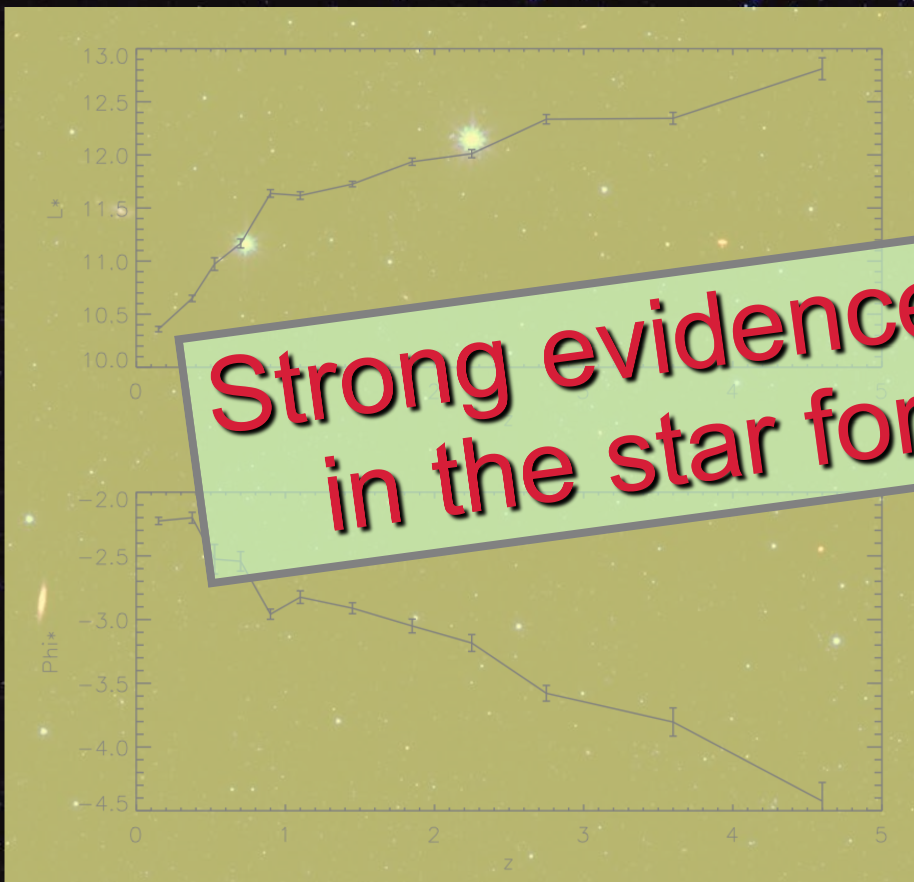
Cucciatti + 2012
Shimasaku + 2005
(@ high z)



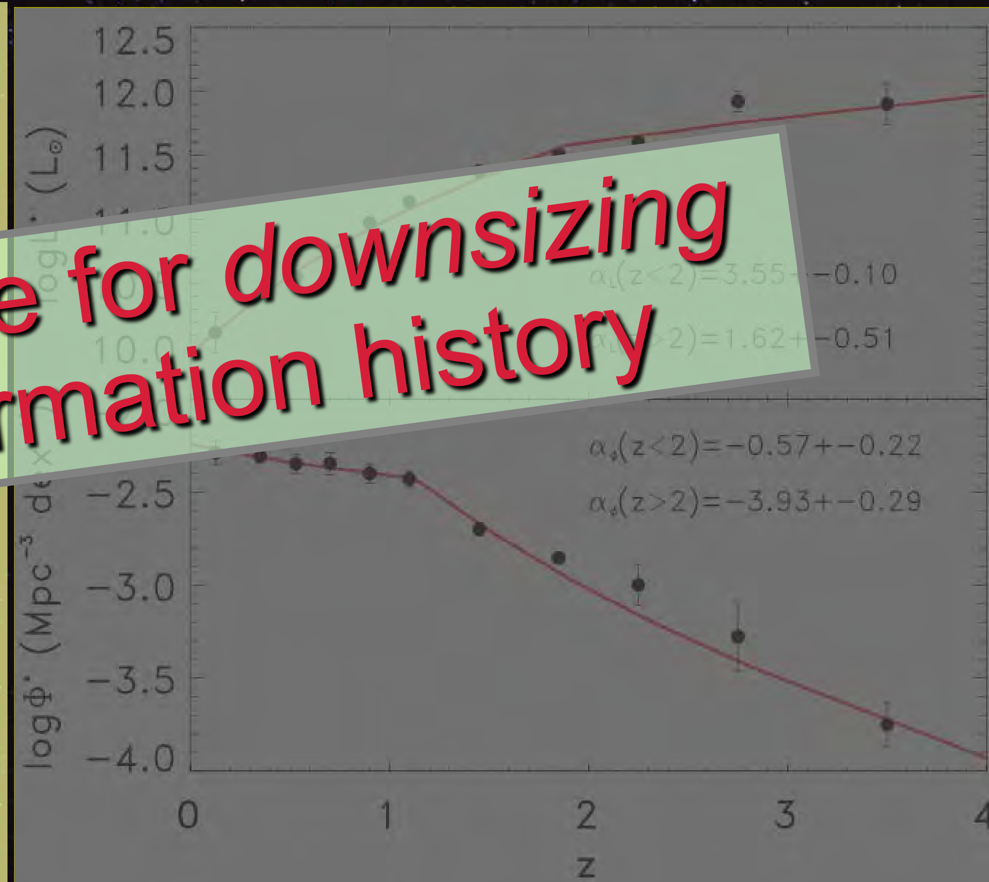
1. The bulk of SF activity at z<3-4 appears to be produced by strongly dust-extinguished galaxies
2. UV bright objects instead dominate on average at z>4

Evolutionary Population Properties of IR sources

Vaccari + (in prep.)



Gruppioni + (in press)



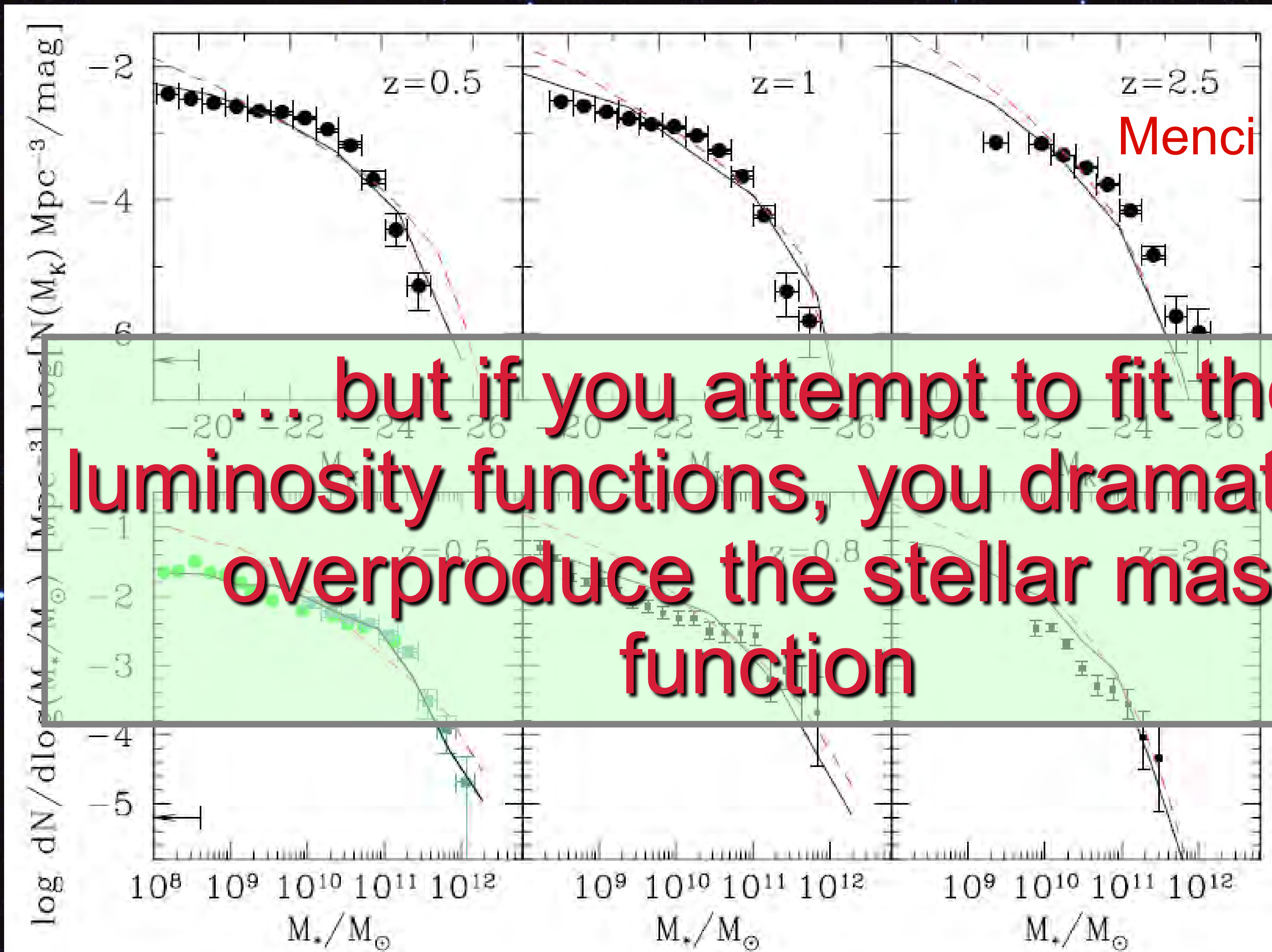
Strong evidence for *downsizing* in the star formation history

Distribution of Dark Matter in the Millenium Simulation ...

... plus physical (analytic) recipes to treat the baryon collapse & SF

Present models appear to largely underestimate the SFR density at high values of L_{IR} at large redshifts

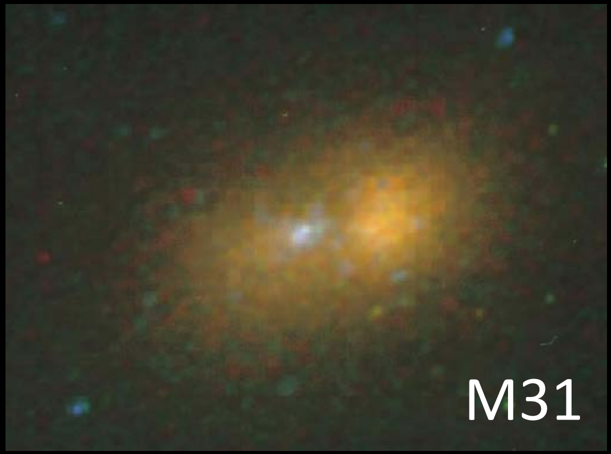
... at the same time the best physical models appear to fit relatively well the galaxy stellar mass functions...

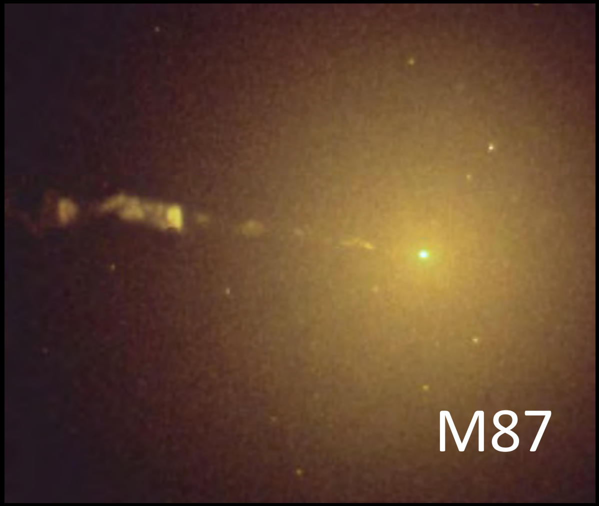


Menci et al. 2012

... but if you attempt to fit the luminosity functions, you dramatically overproduce the stellar mass function

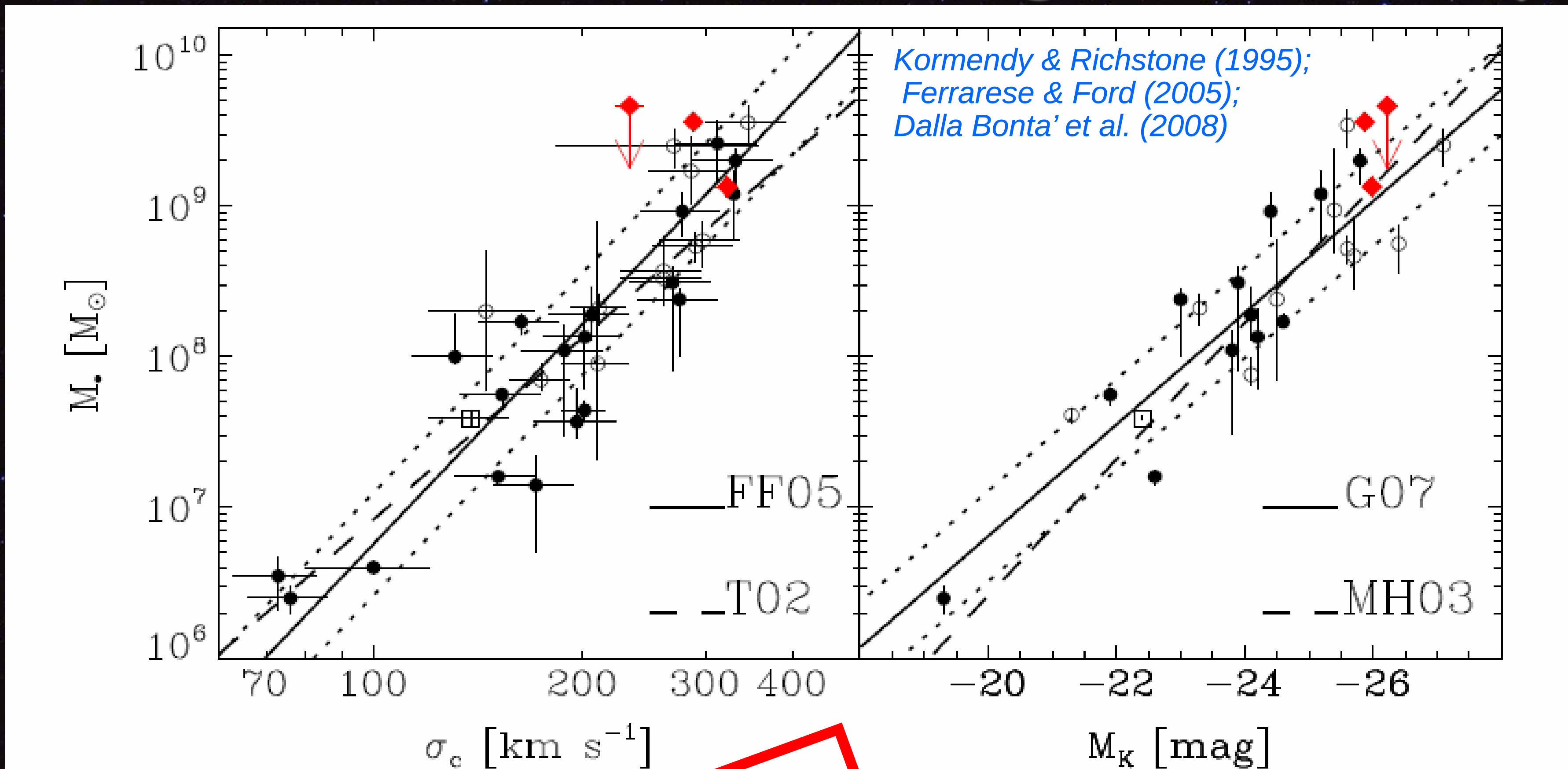
Supermassive Black Holes in the Nuclei of Galaxies & AGN activity





Most massive galaxies possess supermassive black holes in their nuclei.

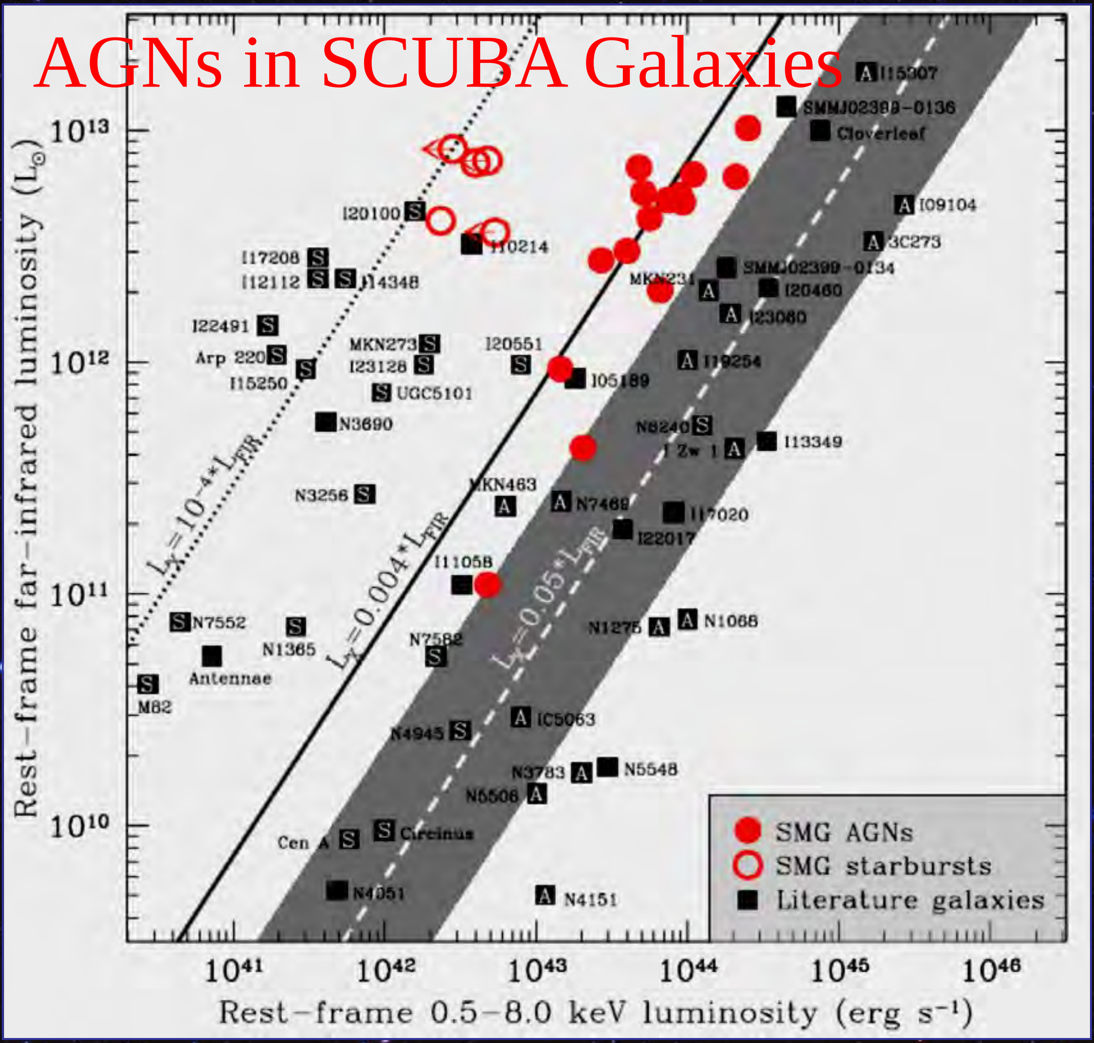
The Nuclear BH / Host Bulge Relationship



Question: where, when, and how the relation of SF and AGN has taken shape ?

Left panel: Location of the SBHs masses of our BCG sample galaxies (*diamonds*) with respect to the $M_\bullet - \sigma_c$ relation by Ferrarese & Ford (2005). We plot the SBH masses based on resolved dynamical studies of ionized gas (*open circles*), water masers (*open squares*), and stars (*filled circles*) from Table 2 of Ferrarese & Ford (2005). The dashed line represents the Tremaine et al. (2002) relation. *Right panel*: Location of our BCG sample galaxies with respect to the near-infrared (*K*-band) $M_\bullet - L_{bulge}$ relation by Graham (2007). Data are taken from Table 2 of Graham (2007) and symbols are as in the left panel. Masses and magnitudes of NGC 5252, NGC 6251 and Cygnus A were adjusted to a distance obtained with $H_0 = 75$ km s^{-1} Mpc^{-1}. The dashed line represents the Marconi & Hunt (2003) relation. In both panels, we added the data relative to NGC 1399 (Houghton et al. 2006) and the dotted lines represent the 1σ scatter in $M_\bullet$.

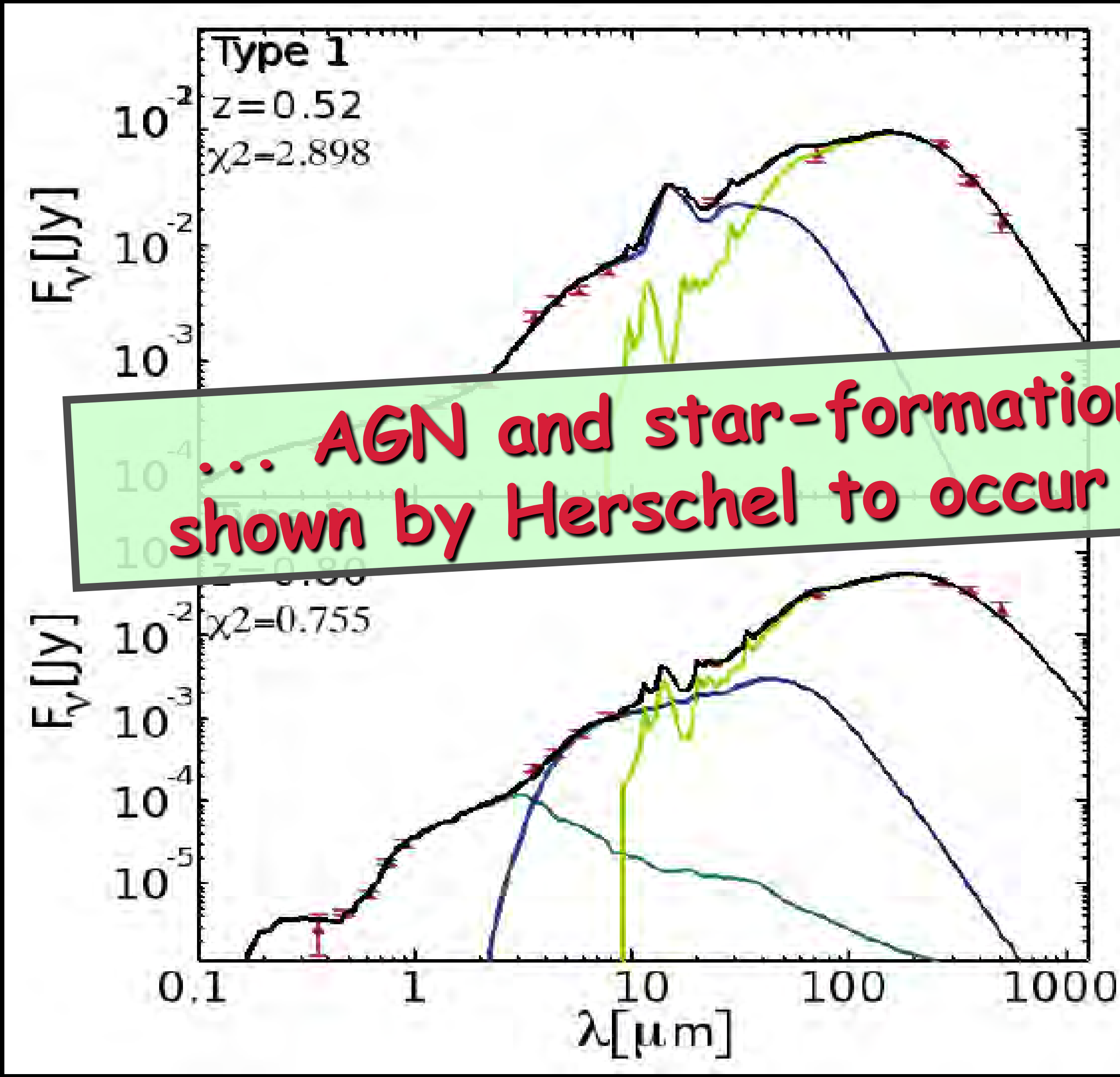
AGN incidence in luminous sub-mm sources



Alexander et al. 2005

" As typical quasars are not undergoing intense star formation and already host massive black holes there must have been an earlier pre-quasar phase when these black holes grew. The likely signature of this earlier stage is simultaneous black-hole growth and star formation in distant luminous galaxies. We find that the black holes in these galaxies are growing almost continuously throughout periods of intense star formation. This activity appears to be more tightly associated with these galaxies than any other coeval populations. We show that the BH growth from these galaxies is consistent with that expected for the pre-quasar phase."

Herschel Investigation of Quasi-Stellar Objects



... AGN and star-formation activities are shown by Herschel to occur simultaneously...

Example fits for a type 1 (upper panel) and a type 2 (lower panel) AGN. In red the [illegible] data points; in blue the AGN/torus model; in light green the starburst component; in dark green the stellar component, and in black the total model SED. The reported χ^2 are *reduced*.

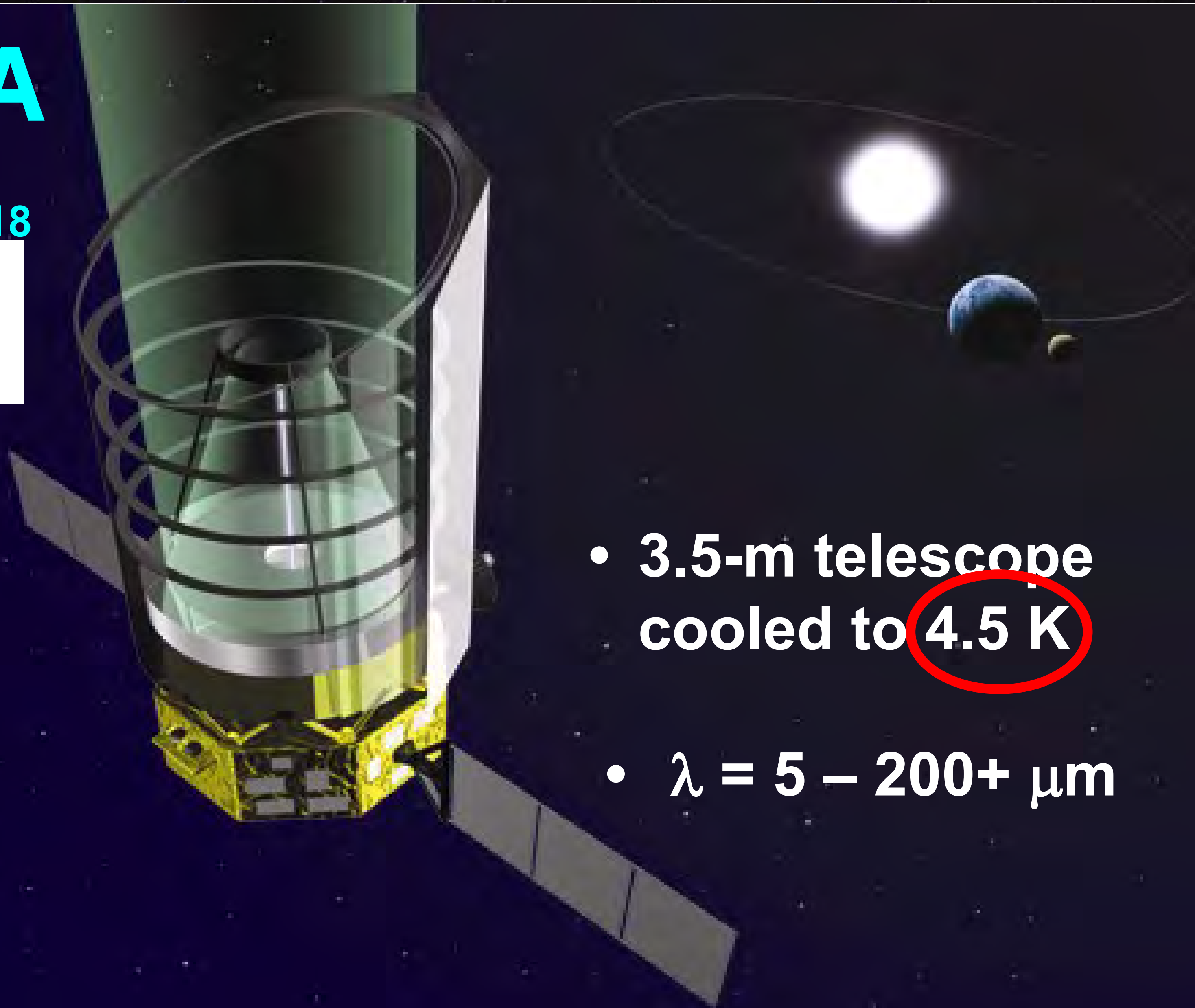
Hatziminoglou et al. 2010

After the Herschel mission …

1. Consistent results from independent surveys, strong constraints on the high-z galaxy comoving emissivity and SFR
2. Current data show: strong *positive* evolution of the bolometric L + very strong *negative* evolution of the comoving density:
3. … this quite at variance wrt *hierarchical clustering* predictions
4. Galaxy & AGN co-evolution, but very unclear any physical relationship between the two

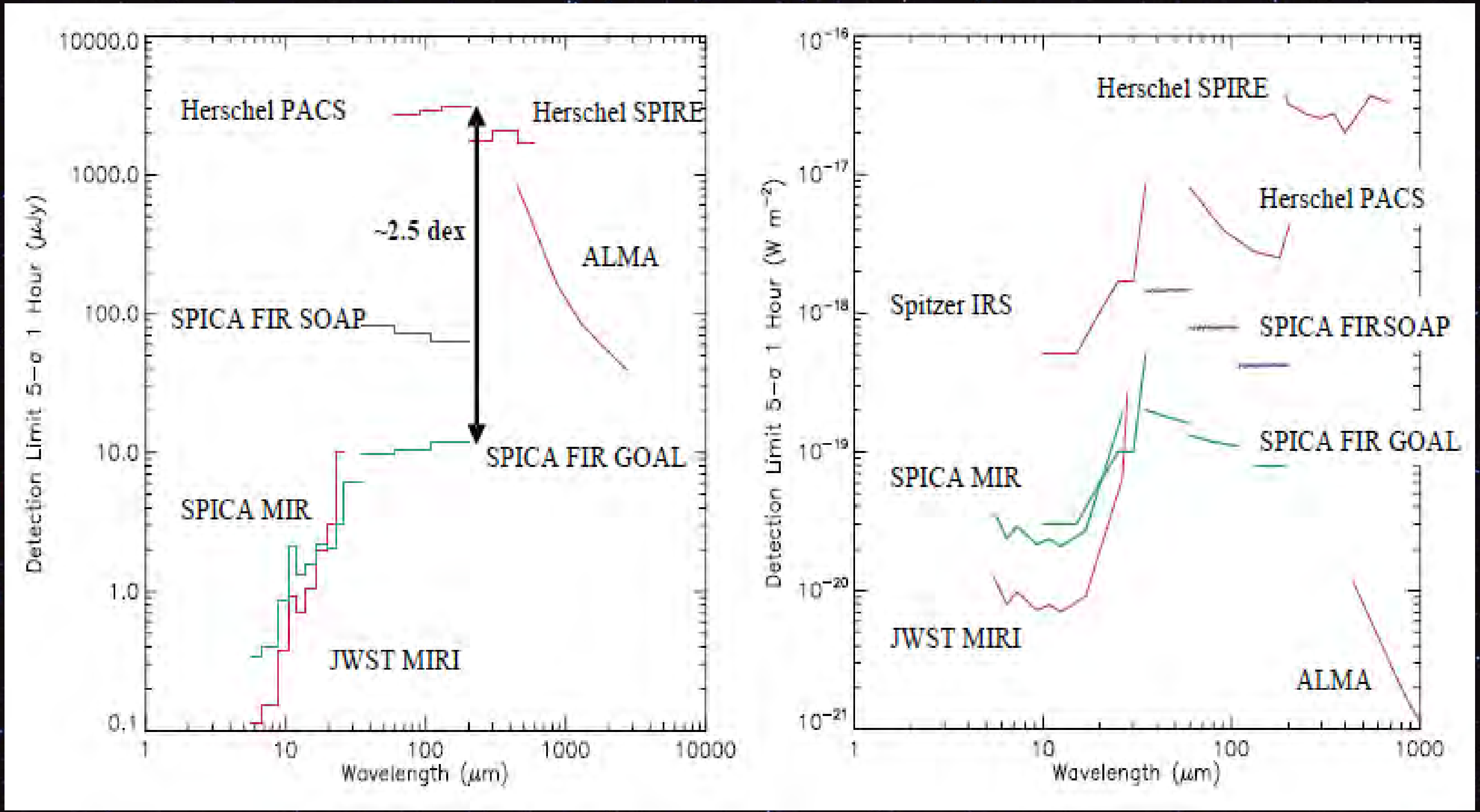
SPICA

Launch ~ 2018

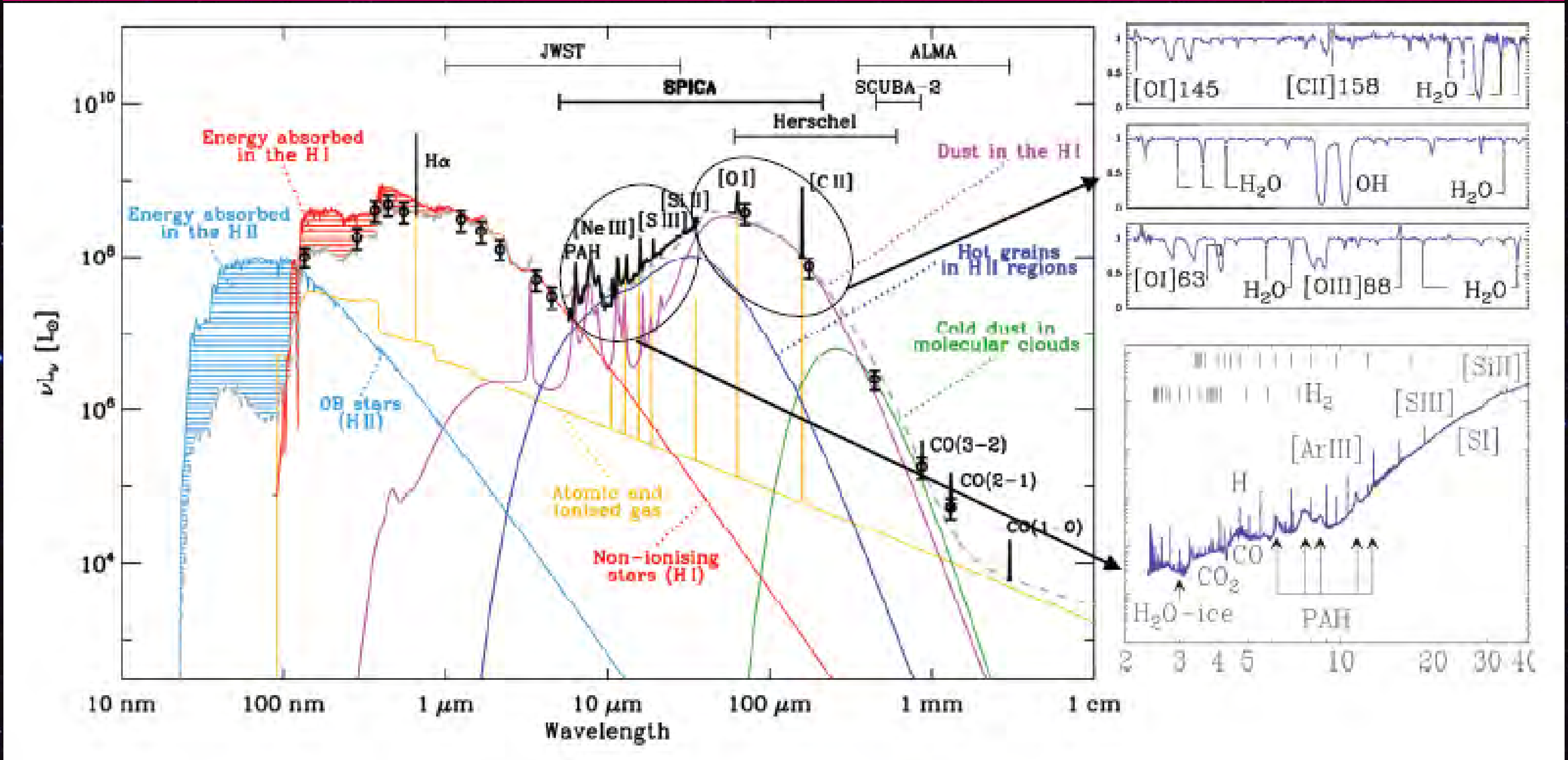


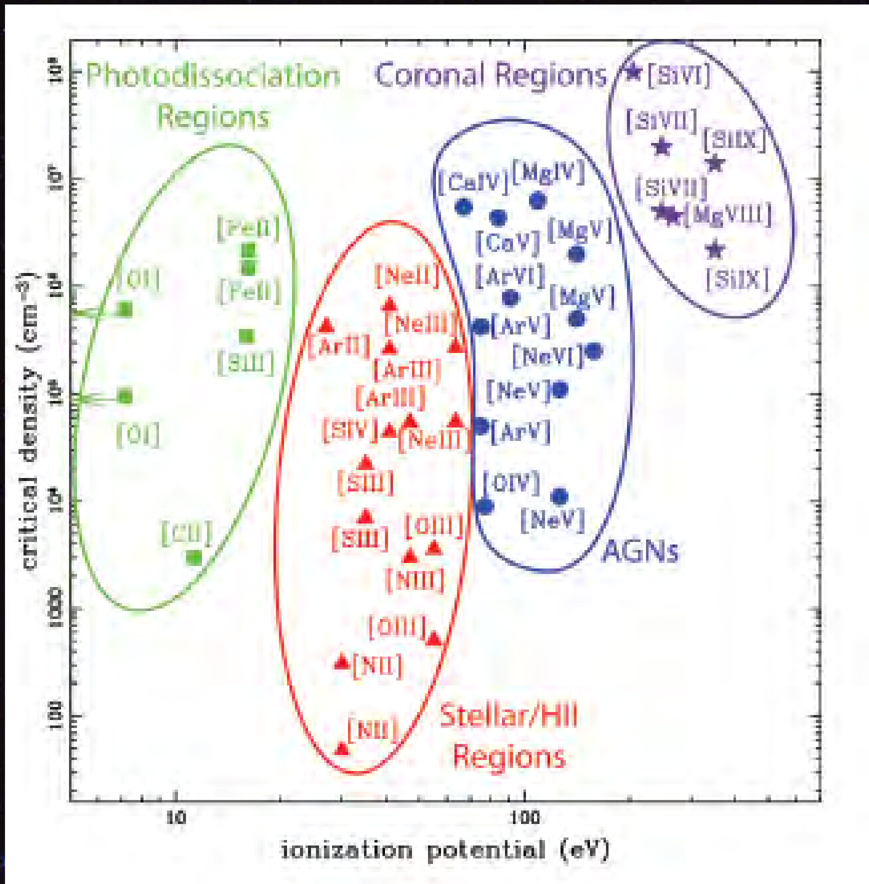
- 3.5-m telescope cooled to 4.5 K
- λ = 5 – 200+ μm

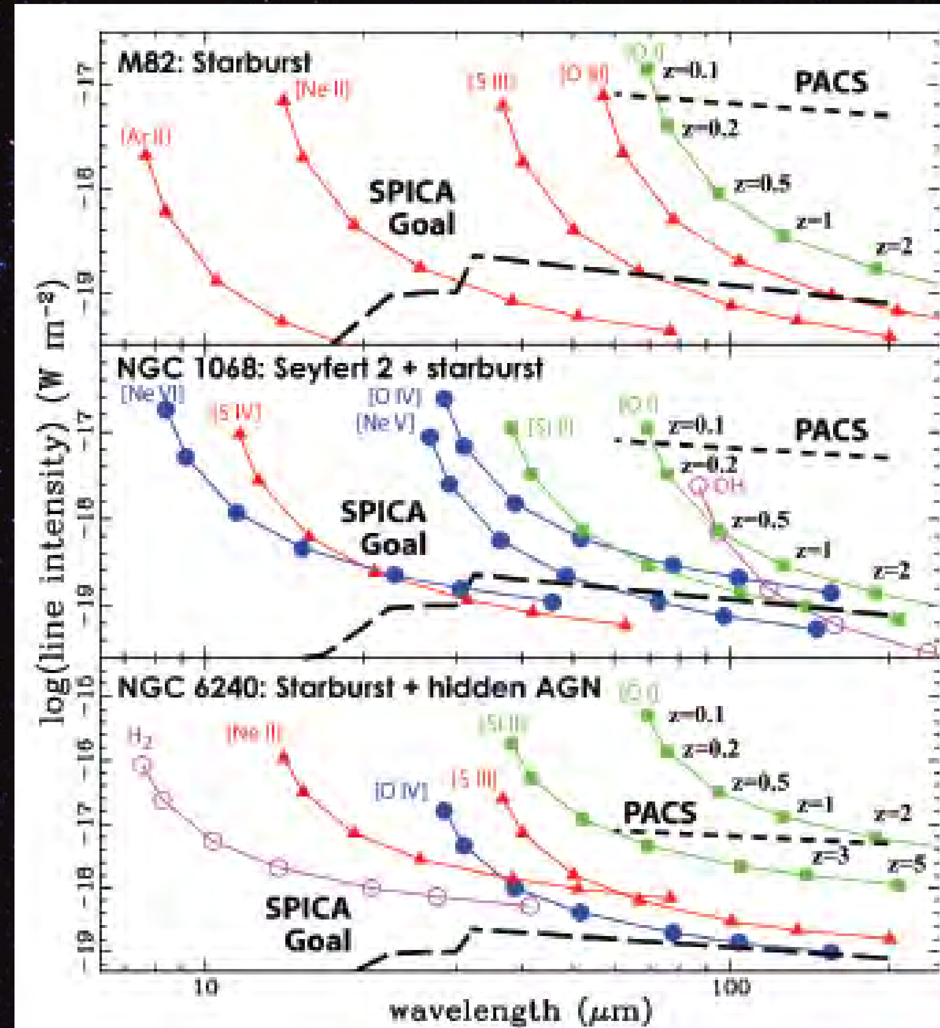
… thanks to the huge sensitivity gain offered by the cooled instrumentation



Given the extremely rich variety of ionic & molecular features in the spectral domain, a top priority case for the mission will be spectroscopy with high-spatial & spectral resolution of cosmic sources



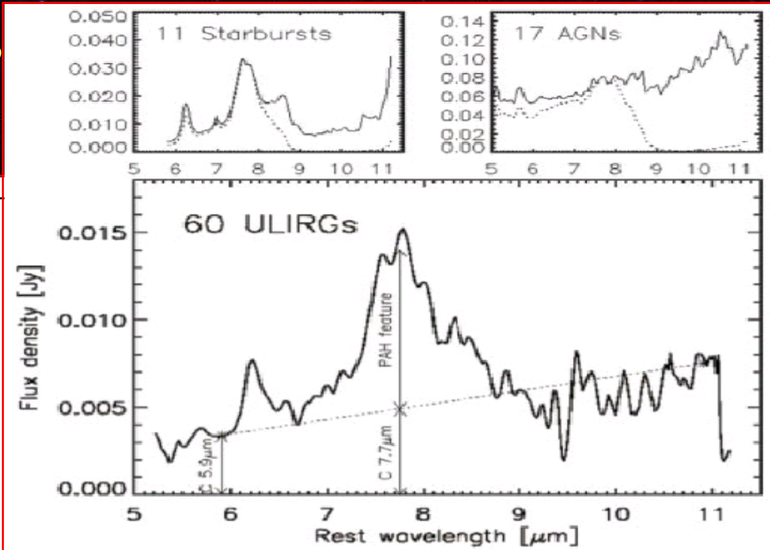


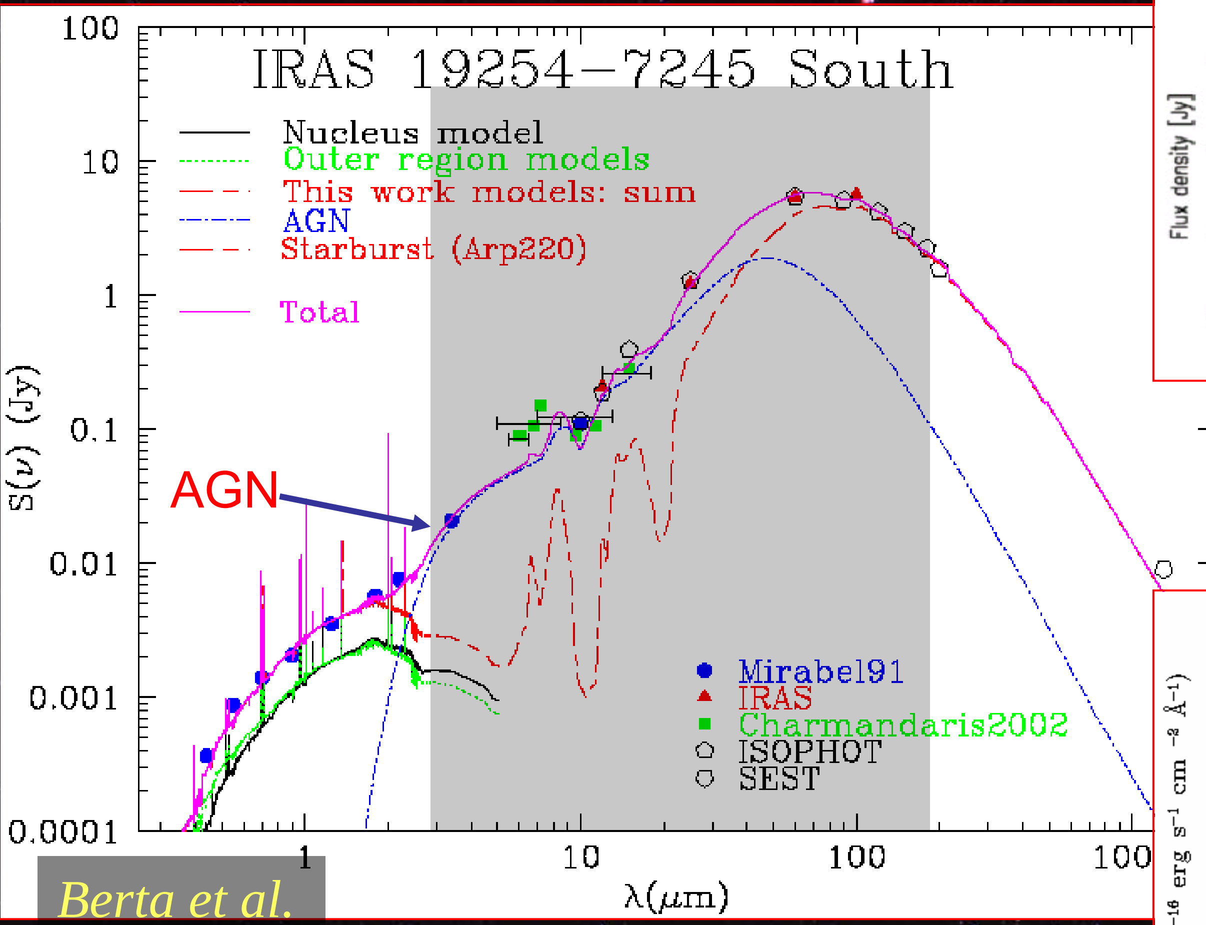


Key MIR/FIR emission lines visible with SPICA in three archetypical objects: M82 (L_{FIR}~$4x10^{10}L_{\otimes}$), NGC1068 (L_{FIR}~$2x10^{11}L_{\otimes}$) and NGC6240 (L_{FIR}~$7x10^{11}L_{\otimes}$) - in each panel the upper/lower dashed lines denote the 5σ-1hr sensitivity of Herschel-PACS/SPICA respectively

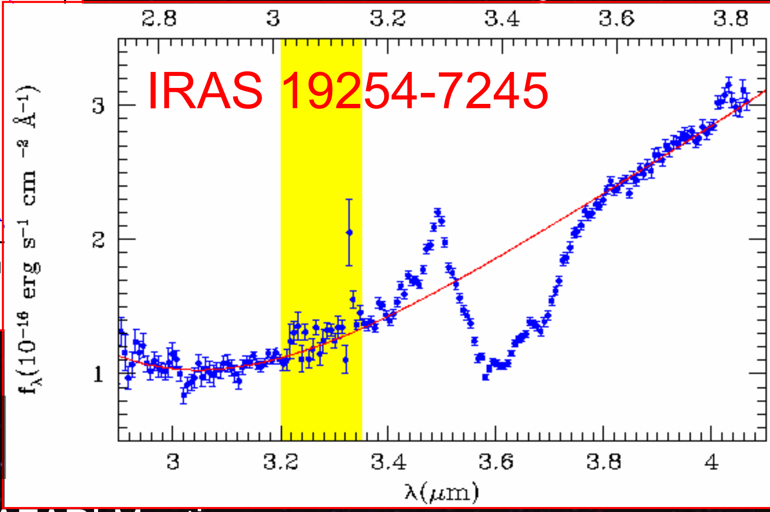
IR diagnostics available for SPICA investigations

Lutz et al. 1998





Berta et al.



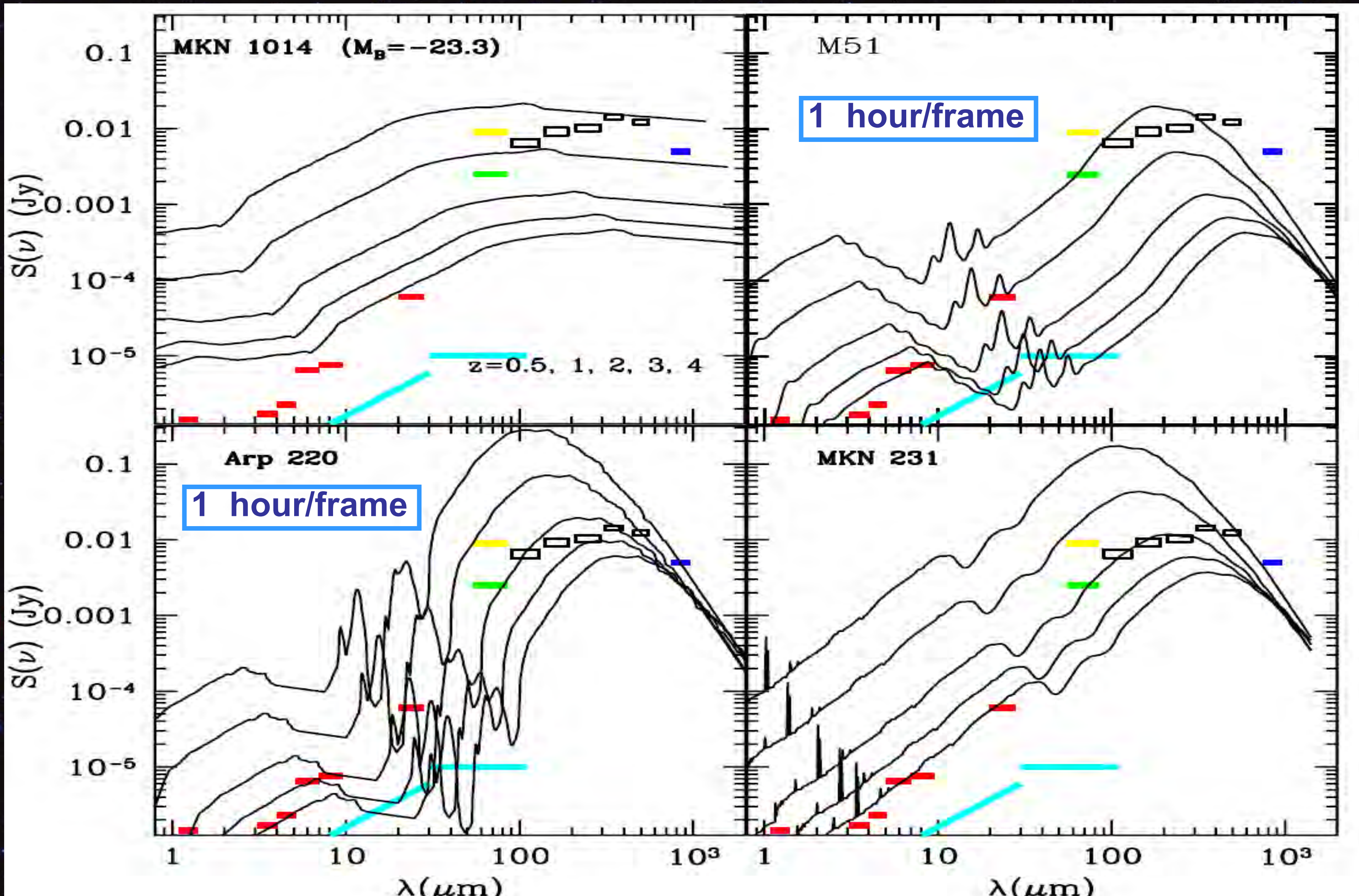
VLT spec. (Risaliti et al)

- Crucial steps forward will also be made by SPICA in the field of deep cosmological imaging surveys

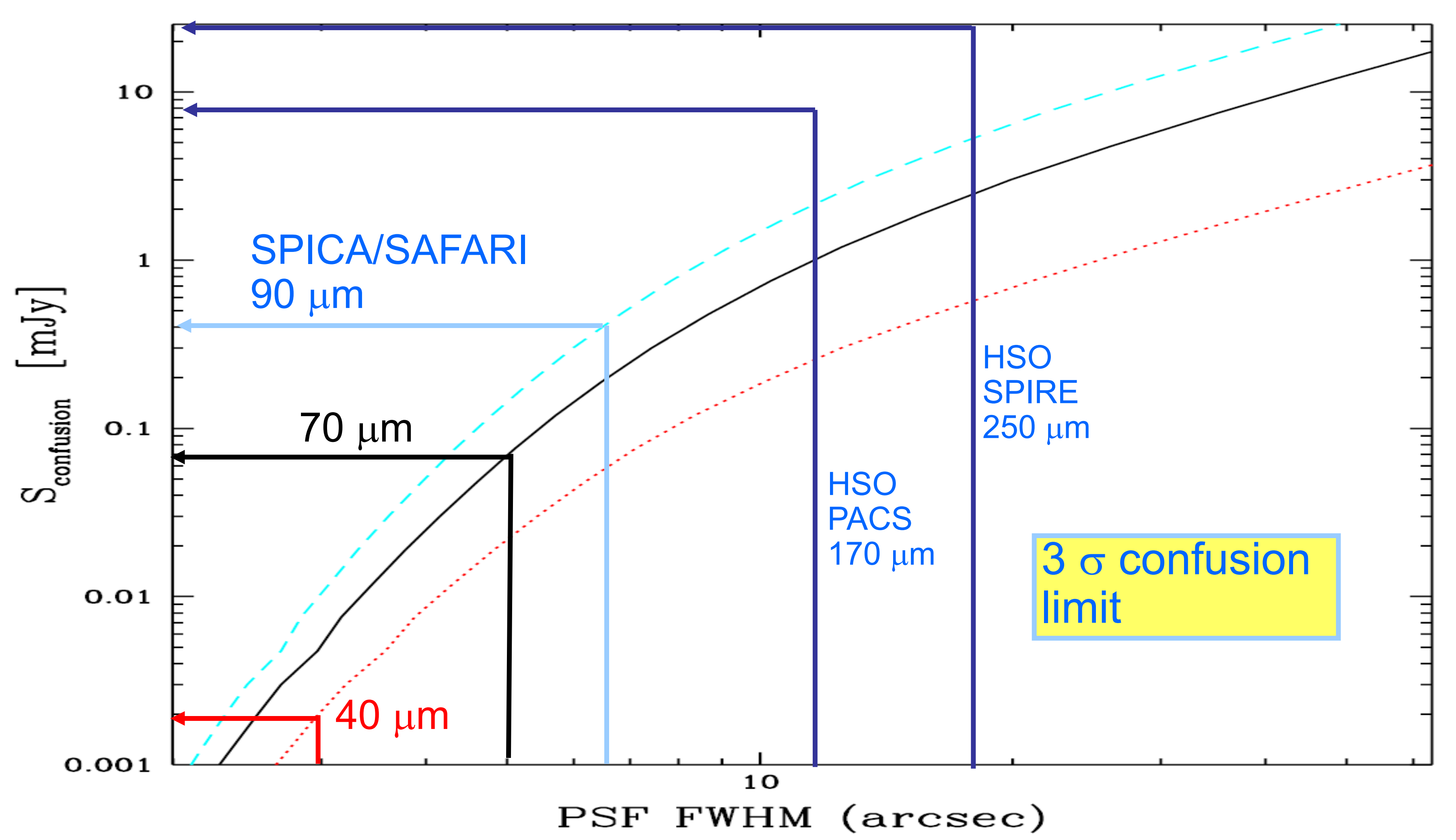
- Deep broad-band surveys => excellent sensitivity (still some limitation by spatial resolution at $\lambda > 100\ \mu m$)

- SPICA has a large ***discovery space*** if we consider that Herschel has essentially been blind at $\lambda < 100\ \mu m$

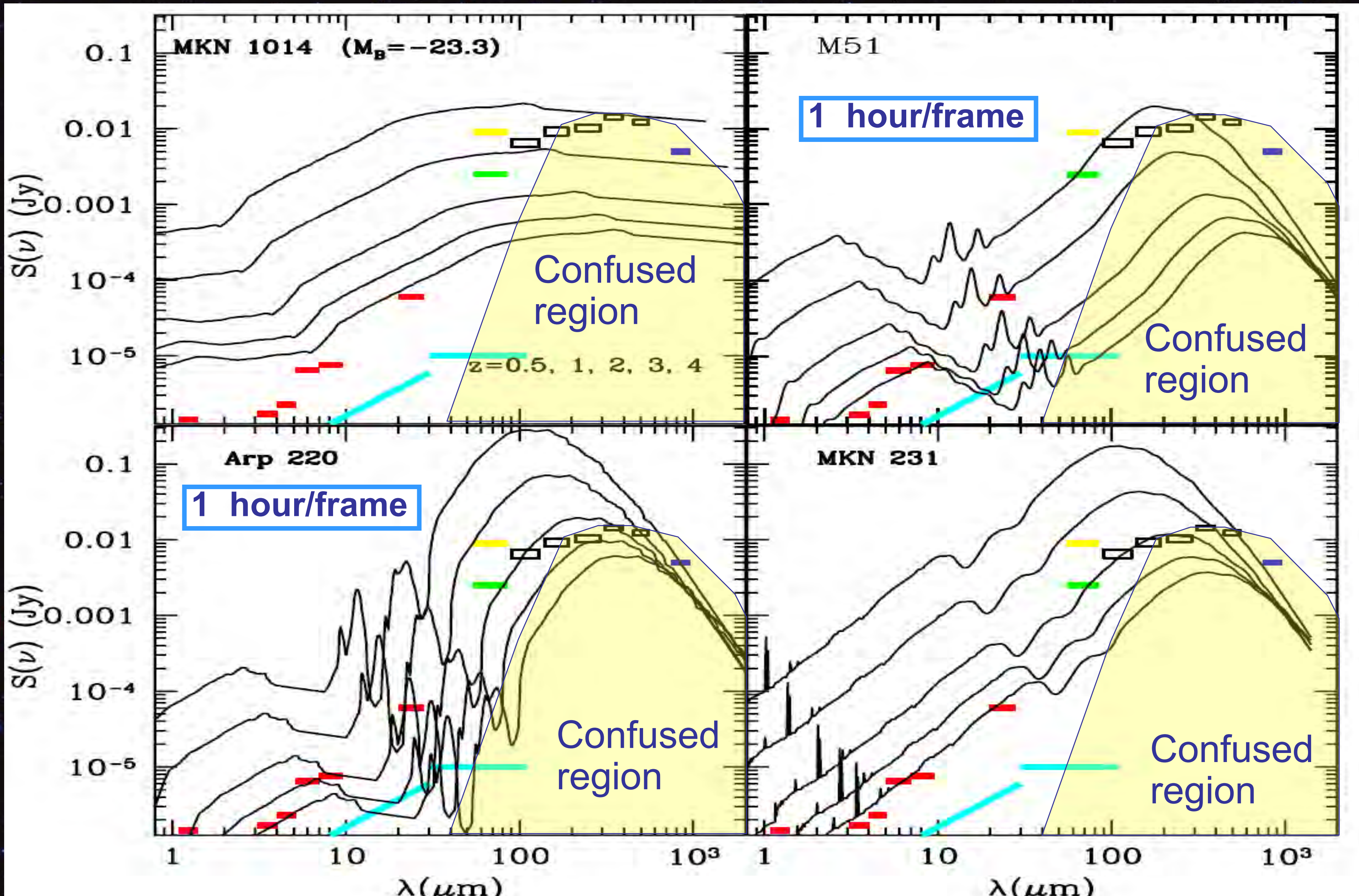
SPICA photometric mode sensitivity



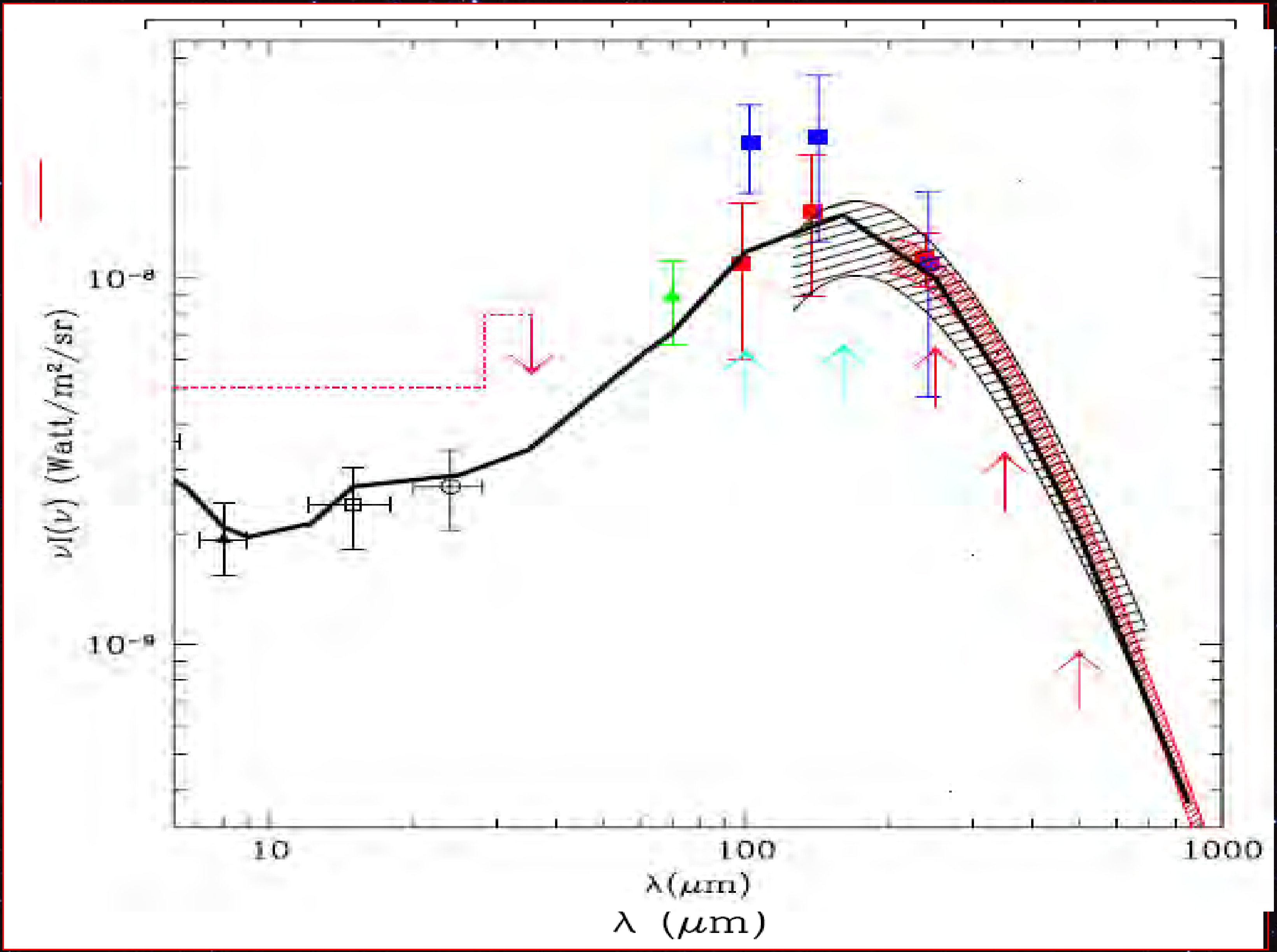
SPICA's SOURCE CONFUSION vs. HSO's: a great improvement! ...



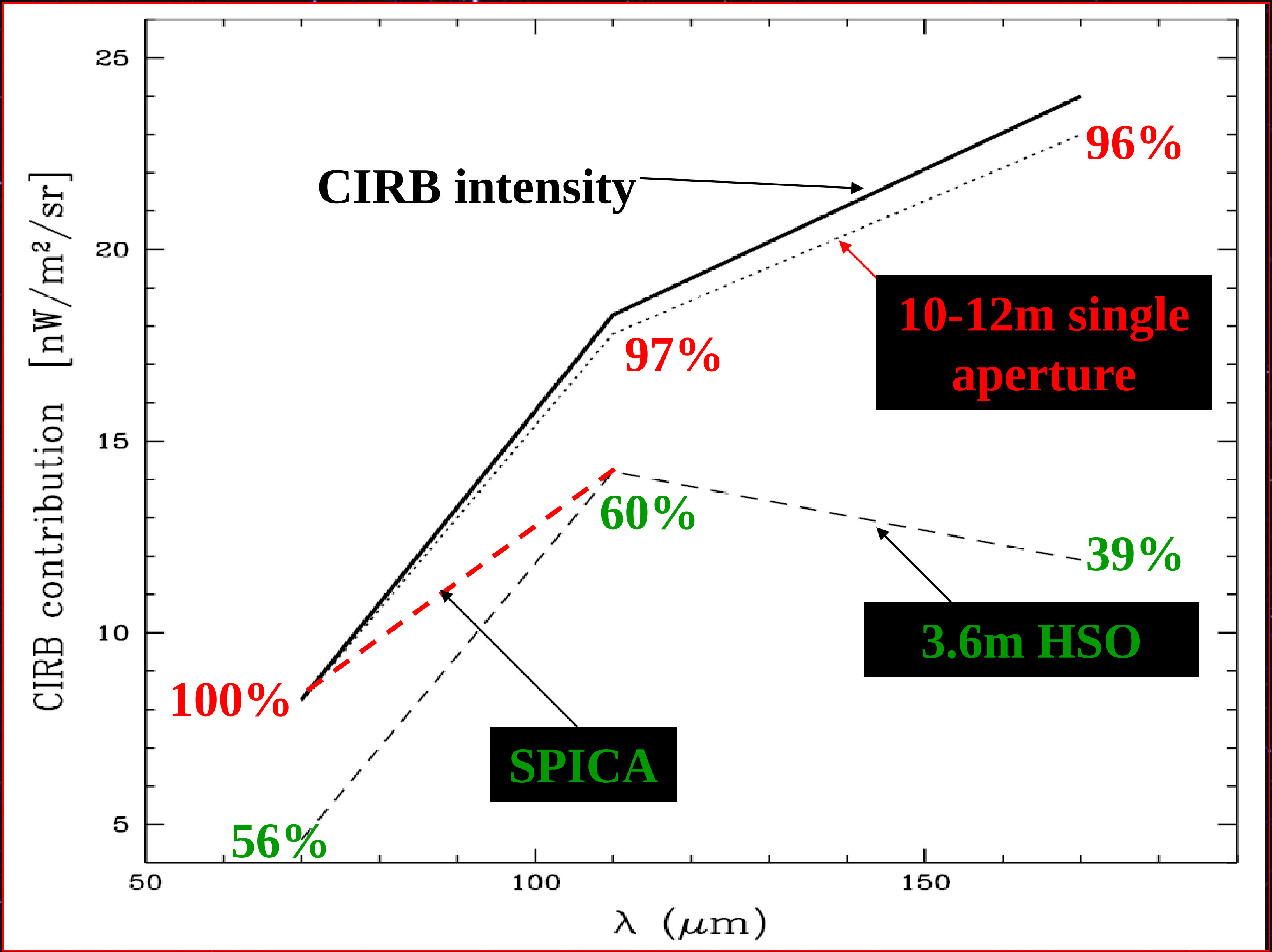
SPICA photometric mode sensitivity



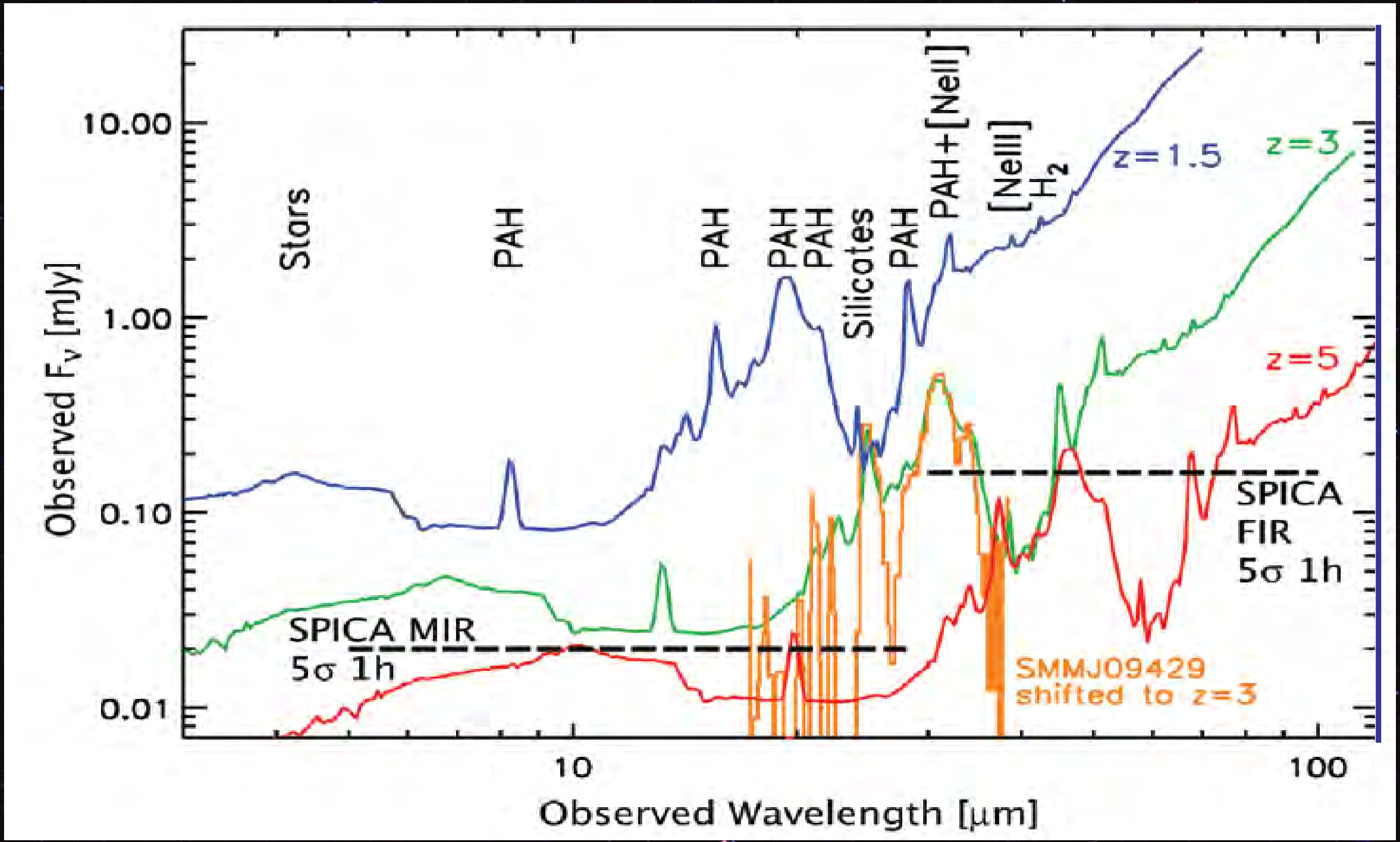
"Resolvable fraction of the CIRB..."



"Resolvable fraction of the CIRB..."

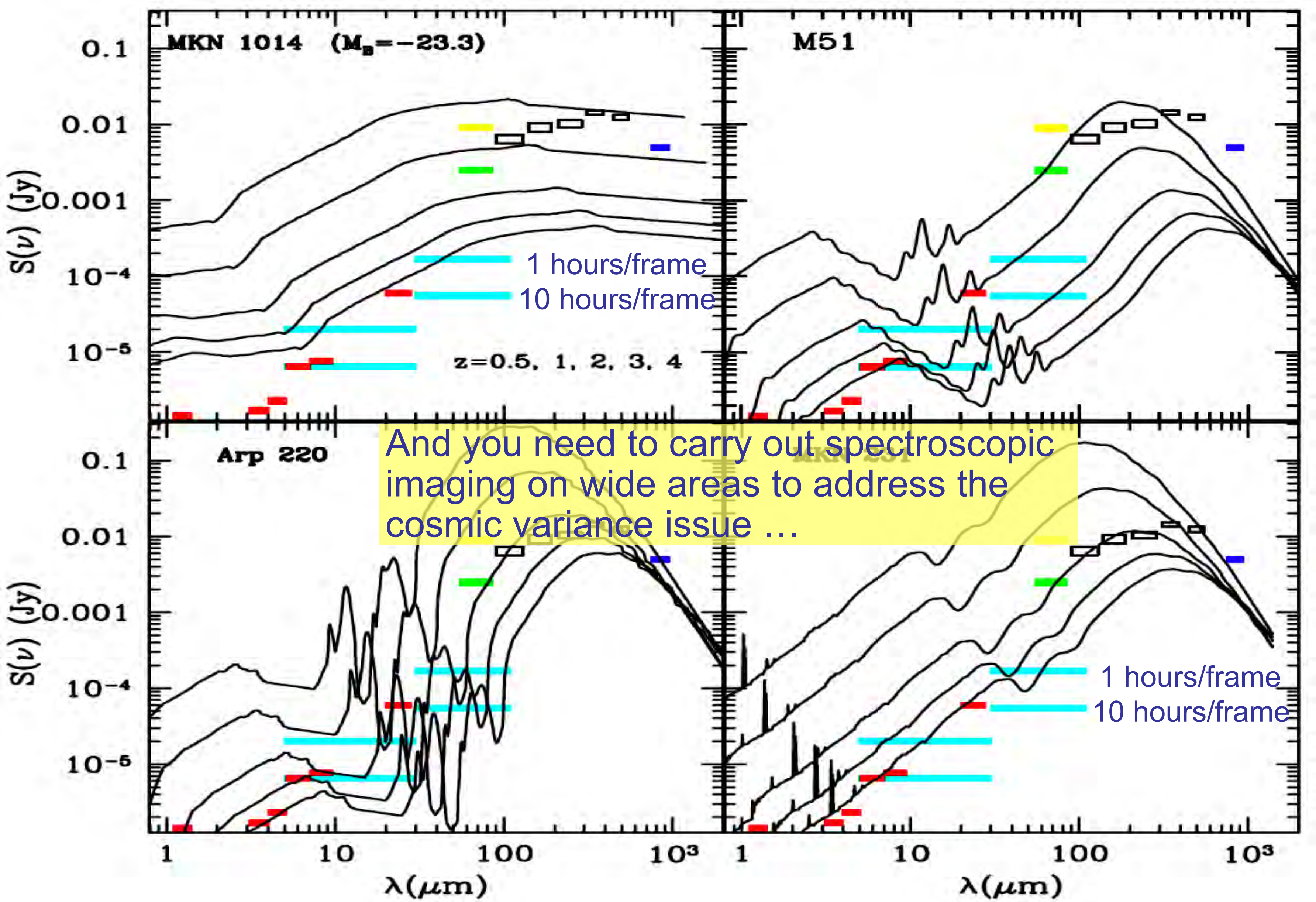


SAFARI low-res spectroscopic imaging mode



SPICA will have the sensitivity in low-resolution mode (R~100) to detect PAH/silicate features in dusty distant galaxies out to z~3 in 1 hour's integration, and out to z>4 in 10 hours

SPICA low-res spec-imaging sensitivity



And you need to carry out spectroscopic imaging on wide areas to address the cosmic variance issue …

Summary

- SPICA definitely appears as a perfect complement to planned instrumentation (JWST, ALMA) for cosmological investigations
- Given the extraordinary sensitivity offered by the cooled instrumentation, SPICA/SAFARI might be the first tool for systematic investigation of the physics of high-redshift dusty cosmic sources through line studies (no extinction)
- Deep multi-wavelength surveys and low-res spectroscopic imaging expected to open a new window for the discovery of sources over wide z-interval and their physical characterization
- All this expected to be essential for uncharting the most elusive phases in the build-up of cosmic structure and the inter-relation of stellar formation and AGN accretion