GALAXY AND AGN EVOLUTION IN THE SPITZER ERA

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Trieste 18 Ottobre 2006

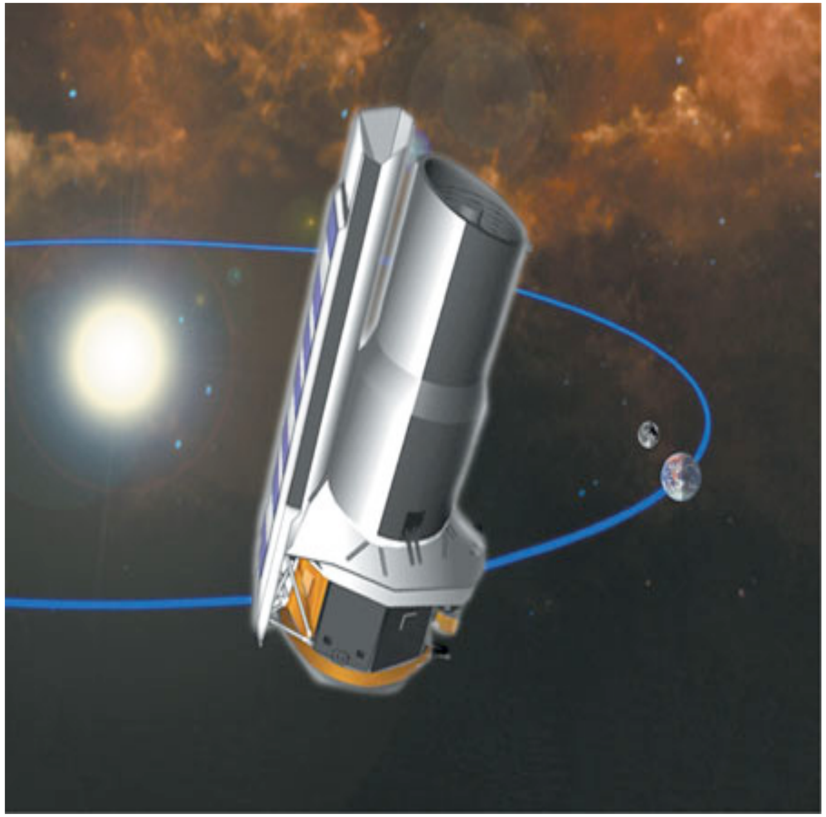
WHY INFRARED?

- Infrared explores the hidden Uiverse (obscured by dust)

- Infrared provides access to many spectral features (emission and absorption bands of molecules)

- Infrared probes the early life of cosmos (early stages optical energy shifted to IR)

About SPITZER



Telescope: 0.85-m

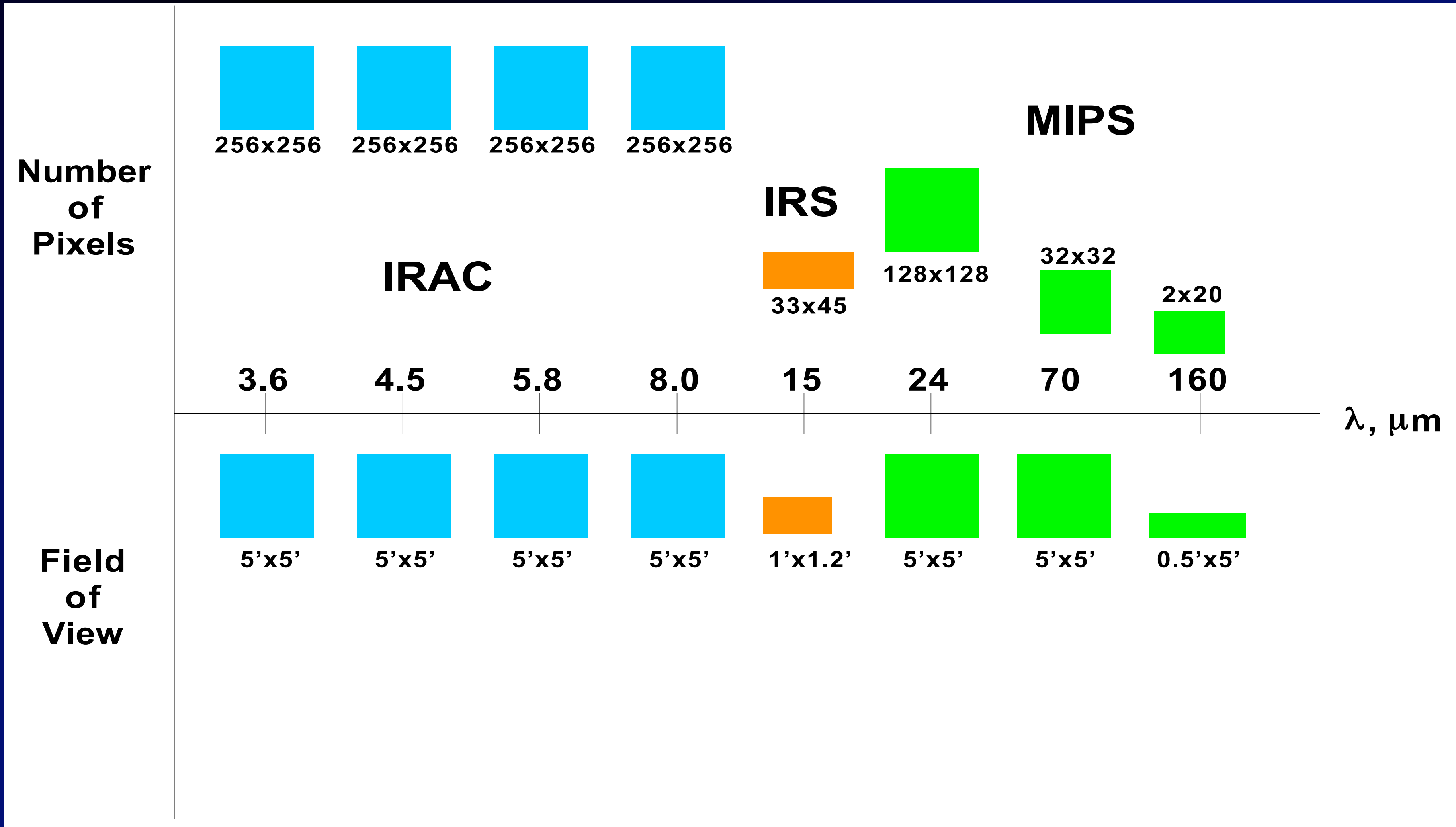
launch: August 2003

Mission: 2.5-5 years

Wavelength: 3 - 180 μm

Capability: Imaging/Photometry 3-180
Spectroscopy 5-40 μm
Spectrophotometry 50-100

SPITZER Measurements - Imaging



Thanks to *IRAS* we know that galaxies forming stars at > 20 $M_\odot$/yr radiate the bulk of their luminosity above 5 μm:

LIGs: $11 \leq \log(L_{IR}/L_\odot) < 12$
ULIGs: $12 \leq \log(L_{IR}/L_\odot) < 13$
HyLIGs: $13 \leq \log(L_{IR}/L_\odot)$

➔Were LIGs/ULIGs more numerous in the past? Are distant LIGs/ULIGs similar to local ones? What do they teach us about star- and galaxy-formation connections?

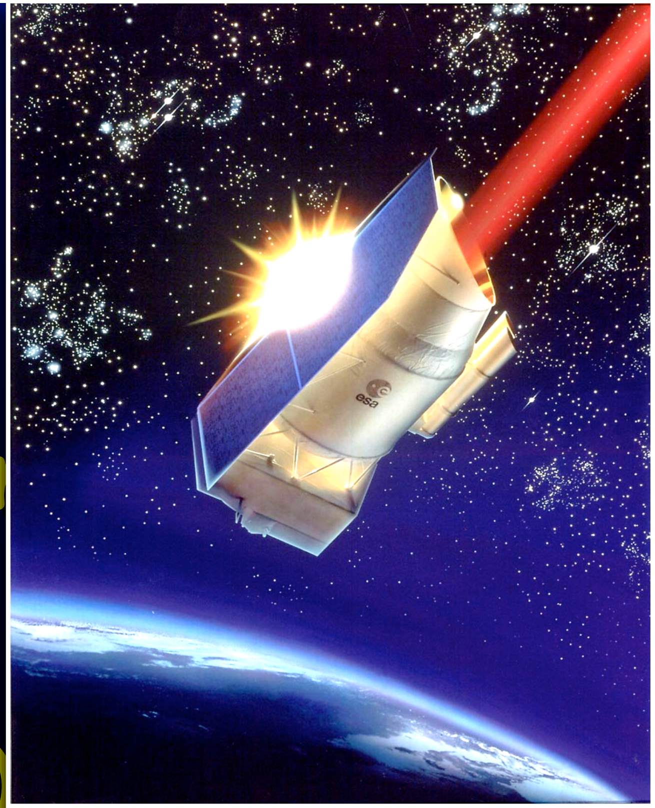
From *IRAS* to *ISO* …

ISO has shown that galaxy formation could not be understood without accounting for dust extinction as a major ingredient.

The *ISO* surveys clearly established that extreme events such as those taking place in local LIGs and ULIGs must have been more common in the past

➡ They can now be considered as a standard phase that most galaxies experienced during their lifetime!

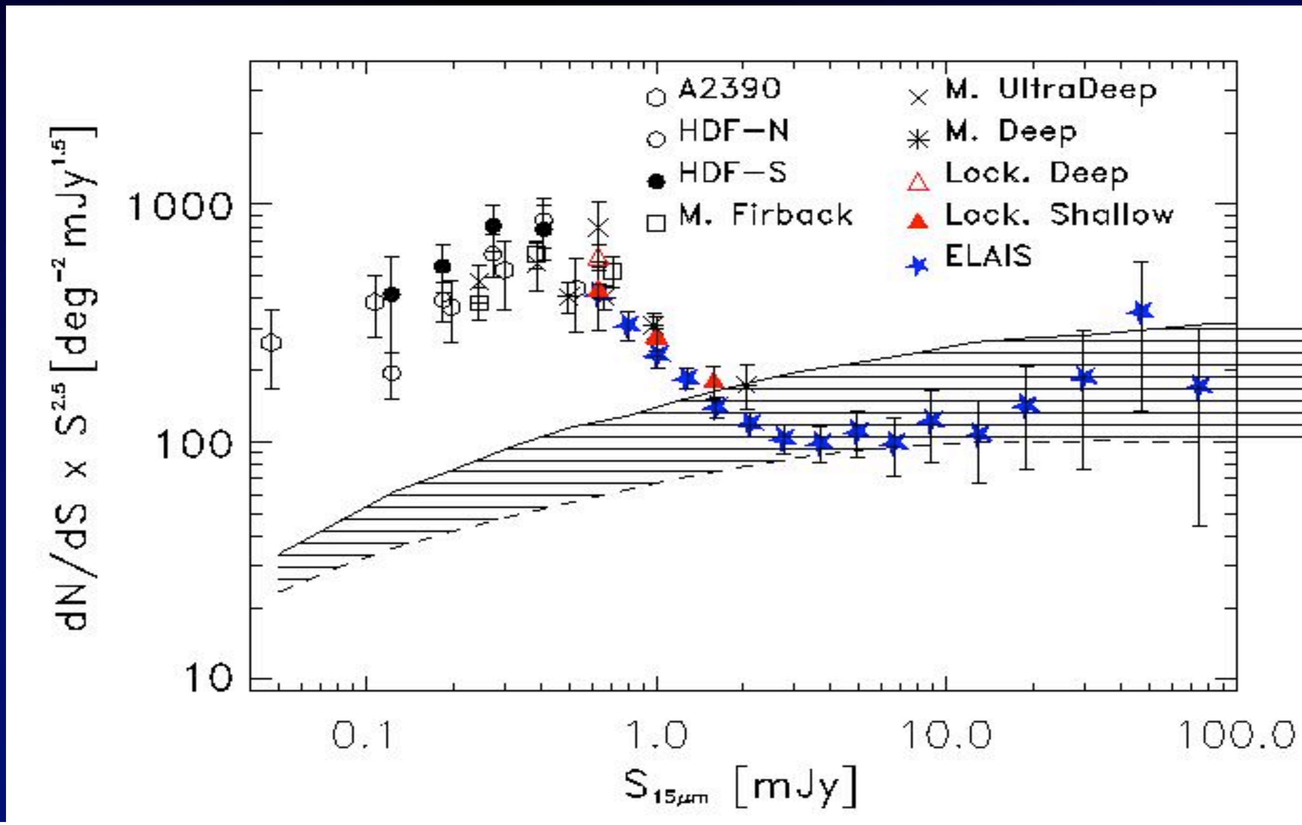
With *ISO* (0.65-m tel.) deep MIR surveys for distant galaxies have been carried out for the first time (especially in the *LW3* ISOCAM filter: 12 - 18 μm).



With > 1000 times better sensitivity than *IRAS*, *ISOCAM* has explored for the first time the Universe at z > 0.5 in the Infrared band

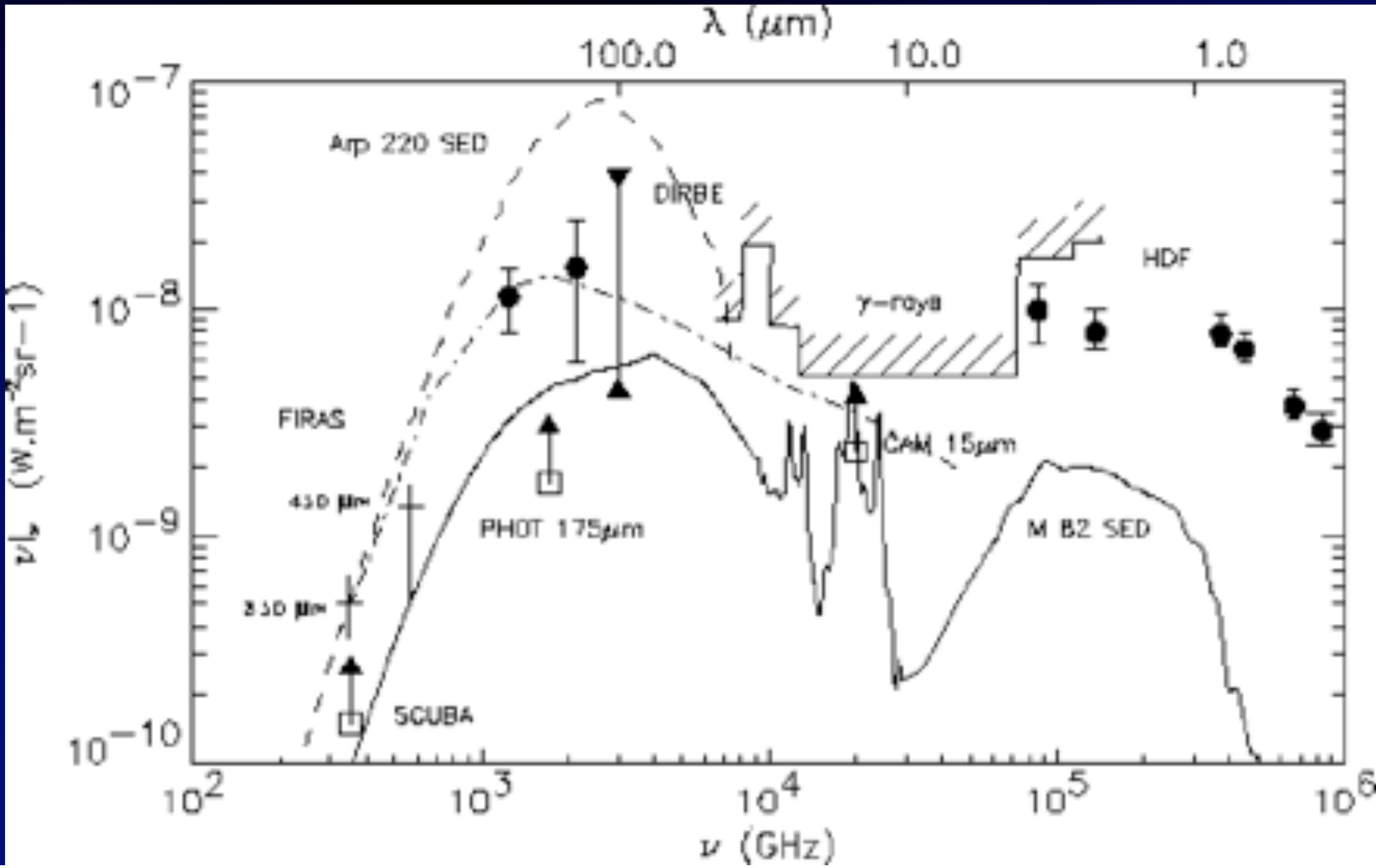
Nearly simultaneous discoveries…

1. from *ISOCAM* surveys:
   excess of faint galaxies in source counts
   ➜ galaxies were more IR luminous or
   more numerous in the past



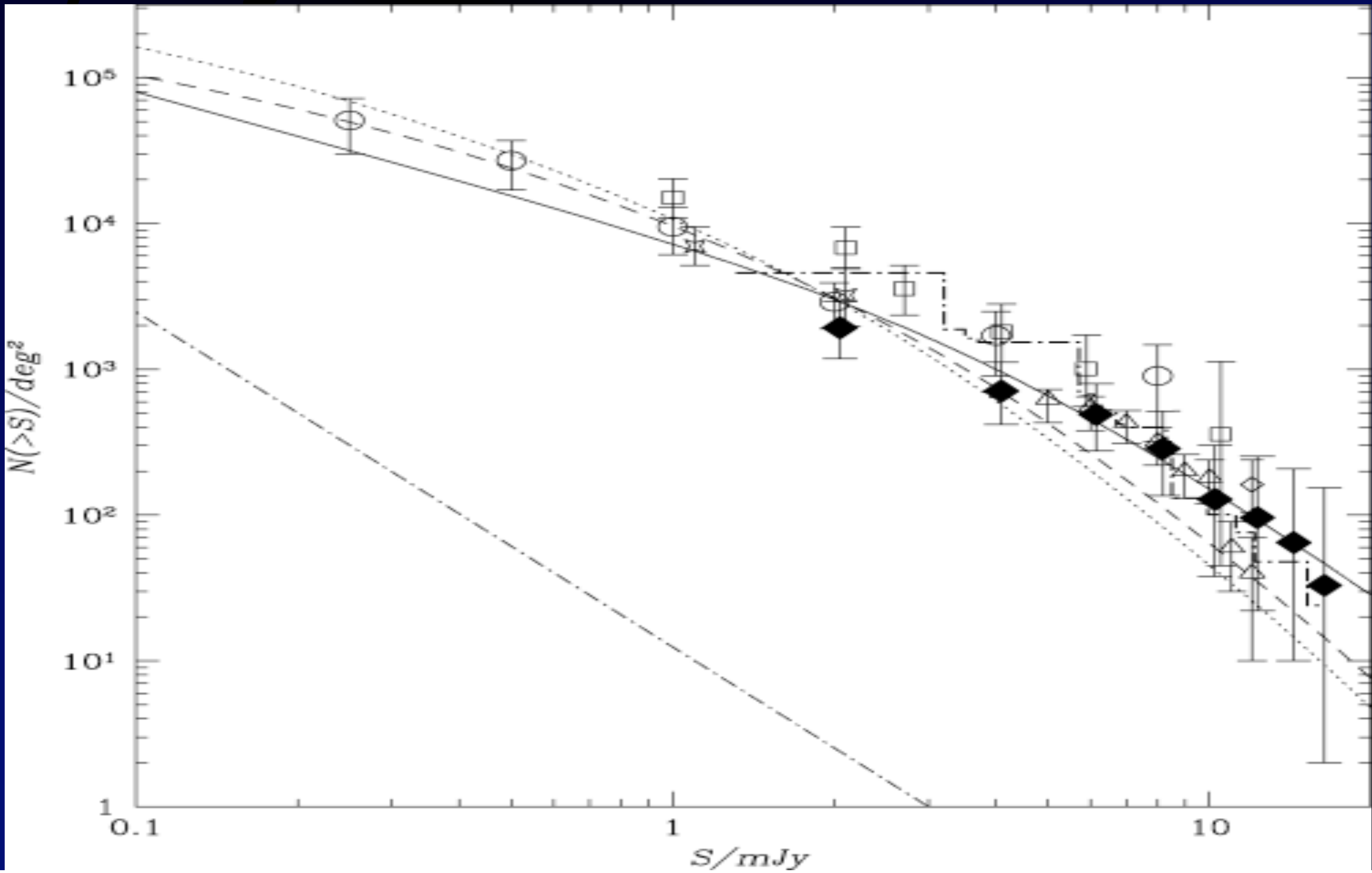
Nearly simultaneous discoveries…

2. Cosmic IR Background (CIB; *Puget et al.96*) at least as strong as UV-optical-NIR one



Nearly simultaneous discoveries…

3. 850-μm SCUBA number counts ➜ excess of faint objects: even at large redshifts very large dust emission!



Nature of ISOCAM galaxies

Most are star-forming galaxies, often showing irregular/merging morphologies.

➜ AGN <15-20% *(Fadda et al. 2002)*

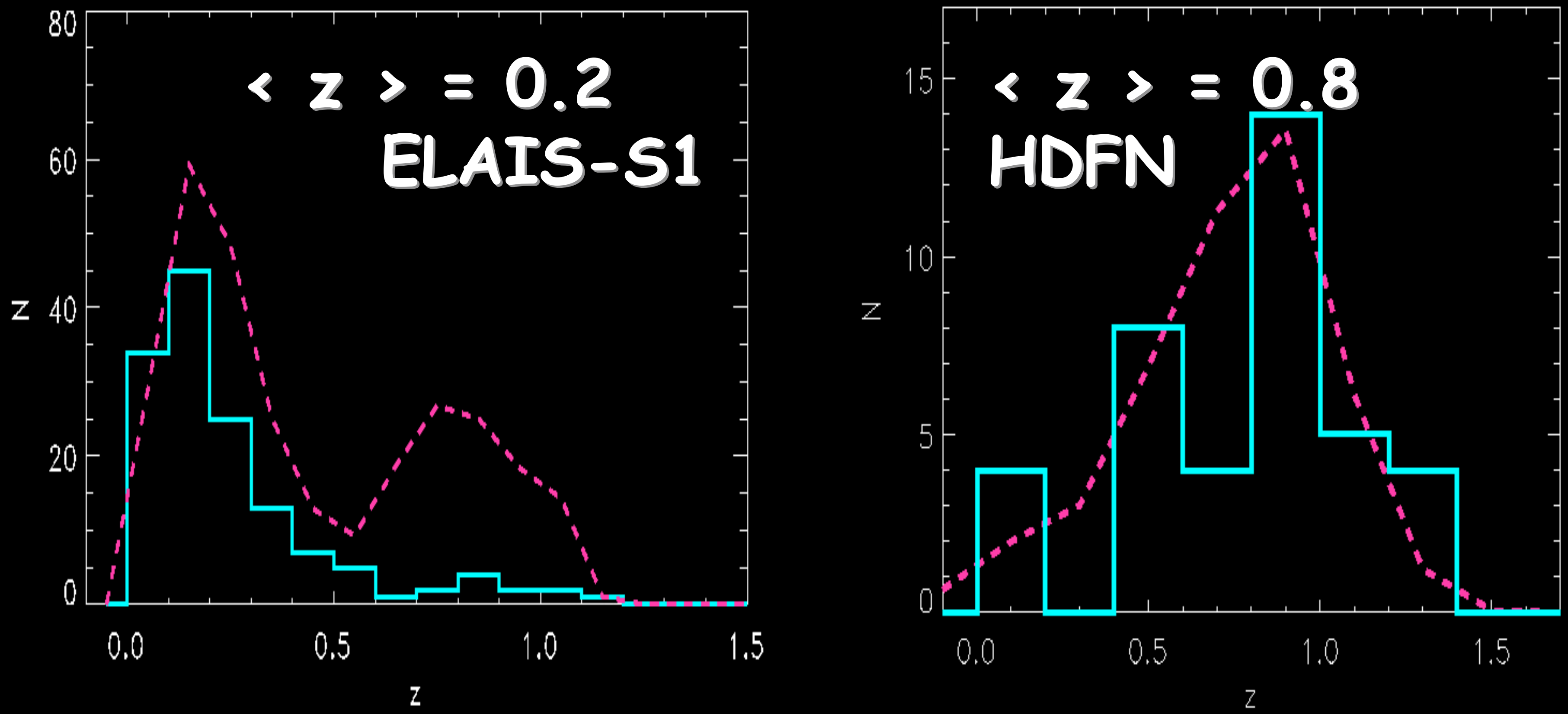
★ from Shallow Surveys (i.e. ELAIS; *La Franca, Gruppioni, Matute et al. '04*) :

$\langle L_{15} \rangle \sim 10^{10}\ L_{\odot}$, $\langle z \rangle \sim 0.2$

★ from Deep Surveys (i.e. IGTES; *Elbaz et al. '99, '01*) : $\langle L_{15} \rangle \sim 10^{11}\ L_{\odot}$, $\langle z \rangle \approx 0.8$

➜ LIG is an important phase in galaxy life: a galaxy might experience several bursts of intense SF

Nature of ISOCAM galaxies



Cosmic Evolution

Several authors have produced backwards evolution models to reproduce source counts and redshift distributions of IR (ISO) galaxies and AGN

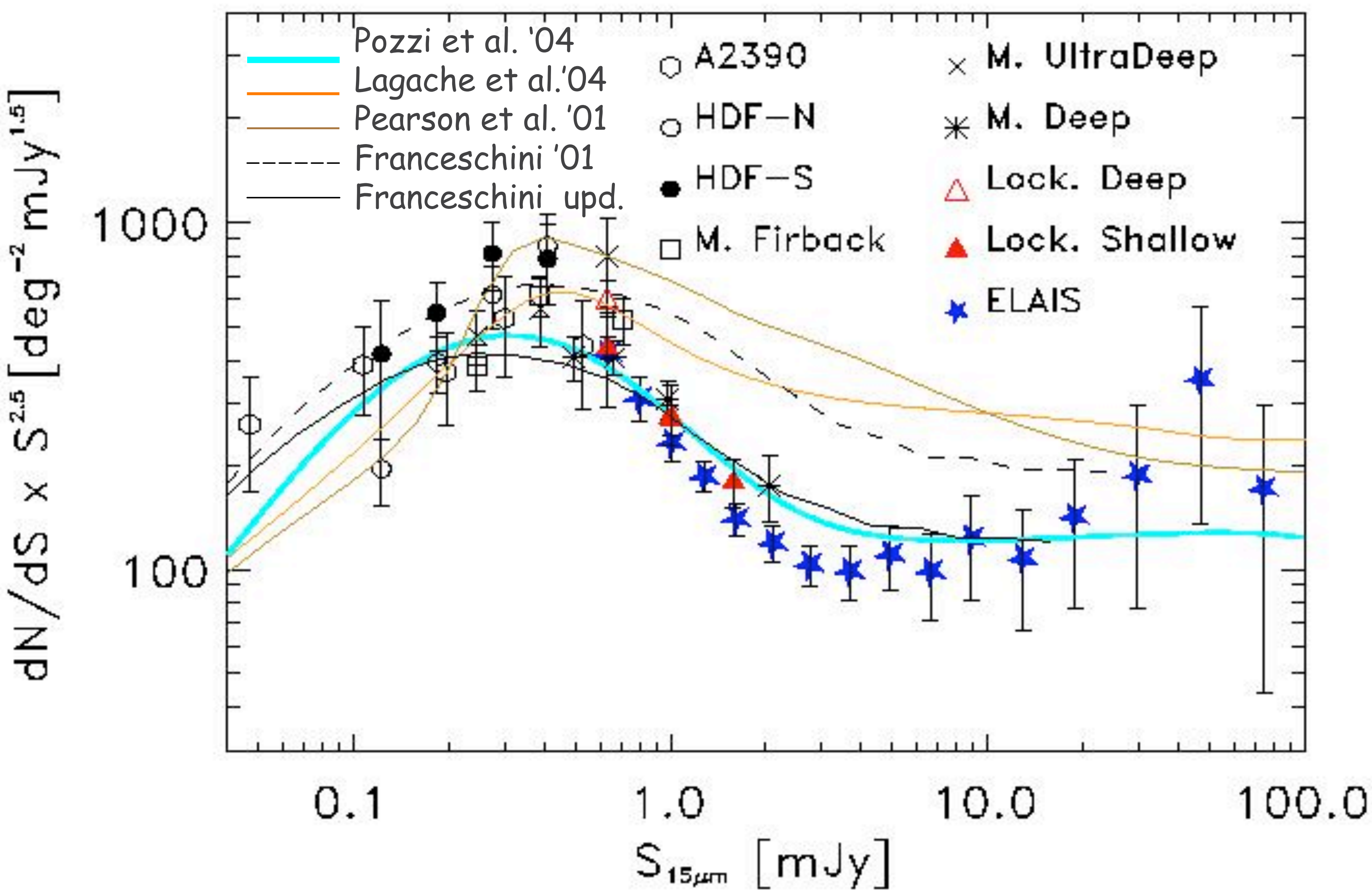
i.e. Devriendt & Guiderdoni '00; Dole et al. '00; Chary & Elbaz '01; Pearson '01, '05; Franceschini et al. '01, '03; Malkan & Stecker '01; Xu et al. '01, '03; King & Rowan-Robinson '03; Lagache, Dole & Puget '03; Pozzi et al. '04; Gruppioni et al. '05

Cosmic Evolution

All use a combination of luminosity and density evolution as a function of z and start from the local 15 or 60 μm LF

The major output of these models was to show that LIGs/ULIGs were much more common in the past than they are today (i.e. *Chary & Elbaz '01*: comoving IR luminosity due to LIGs ~ 70 times larger at z~1 than today)

Cosmic Evolution



GAL Luminosity Function

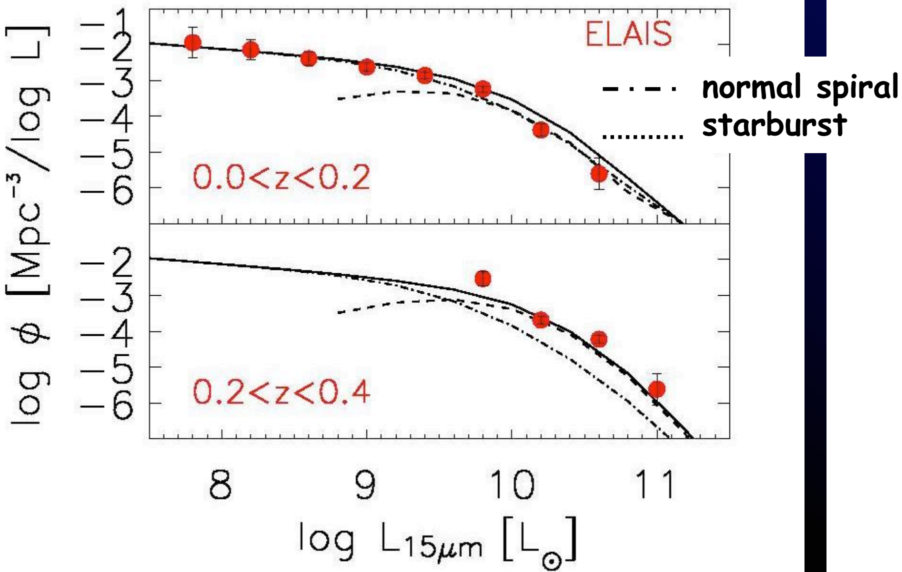
Two galaxy components:

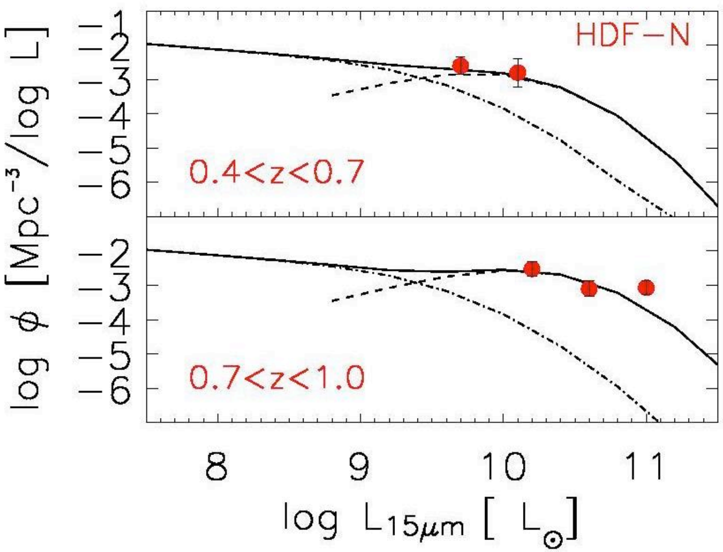
Normal spirals (non-evolving): dot-dashed

Starburst (evolving both in luminosity and density: L(z) ~ L(0)x(1+z)3.5 and r(z) ~ r(0)x(1+z)3.8 up to z=1

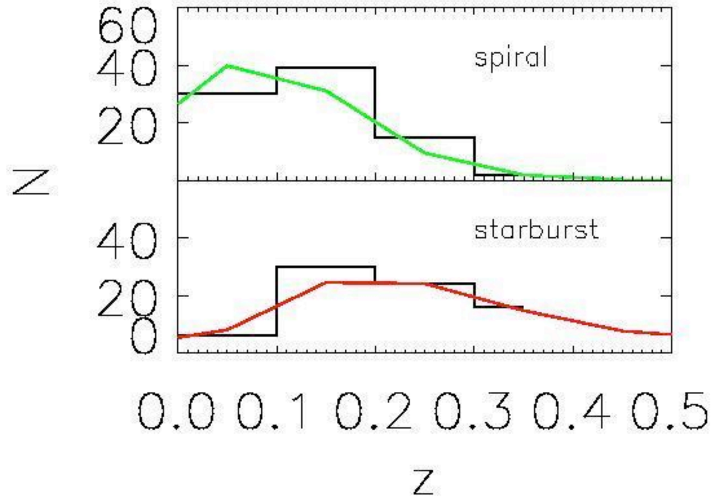
(Pozzi, Gruppioni, Oliver et al. 2004)

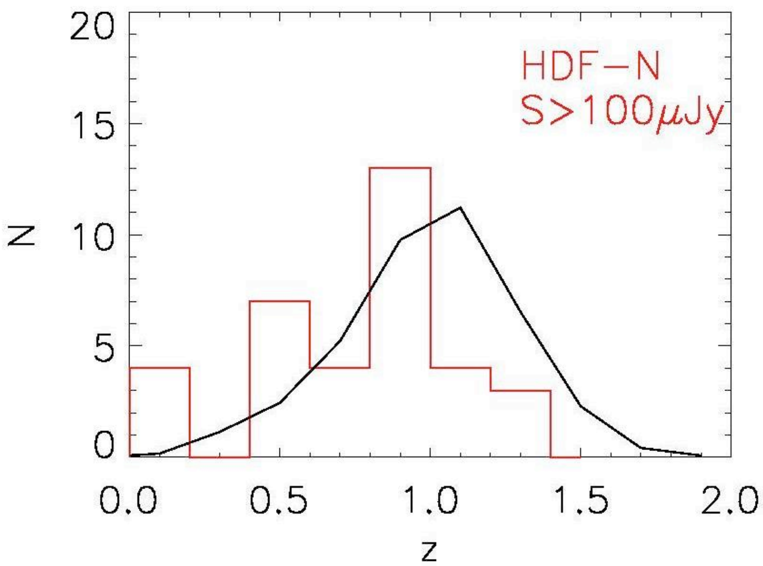
GAL Luminosity Function



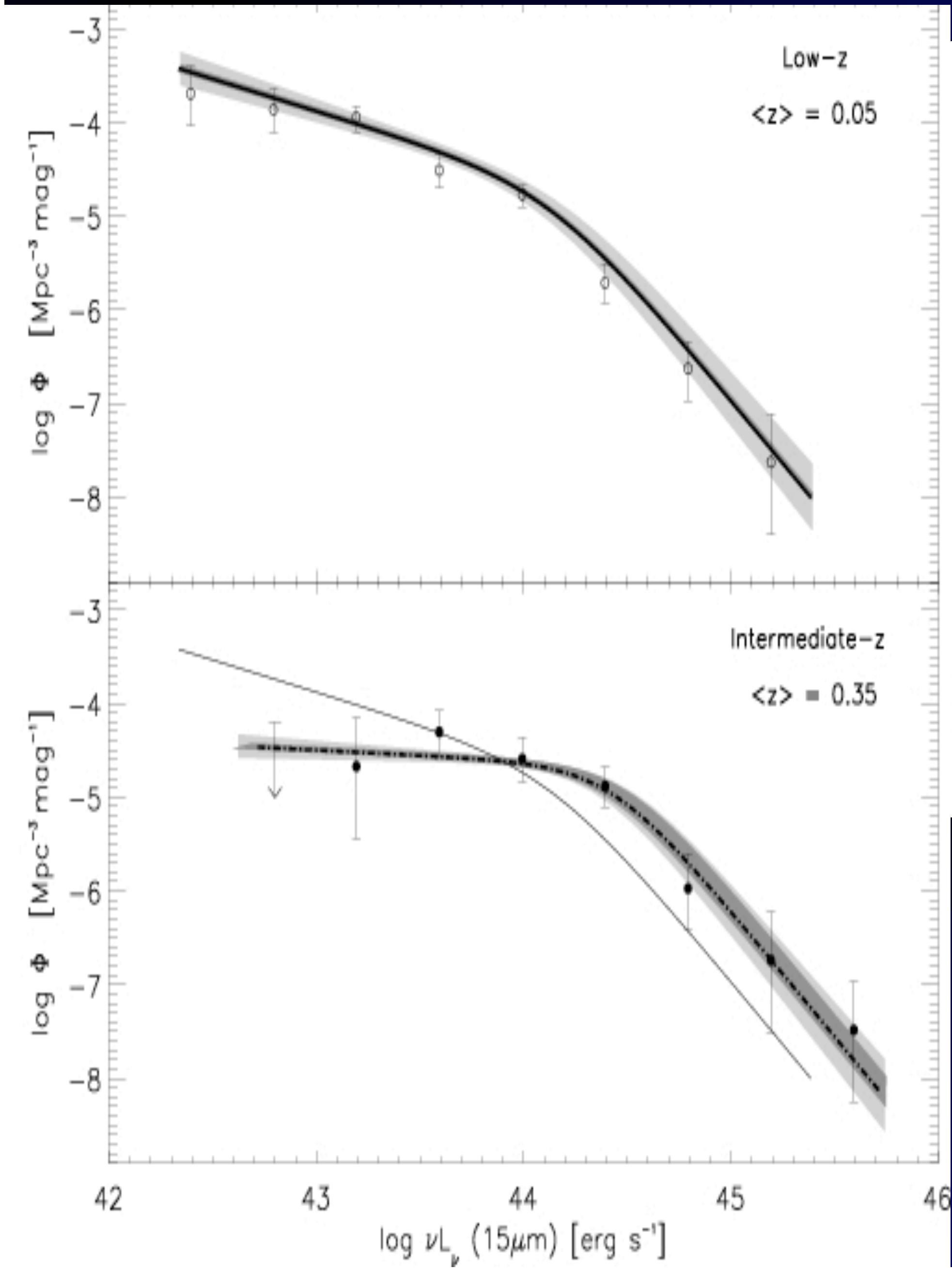


z-distribution

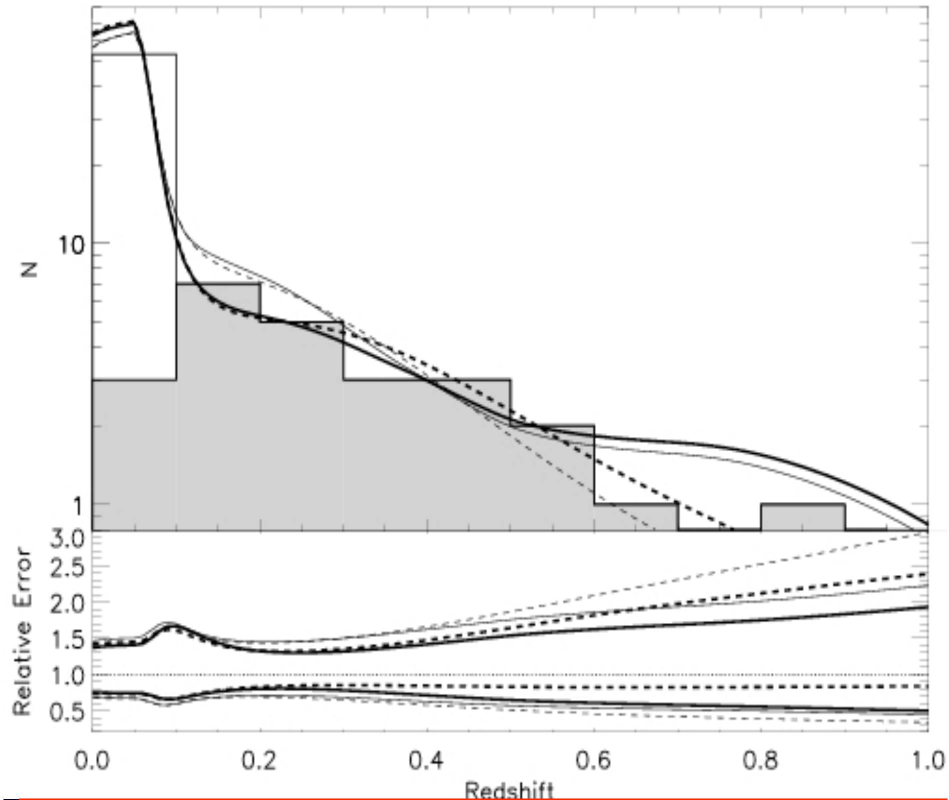




AGN2 Luminosity Function



z-distribution



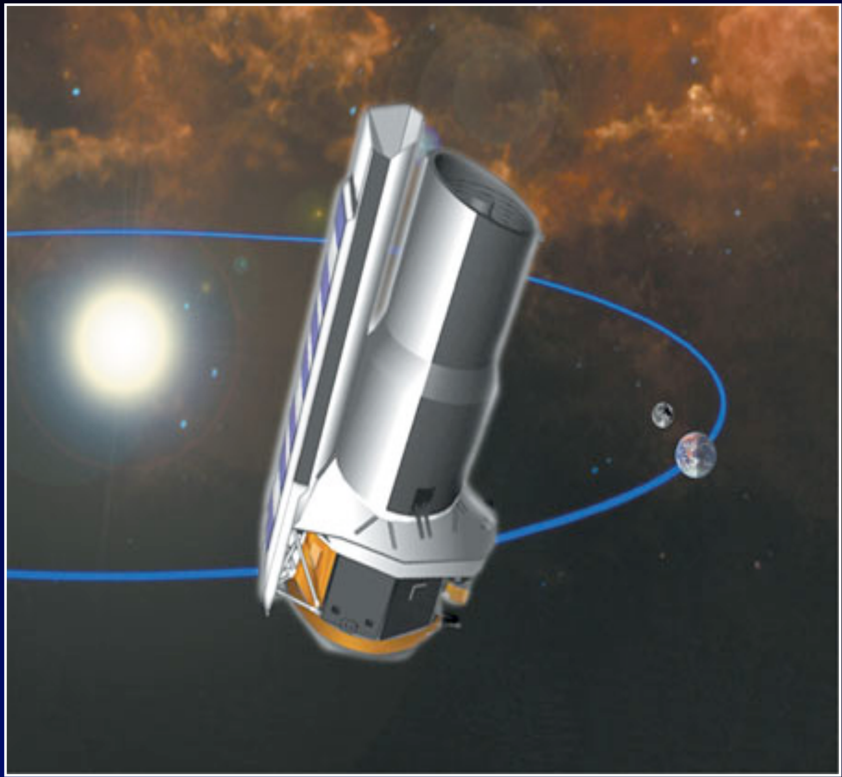
Luminosity Evolution:

$L(z) \sim L(0) \times (1+z)^{2-2.6}$

up to z=2

(Matute et al. 2006)

From *ISOCAM* to *Spitzer* ...

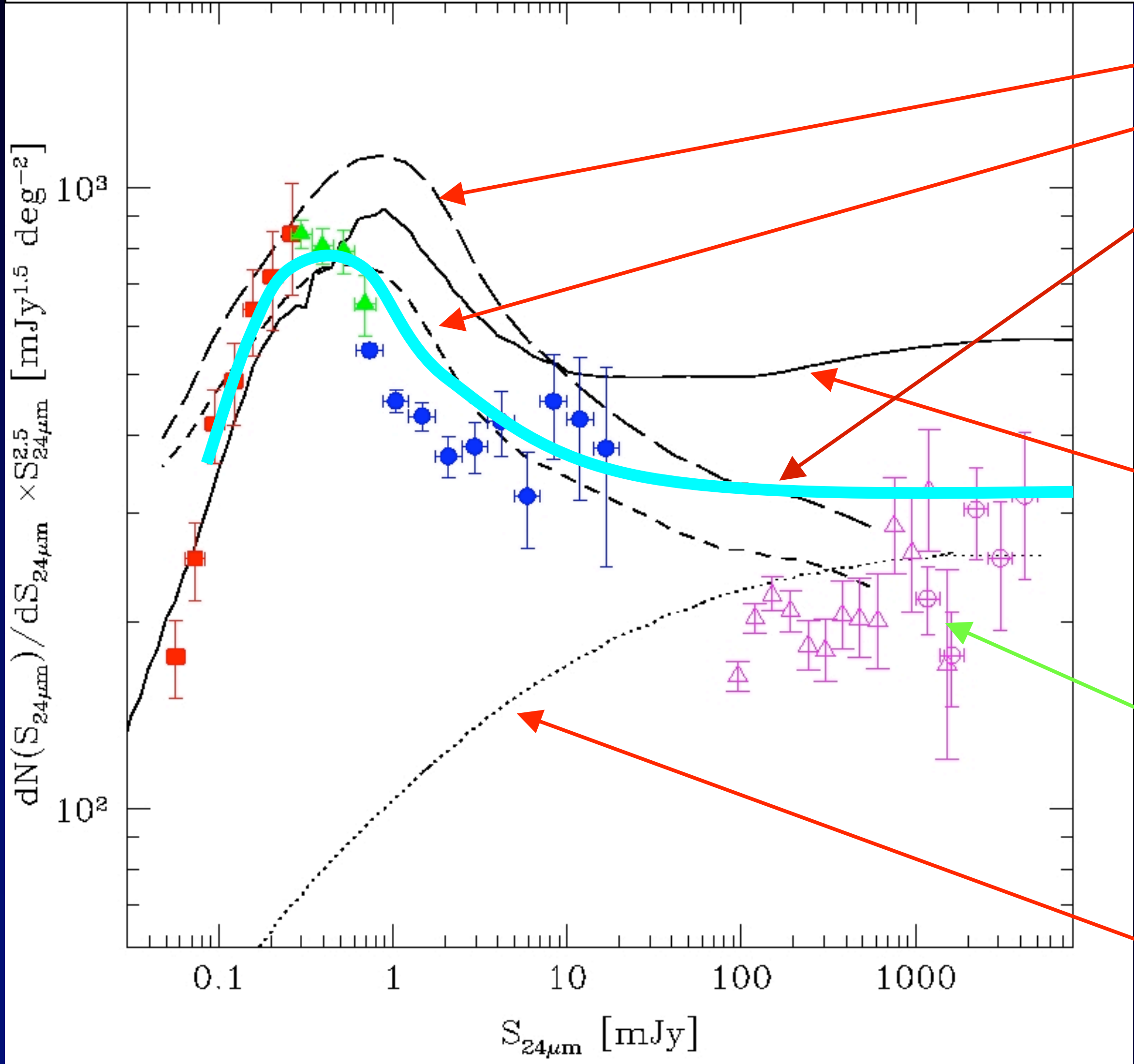


Spitzer Telescope is now providing new insight into the IR population of galaxies and AGN

In particular with the MIPS 24-μm band, which is starting to detect the high-z (z~1.5-3.0) analogs of the 15-μm sources

... What is *SPITZER* finding in terms of galaxy evolution?

FLS 24 μm: Marleau, Fadda, Storrie-Lombardi, et al. 2004



Galaxy evolution models:

Franceschini et al. (2001) & Rodighiero et al. (2004):

Pozzi et al. (2004)
Gruppioni et al. (2005)

non-evolving normal pop, fast-evolving type-II AGNs & starbursts, evolving type-I AGNs

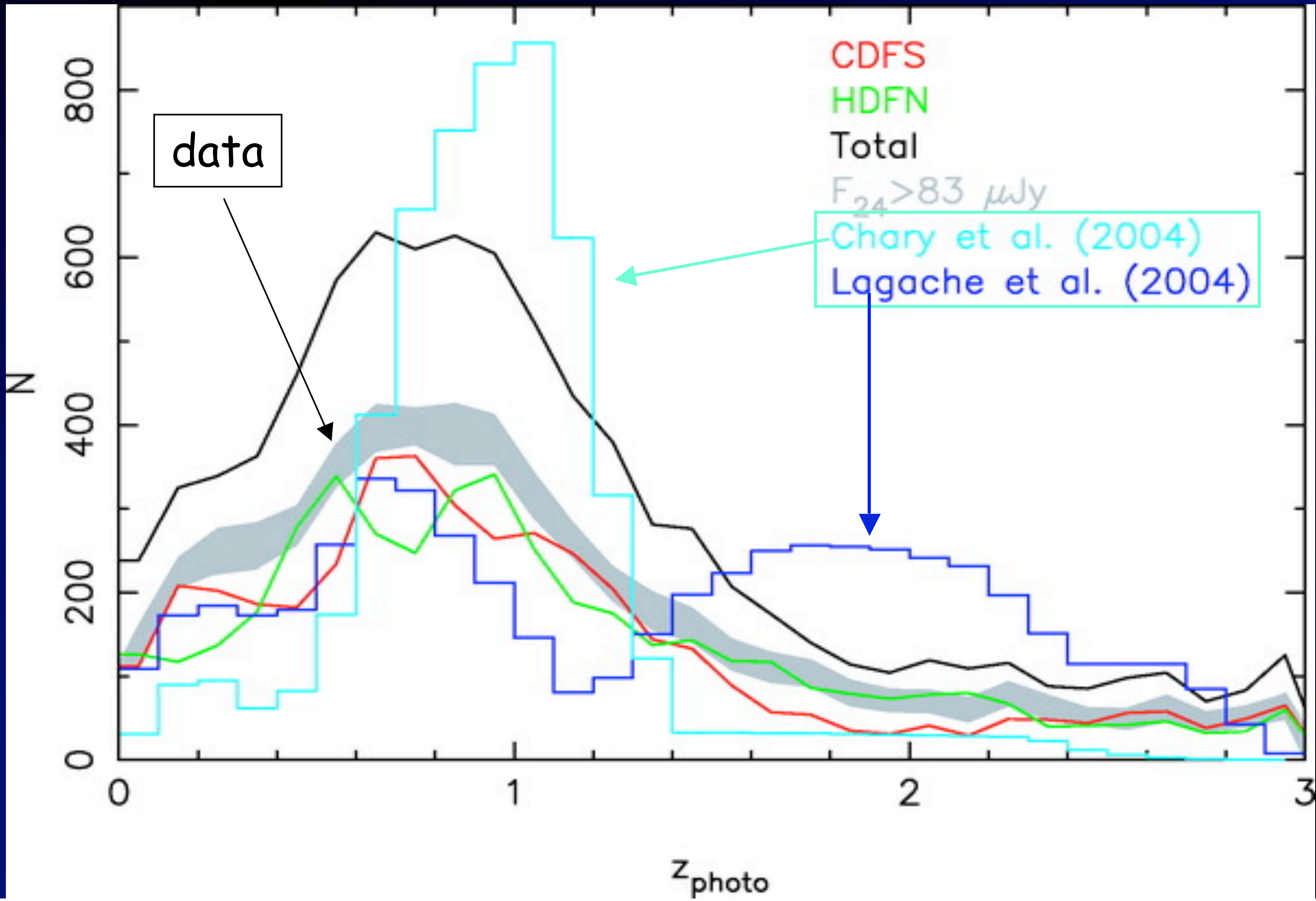
Lagache, Dole & Puget (2003):
non-evolving normal spirals and starbursts with L density evolving with redshift

IRAS data points (transformed to 24 μm) *(Hacking & Soifer 1991; Sanders et al. 2003)*

No-evolution model normalized to IRAS counts

Spitzer view on the evolution of star-forming galaxies from z=0 to z~3

(Perez-Gonzalez et al. 2005; Le Floc'h et al. 2005)



What's wrong with models?

1. Few local Spectral Energy Distributions (SEDs) extrapolated to high z's
2. All models of galaxy evolution in the IR do not consider (or significantly underestimate) the AGN contribution
(i.e. No AGN: Chary & Elbaz '01; Lagache et al. '03, '04)

⬇

How can we distinguish galaxies from AGN? Can *Spitzer* help?
… it helps a lot with SEDs!!!

Does IR Reveal Hidden AGN Activity?

(see Houck et al. 2004; 2005; Higdon et al. 2004; etc…)

★ Obscured AGN are needed:

- to reproduce the X-ray background peak *(Setti & Woltjer 1989, Comastri et al. 1995 etc.)*
- Unified Models: dusty torus around AGN responsible for absorption of X-ray to NIR nuclear radiation
- models predict that AGN activity in the past take place in "dusty" environments/systems

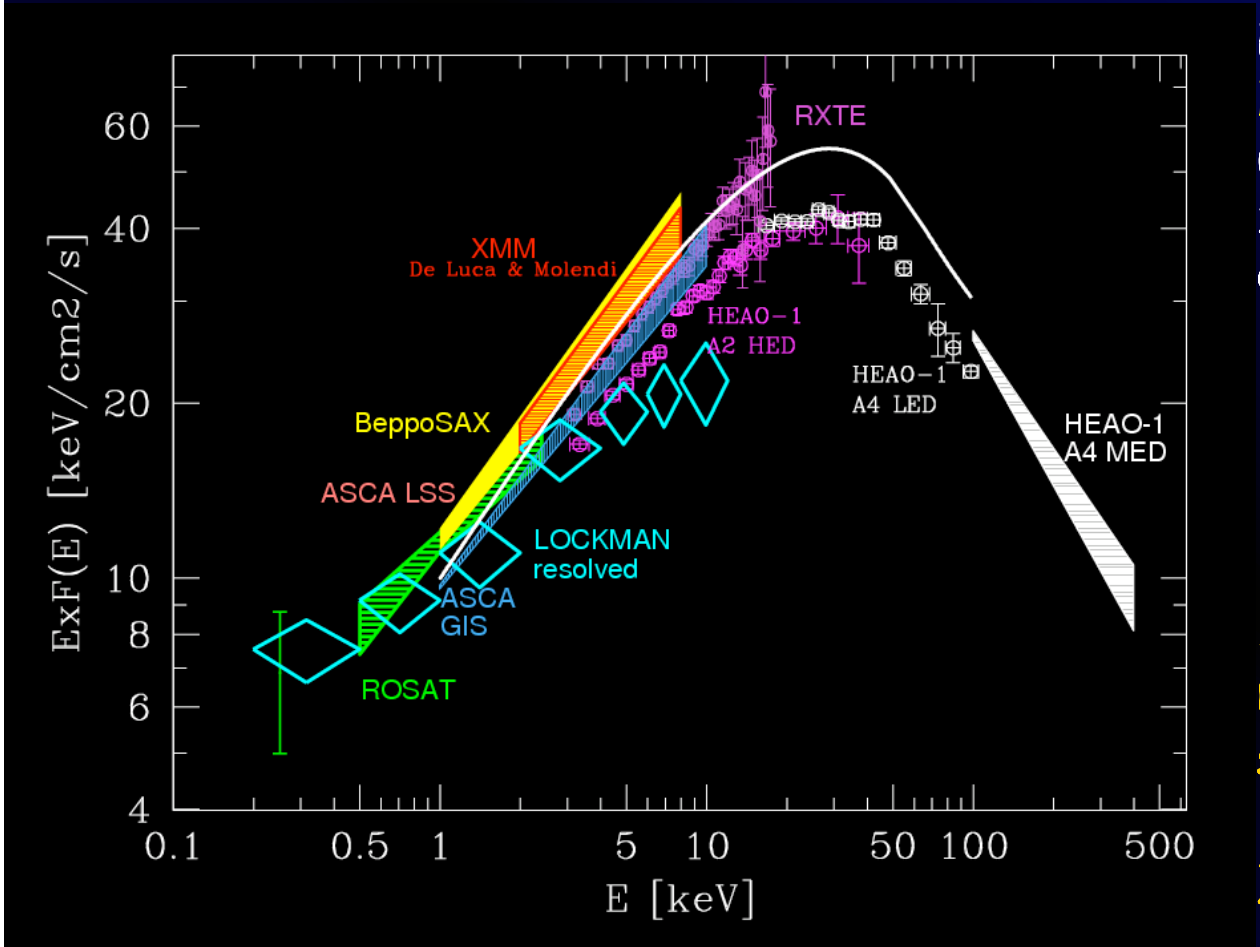
★ Need to separate AGN from stellar activity to:

- Have a complete picture of galaxy(-AGN) formation and (co)evolution, since

➡ Luminous Infrared Galaxies (LIGs) represent an active phase of star-formation and/or AGN activity and dominate the luminosity density at z>1

Selection of obscured AGN

➡ **Most efficient way: Hard X-ray surveys**



Examples:
high X/O sources
(moderate obscured AGN at z~1-2 hosted in massive ellipticals)

Fiore et al. 2003, A&A
Mignoli et al. 2004, A&A
Mainieri et al. 2005, A&A
Maiolino et al. 2006, A&A

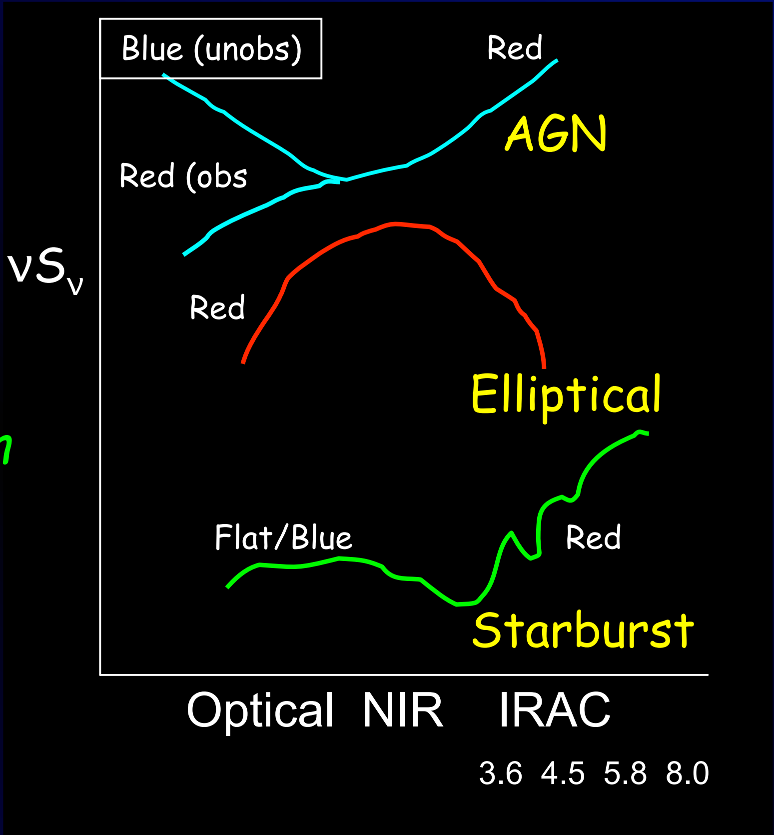
BUT:
hard X-ray surveys still miss the highly obscured sources (i.e. ***Compton thick***): don't sample the XRB peak

Missing population: (numerous) moderately luminous, NH>23, z=0.5-2 AGN *(Worsley et al.)*

Complementary approach: IR colour selection

AGN (unobs and obs) are expected to have **warm power-law SEDs** at **>1 μm** (≠ from elliptical/starburst)

AGN (both type 1 and 2) can be isolated in NIR/MIR diagrams



SEVERAL IR colour-selection criteria proposed so far *(i.e. Lacy et al. 2005; Stern et al. 2005; Barmby et al. 2006, etc.)*

➡ PROBLEMS:

Completeness (are all AGN selected?)

Reliability (are only AGN selected? How much galaxy "contamination"?)

NEED Complete Multiwavelength Characterization

What should be done?

➔ Find reliable way to select AGN and disentangle from pure stellar activity

➔ Use all the available multi-λ informations for complete samples of sources (i.e. optical spectroscopy + broad-band SEDs + X-ray properties)

⬇

I will show 3 different studies: hidden activity from multi-λ analysis of morphologically/X-ray/IR selected sources

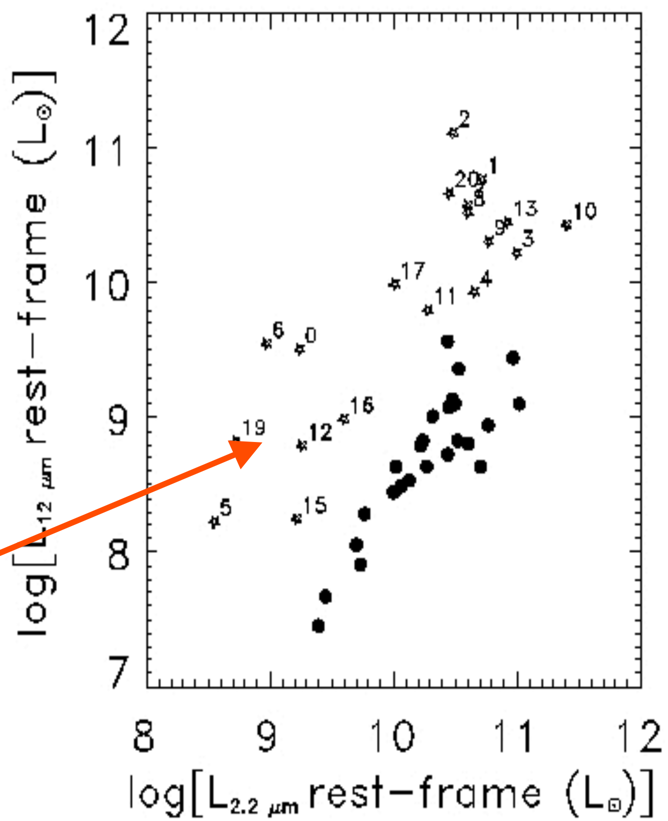
1. Hidden Activity in High-z Spheroidal Galaxies from MIR and X-ray Observations in the GOODS-N Field

(Rodighiero, Gruppioni, Civano et al. 2006, MNRAS, submitted)

168 morphologically classified *(Bundy et al. 2005)* spheroidal galaxies in the GOODS-N field:

19 with (unexpected) 24 μm detection (12 also detected in X-rays)

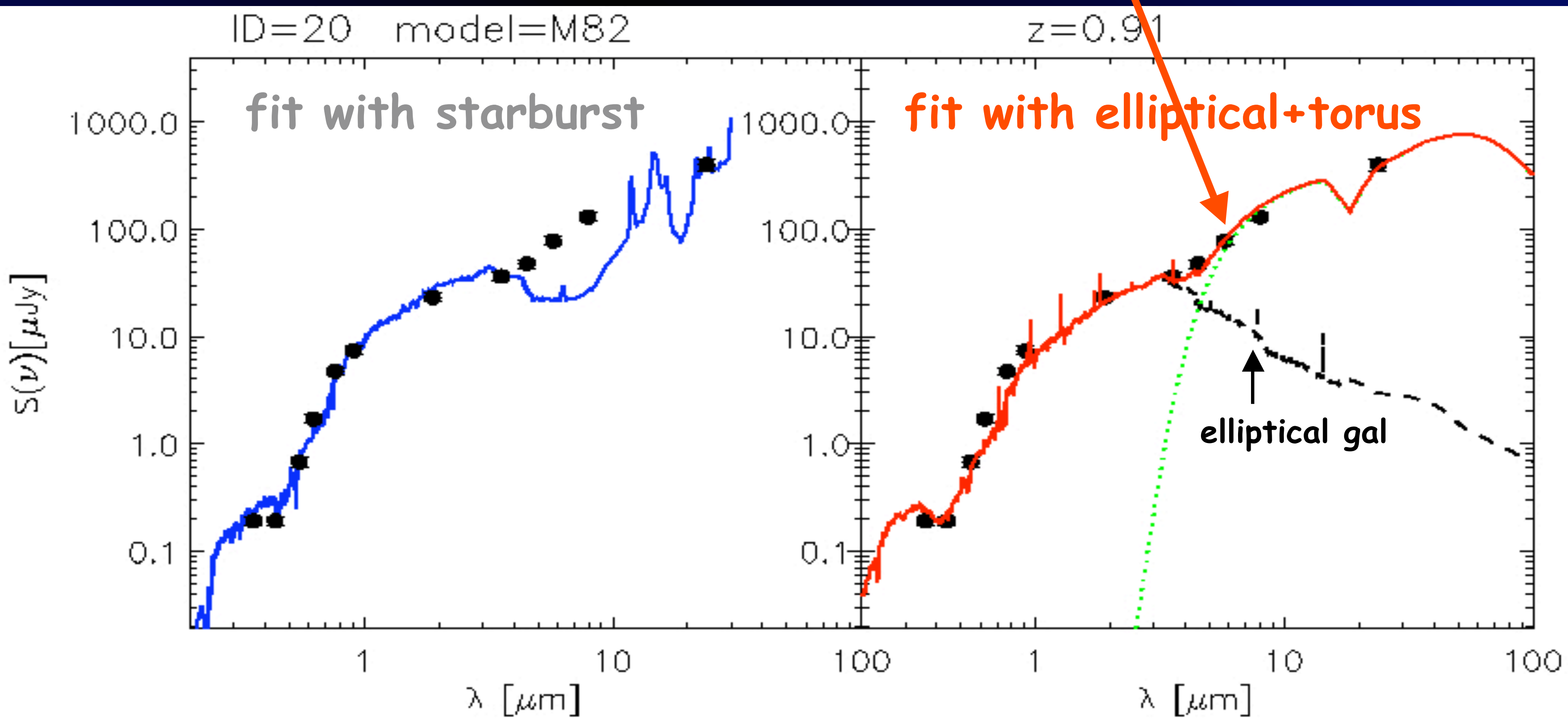
MIR to NIR luminosity ratios in our objects (<z> ≈ 0.7) ~10x higher than in local early-types detected by IRAS (Knapp et al. 1992)



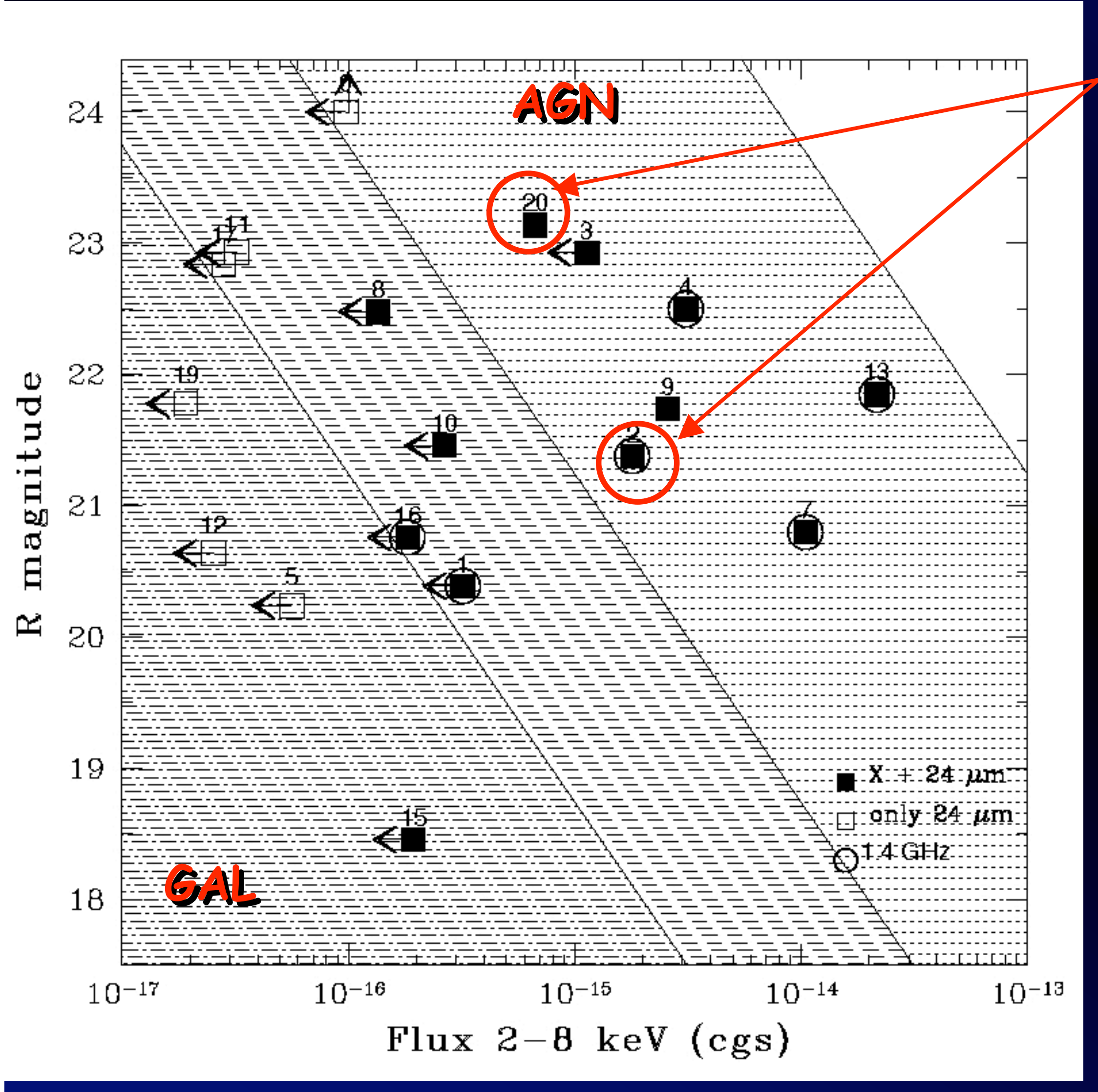
→ No mass loss from evolved giant stars dominating MIR

➜ Broad-band SEDs: MIR in excess with respect to expectations for elliptical galaxies

In most cases: SED well fitted by evolved stellar pop (reproducing opt/NIR) + dusty torus heated by AGN (reproducing MIR/FIR) *(Fritz et al. 2006)*



X-ray properties of MIR spheroids



2 COMPTON THICK AGN
(strong iron line)

7 objects have enough counts for X-ray spec: luminous AGN (high L_X)

X-ray/optical/IR properties of high-z spheroids

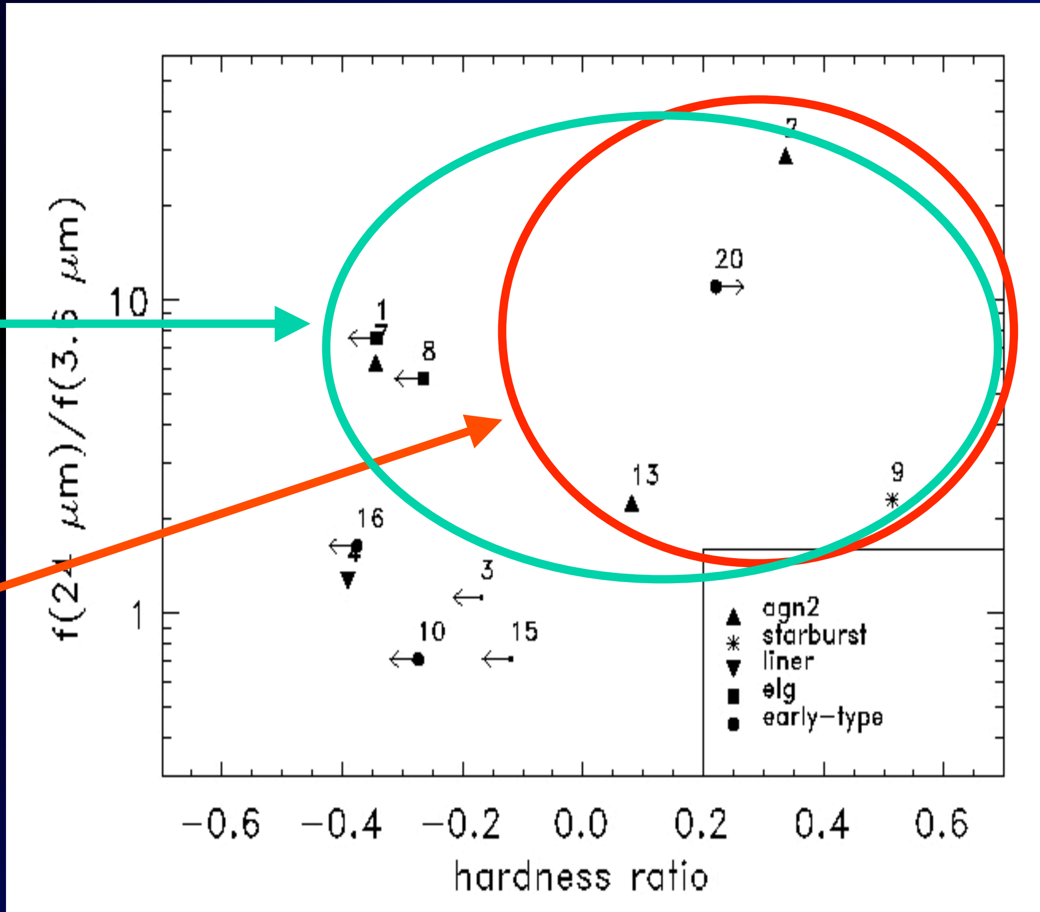
from spectroscopy:
emission lines in most optical spectra

Higher activity (either AGN or star-formation)

higher f24/f3.6

AGN activity

Higher hardness ratio



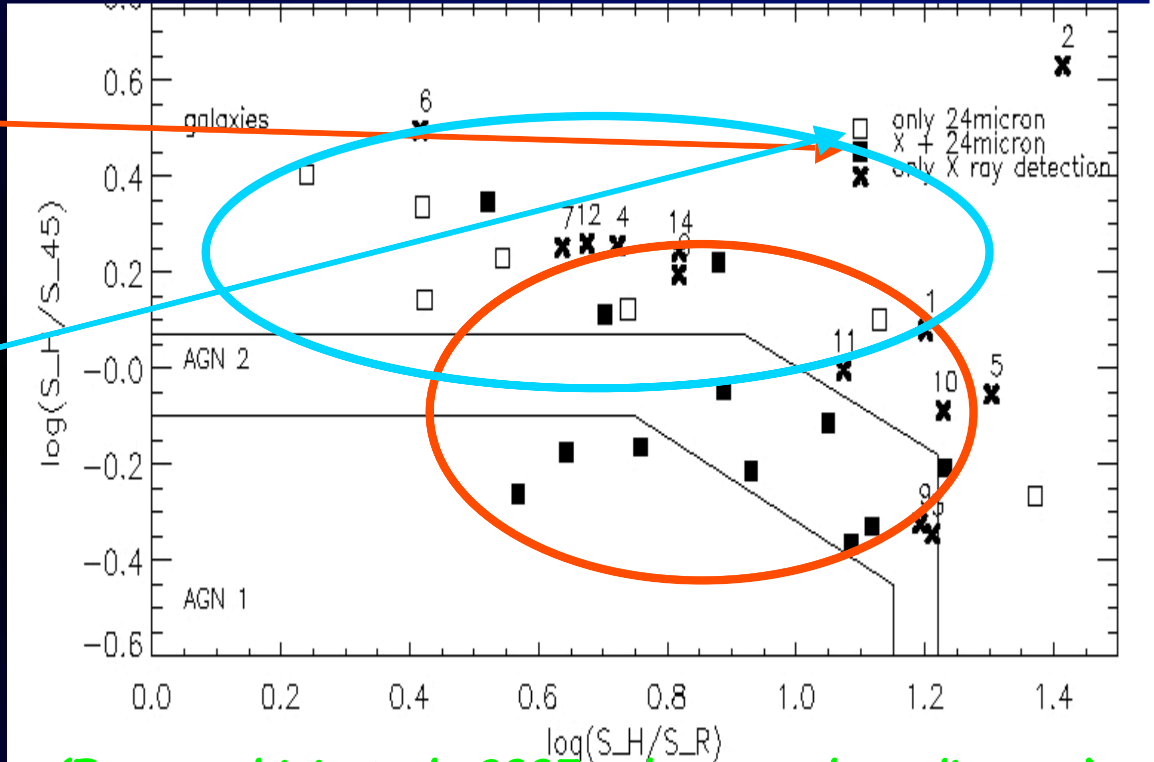
→ Obscured AGN and/or residual star-formation

★ MIR+X-ray:

Mostly AGN activity

★ Only MIR:

Mostly Star-formation
(SFR ~ 2-20 $M_{\odot}$/yr)



(Franceschini et al. 2005 colour - colour diagram)

15% (19/168) of the spheroidal gal's at z~1 are in a phase of prominent activity (both AGN and stellar origin)

2. MIR Properties of X-ray Sources in ELAIS-S1

(Gruppioni, Vignali, Comastri et al. '06 in prep.+ SWIRE collab.)

Four XMM pointings 100 ksec each in the central 0.6 deg^2 of the ELAIS/SWIRE-S1 area *(Puccetti et al. 2006)*:
479 sources with S (0.5-10 keV) > 2.5 x 10^{-15} erg cm^{-2} s^{-1}

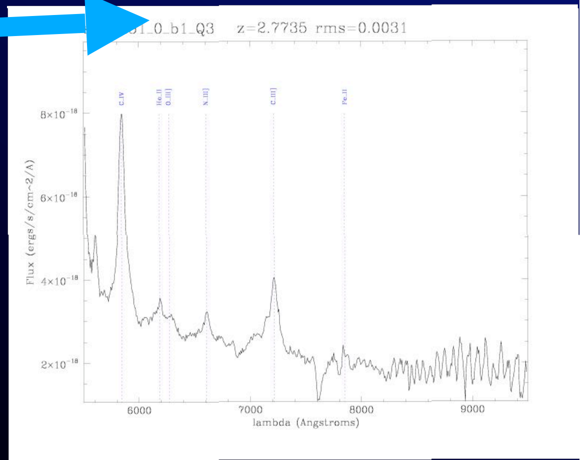
Same area covered in radio, all Spitzer bands (3.6-160 μm), 15, 90 μm (ISO), K, J, z, i, R, V, B, far-UV (GALEX)

Look for obscured AGN by studying the multi-wavelength properties of X-ray sources

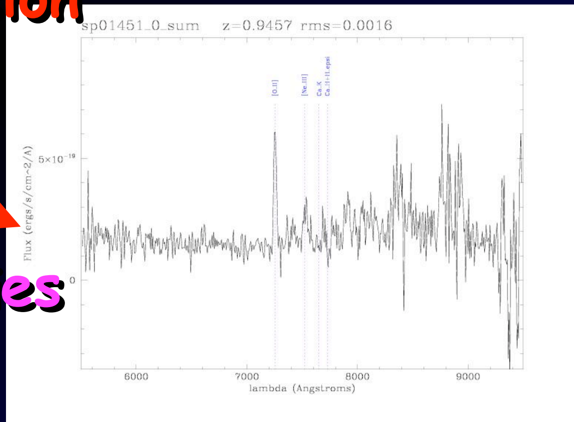
OPTICAL SPECTROSCOPY

Actually we have secure redshifts and spectral classification for 142 X-ray sources (with R < 23.5) [VIMOS data reduction still ongoing...]

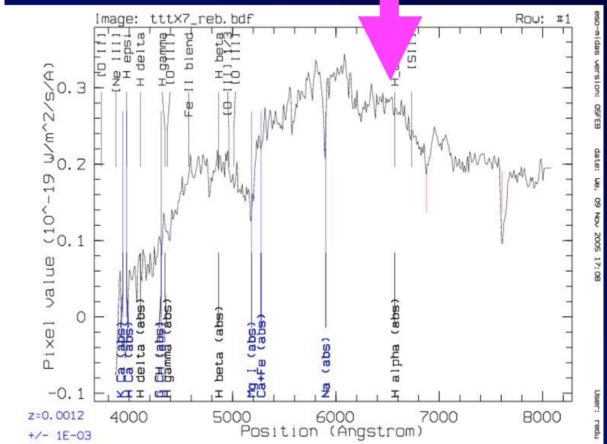
74 type 1 AGN (51%)



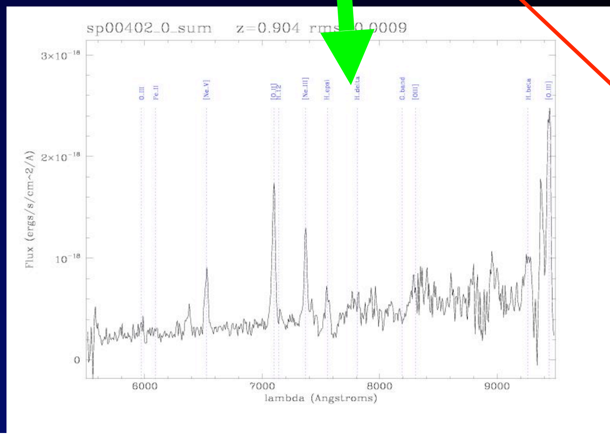
45 type 2 AGN / Emission line Gal's (31%)



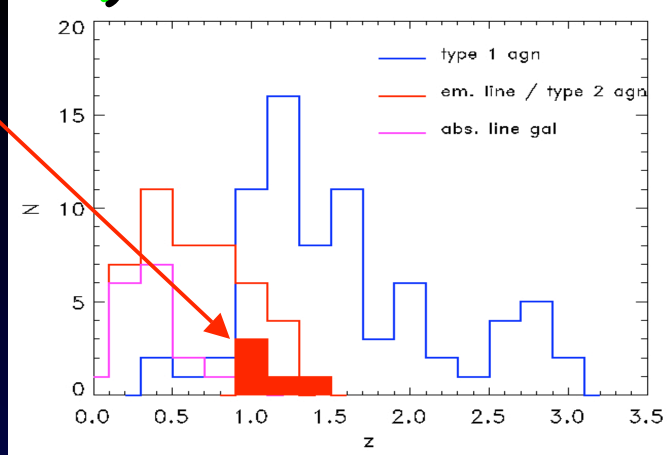
18 absorption line galaxies (12%)



5 QSO2 (from line ratios)



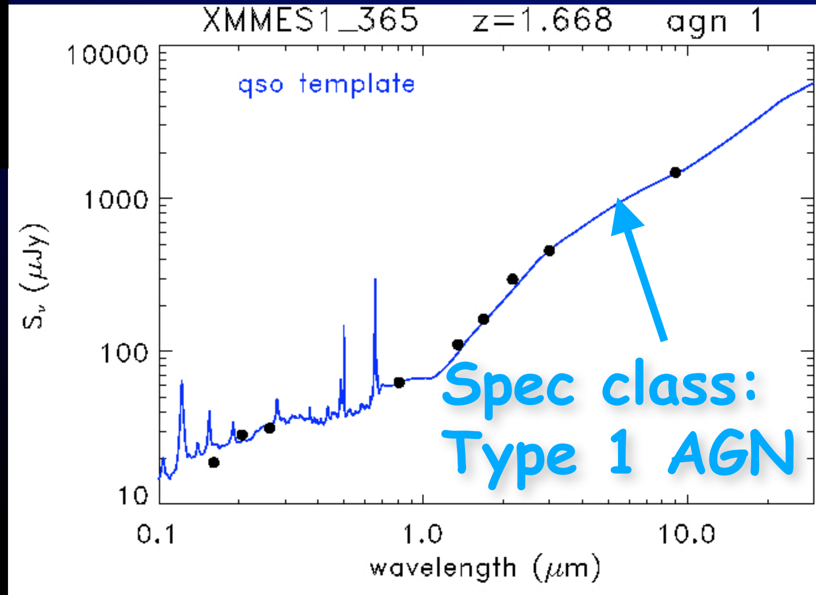
z-distribution

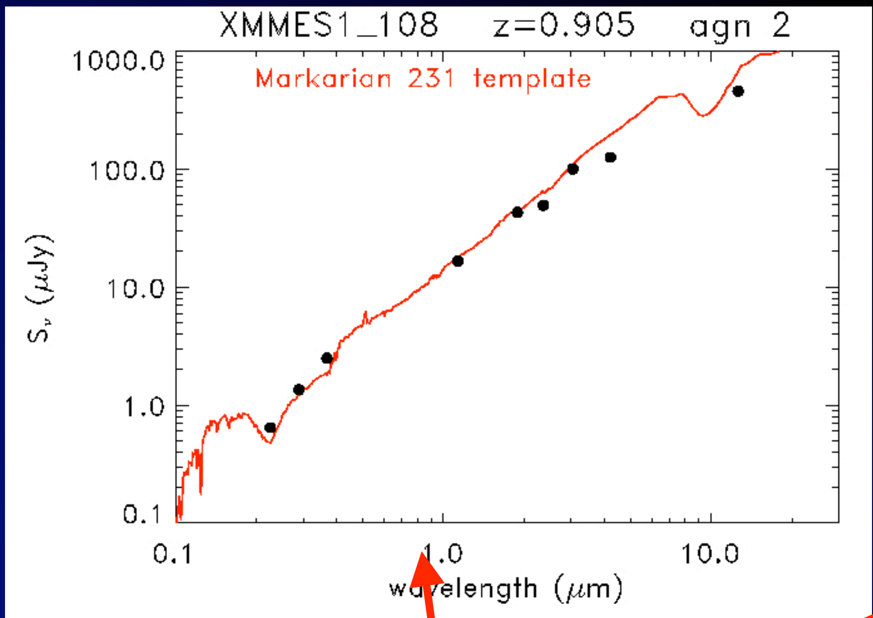


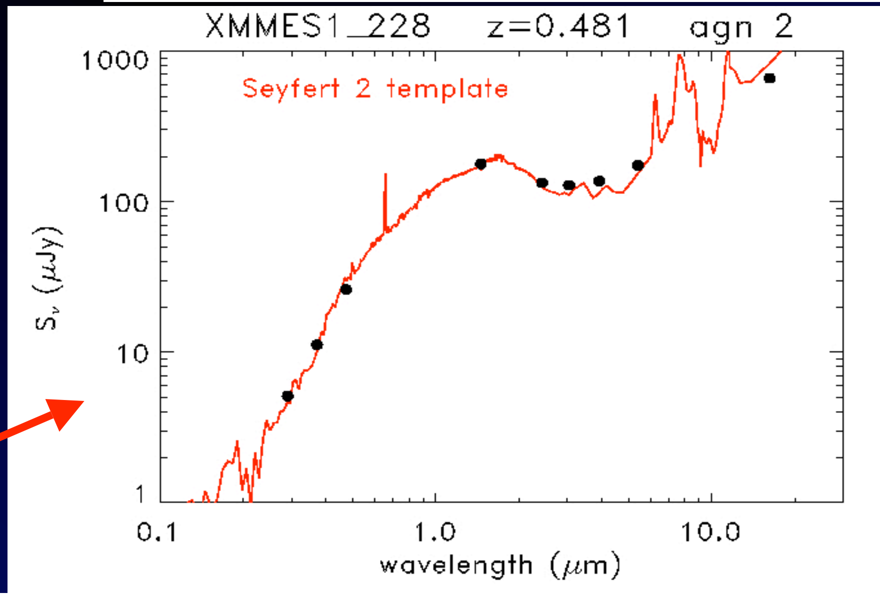
Spectral Energy Distributions of X-ray Sources

secure redshifts and spectral classification for 142 X-ray sources (with R < 23.5) [VIMOS data reduction still ongoing...]

Typical SEDs from optical to Mid-IR (21 AGN/galaxy Templates by *Mari Polletta et al. 2006, in preparation*)







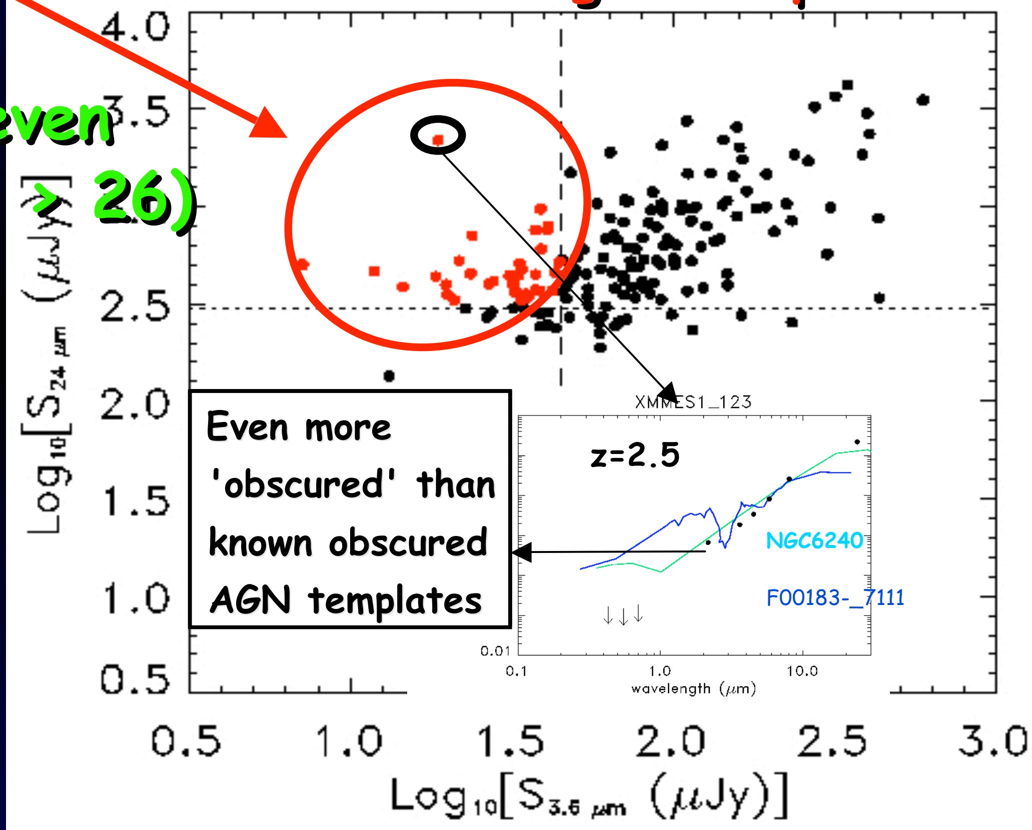
Spec class: Type 2 AGN

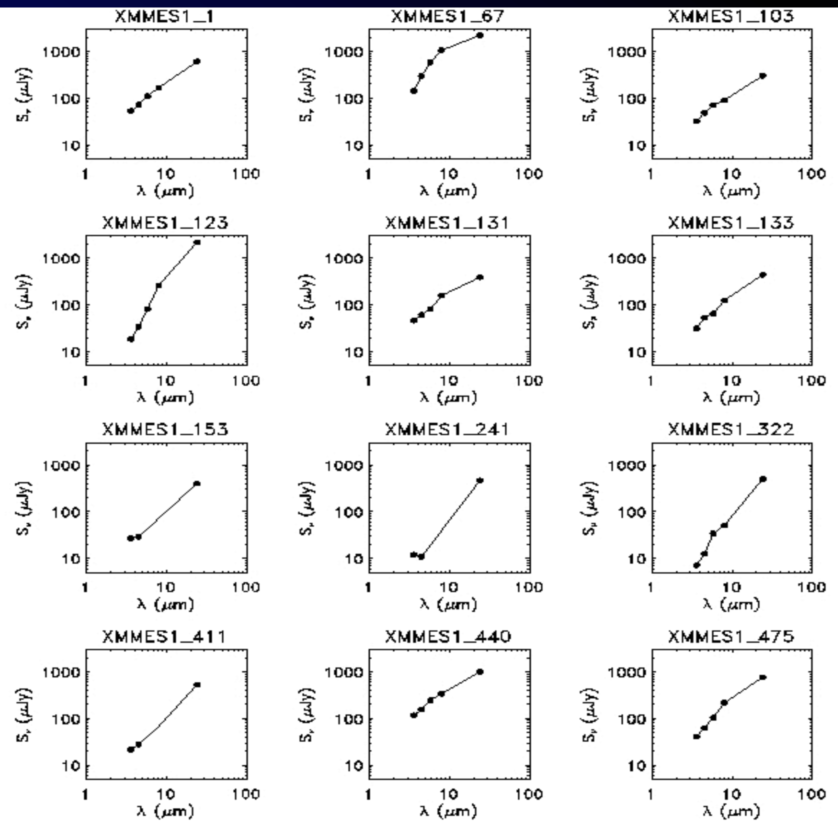
Obscured AGN?

Are these objects obscured AGN?

Indeed most of them do have faint (R > 24.5) or even NO optical counterpart (R > 26)

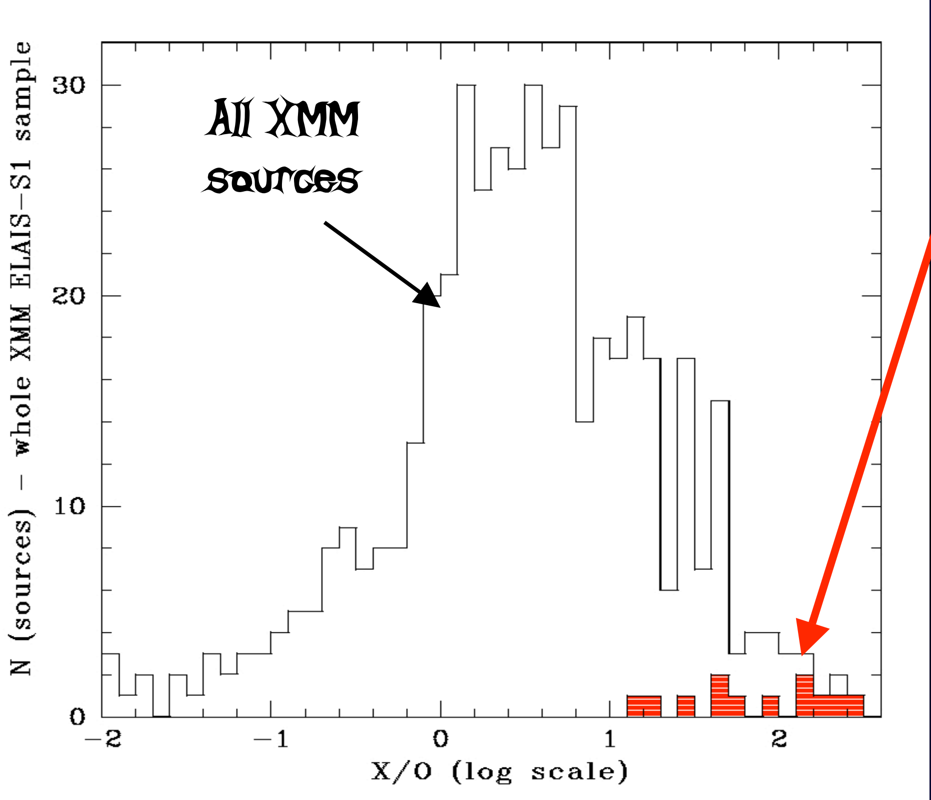
Martinez-Sansigre '05 plot





Typical SEDs rising very steeply from NIR to MIR

Obscured AGN?



extremely high X-ray to optical ratios X/O

[X/O of a few hundreds, where X/O=log(fx/fR)]

Absorption column densities estimated from the observed hardness ratios:

> 10^{22}—10^{23} cm^{-2}

best candidates to search for highly obscured luminous quasars at high z

How to quantify AGN (both obscured and unobscured) versus galaxy fraction in complete / statistical samples (i.e. MIR selected)?

➜ Study SEDs and multi-wavelength properties of a complete sample of MIR selected sources with optical spectroscopy:

ISOCAM 15-μm sample in ELAIS/SWIRE-S1 (200 redshifts over 228 extragalactic objects with opt ID: 88% [tot extragal. 311 objs: 65%])

(La Franca et al. 2004)

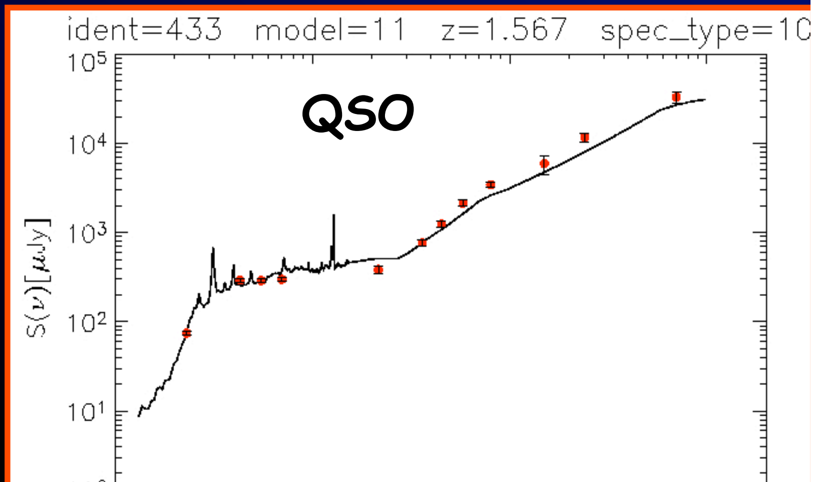
➜ Galaxy and AGN 15 μm Luminosity Functions

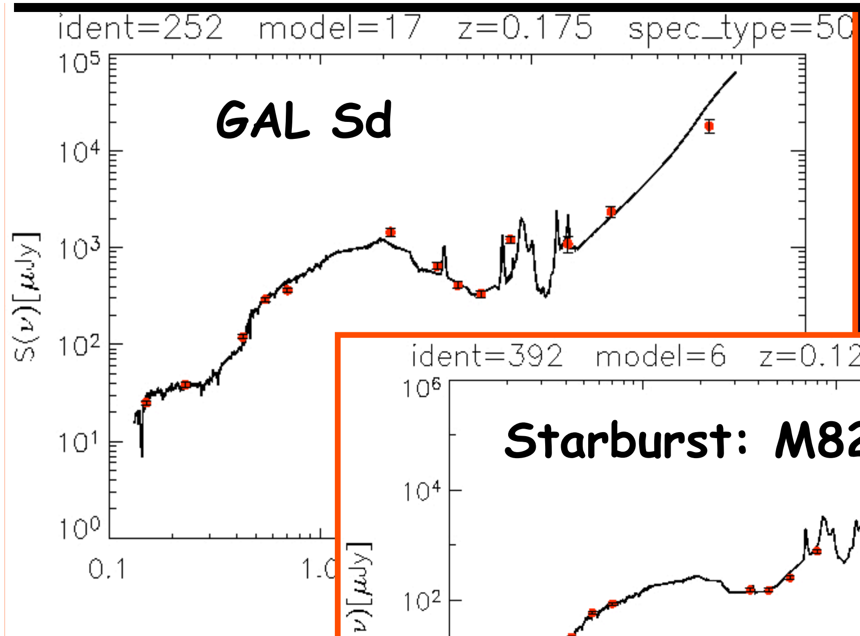
(Pozzi et al. 2004; Matute et al. 2006)

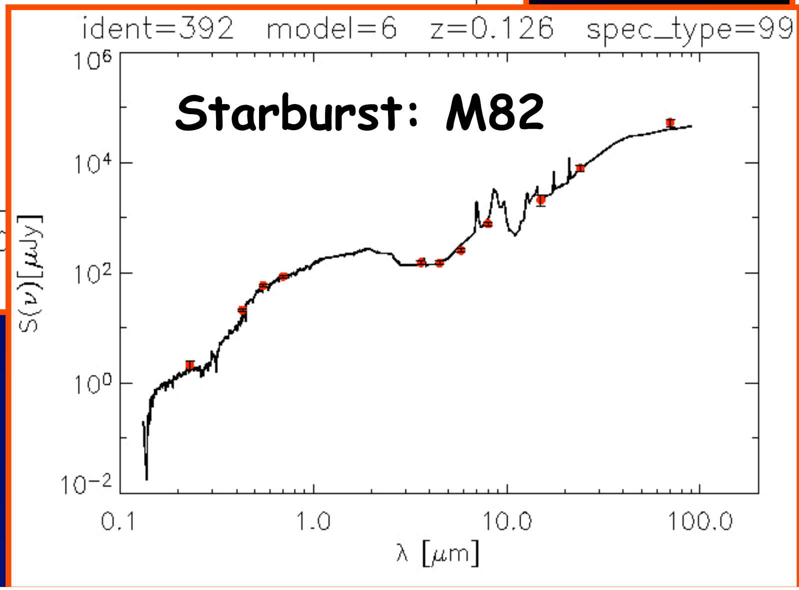
3. Broad-band SEDs (from Far-UV to FIR) of 15 μm sources

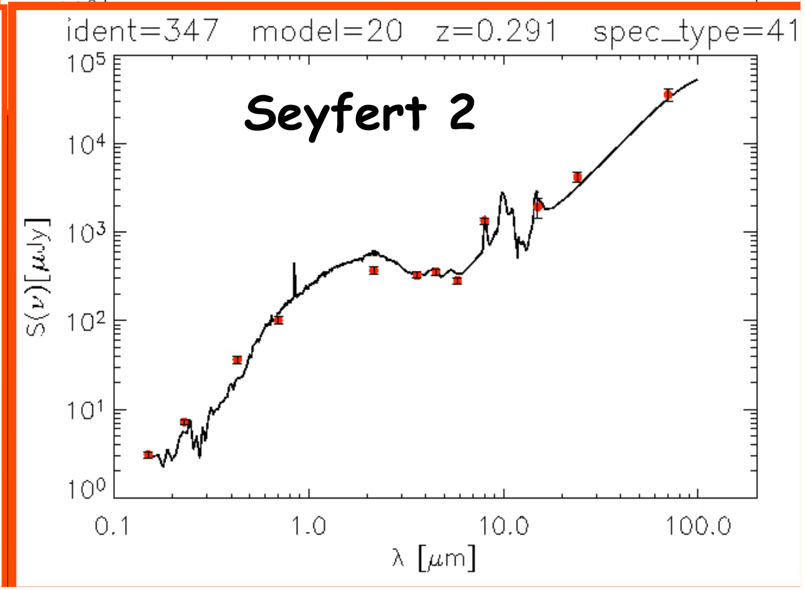
(Gruppioni, Pozzi, Polletta et al. in preparation)

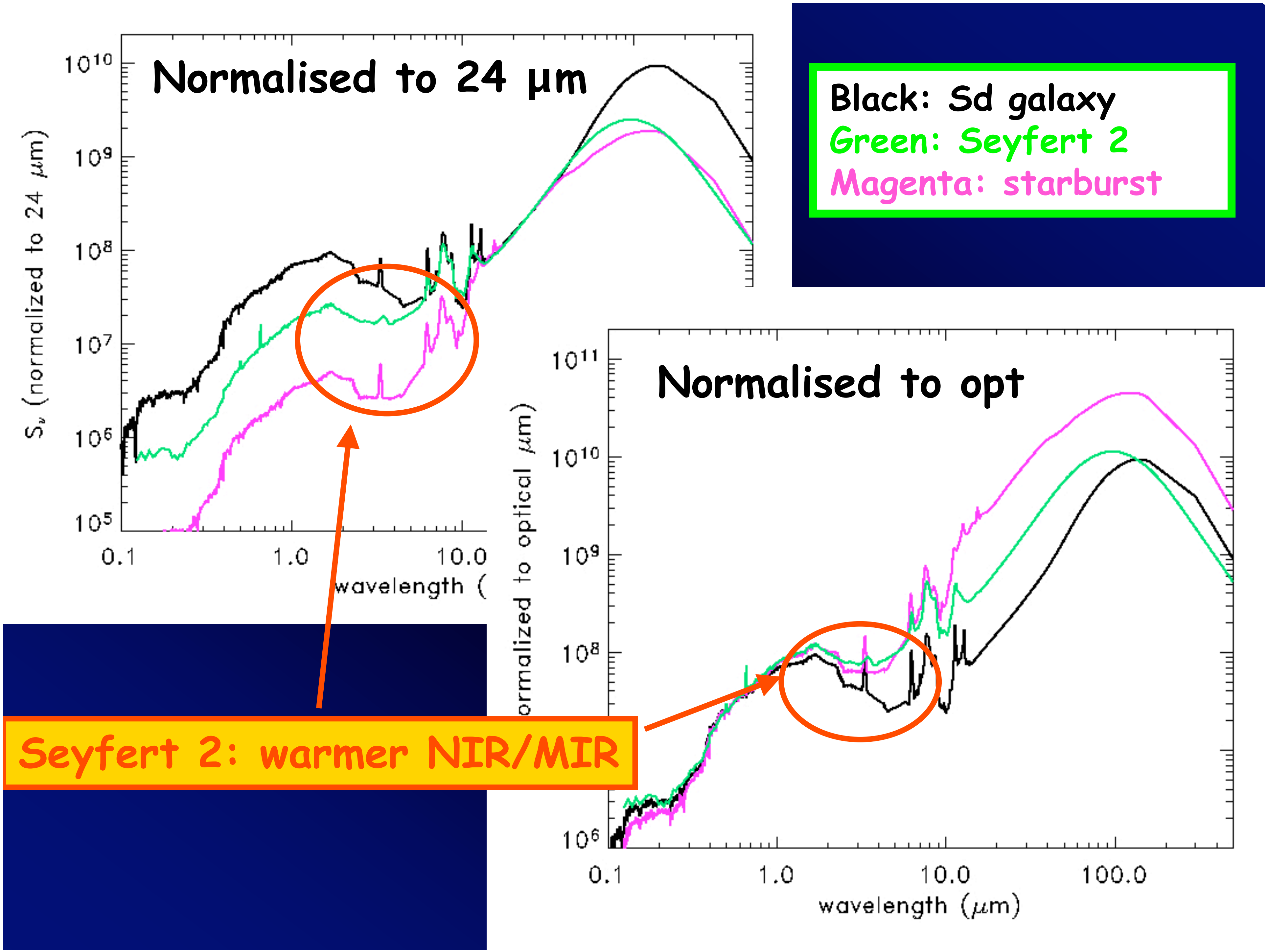
Data fitted with 21 Template SEDs of IR galaxies/AGN by *Mari Polletta et al. (2006? in preparation)*










Normalised to 24 μm
Black: Sd galaxy
Green: Seyfert 2
Magenta: starburst
Normalised to opt
Seyfert 2: warmer NIR/MIR
S_ν (normalized to 24 μm)
ormalized to optical μm)
wavelength (
wavelength (μm)
0.1
1.0
10.0
100.0
10^5
10^6
10^7
10^8
10^9
10^10
10^11

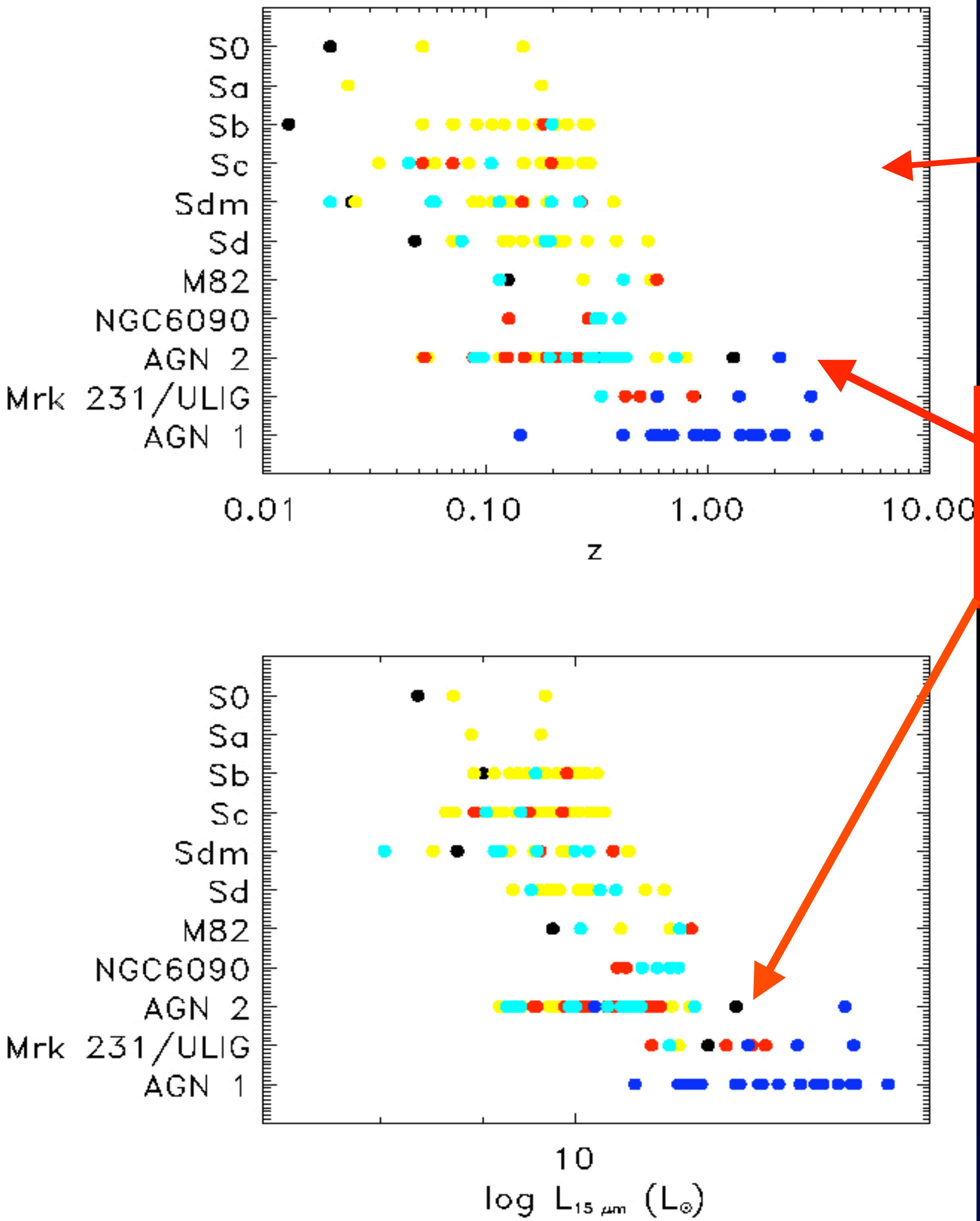
SED-fitting versus spectroscopic classification

SED Classification:		Spectroscopic Class
S0/Sa/Sb/Sc/Sd/Sdm:	Galaxy (81)	Galaxy (108)
M82/NGC6090/Arp220/IRAS19254:	Starburst (26)	Starburst (32)
Syfert2/Seyfert1.8:	AGN 2 (59)	Liner/AGN 2 (33)
QSO/RedQSO/Mrk231:	AGN 1 (34)	AGN 1 (25)

Main differences:

1. SEDs classify more AGN (especially type 2)
2. Many galaxies with only Hα emission in their spectra [e(a)] show AGN-like SEDs

SED versus spectroscopic classification



Spec class: AGN 1, AGN 2, STARB, GAL

★ early ➜ late-type ↗ z,L

Seyfert 2's over almost the whole z and L ranges

★ Broad line AGN ➜ QSO/Seyfert1/Mrk 231

★ Gal, Starb, Narrow line AGN ➜ Gal, Starburst, Seyfert 2 but all MIXED!

Really so many Seyfert 2's?

- Seyfert 2 template: average of several IR (ISO/Spitzer) spectra of Seyfert 2's: Hot dust heated by the AGN:
- warm continuum at λ~3-5 μm, flatter than in gal's (both normal & starburst).
- No continuity with z,L in SEDs (Sey2 not intermediate between i.e. late-type spirals and starbursts)
- Most spec-gal's now Sey2 have only strong Hα emission in spectra ➜ possible AGN (no Hβ, no AGN/gal diagnostics)
- All XMM-selected type 2 AGN: Sey2 SED (or Power-Law)
- BUT: possible degeneracy in SEDs, errors in photometric points, contribution from starburst

Really so many Seyfert 2's?

HOWEVER: it is likely that a fraction of spec-gal's fitted with a Seyfert 2 SED DO really CONTAIN an AGN, although it may not dominate optical and/or FIR

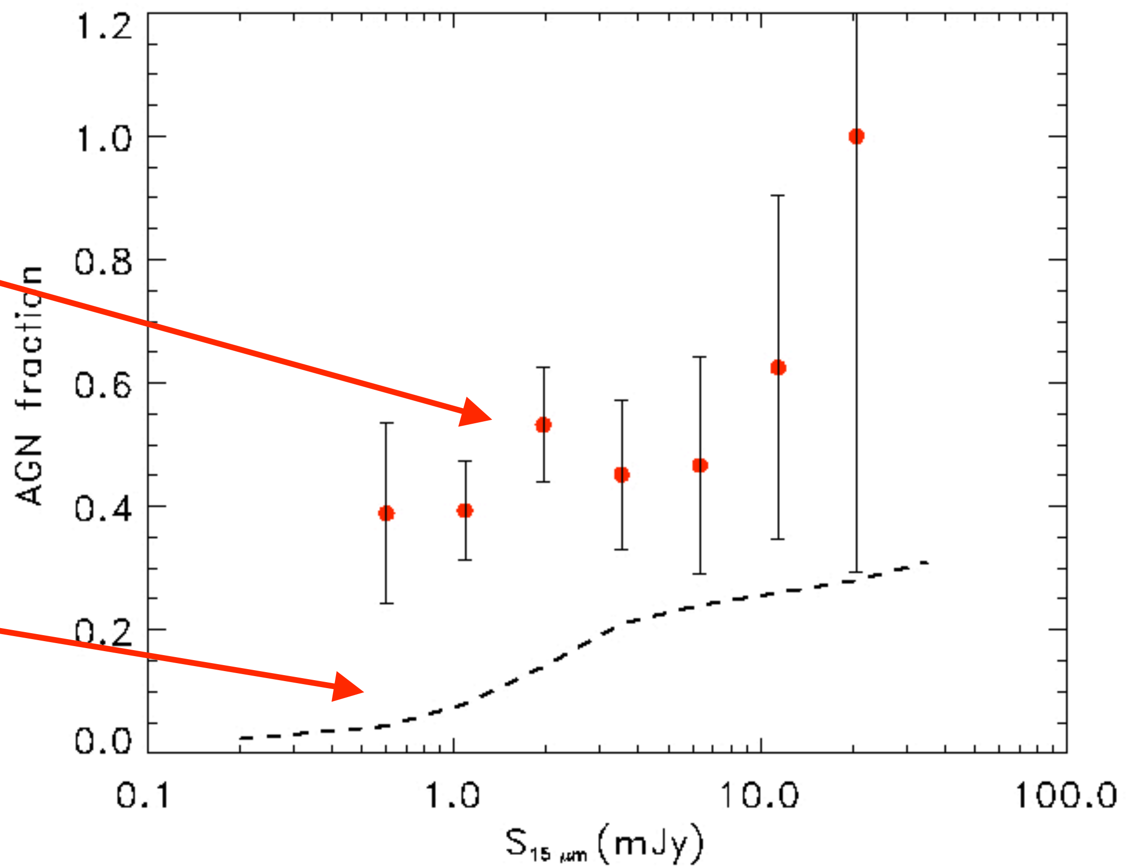
NEED TO REVISE EVOLUTIONARY MODELS?

☛ AGN/galaxy relative fractions

AGN fraction with new classification based on SEDs (UPPER LIMIT?)

Matute et al. 2006 *model predictions* (LOWER LIMIT?)

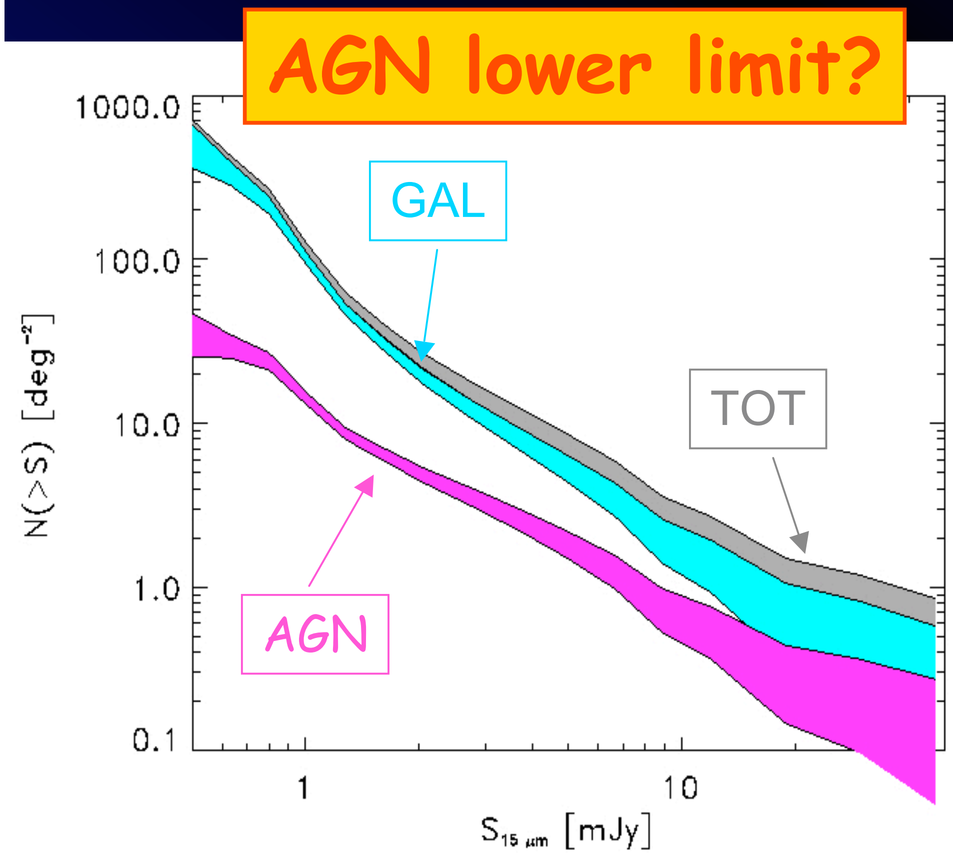
See also *Brand et al. 2006* for a 24 μm selected sample



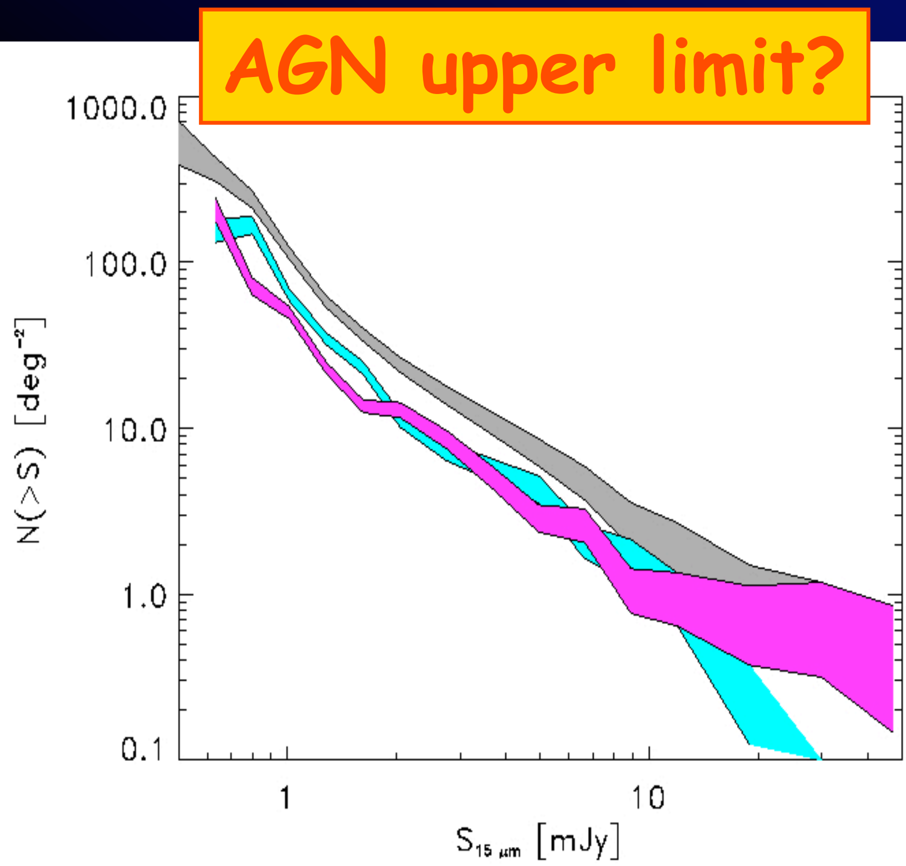
NEED TO REVISE EVOLUTIONARY MODELS!

- Observed Source Counts:

Spectroscopic classification



SED classification



MAIN CHANGES NEEDED

Less objects powered by pure star-formation

➜ Less evolution for galaxies (starburst):
SEDs evolving with L_{IR} (or z) for all:

★ from S0 to Sd/Sdm for normal galaxies
★ from M82 to ULIG for starbursts

More objects containing an AGN

➜ More evolution for AGN (type 2):
both luminosity and density (more numerous)?

➜ Similar evolution for type 1 AGN (slightly more objects…)

CONCLUSIONS

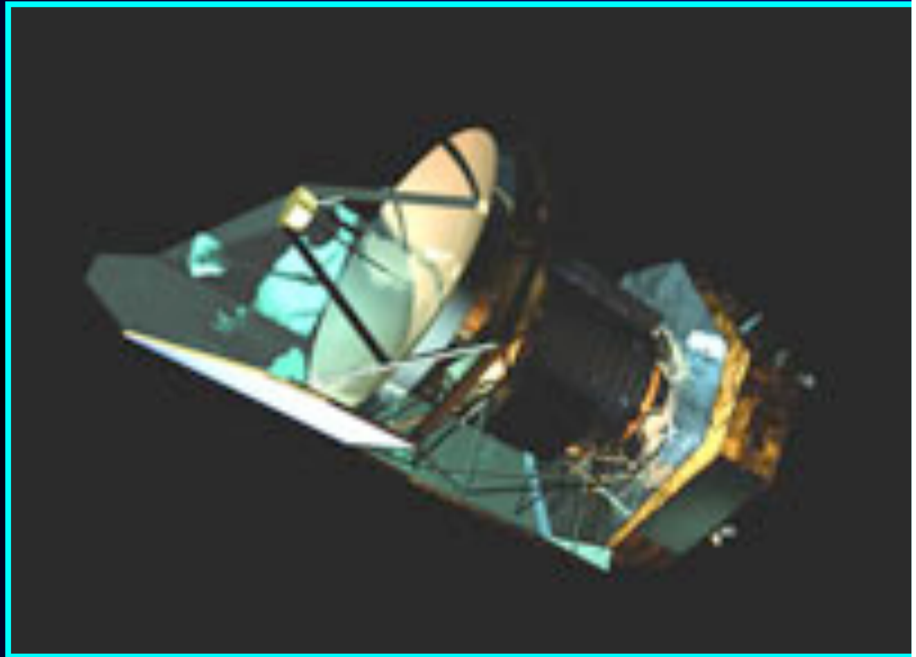
- Strong evolution for Gal/AGN revealed in IR (still to be understood!)
- Main problem: Multi-λ characterization needed to distinguish AGN from galaxies
- *Spitzer* (+XMM/Chandra) helps revealing obscured AGN activity
- In a complete MIR selected sample: SED-fitting reveals more AGN activity than spectroscopy ➜ need to revise models?

…need for HERSCHEL (3.5-m)?

Evolution of dusty galaxies up to:

ISOCAM: ➜ z=1.5

SPITZER: ➜ z=3



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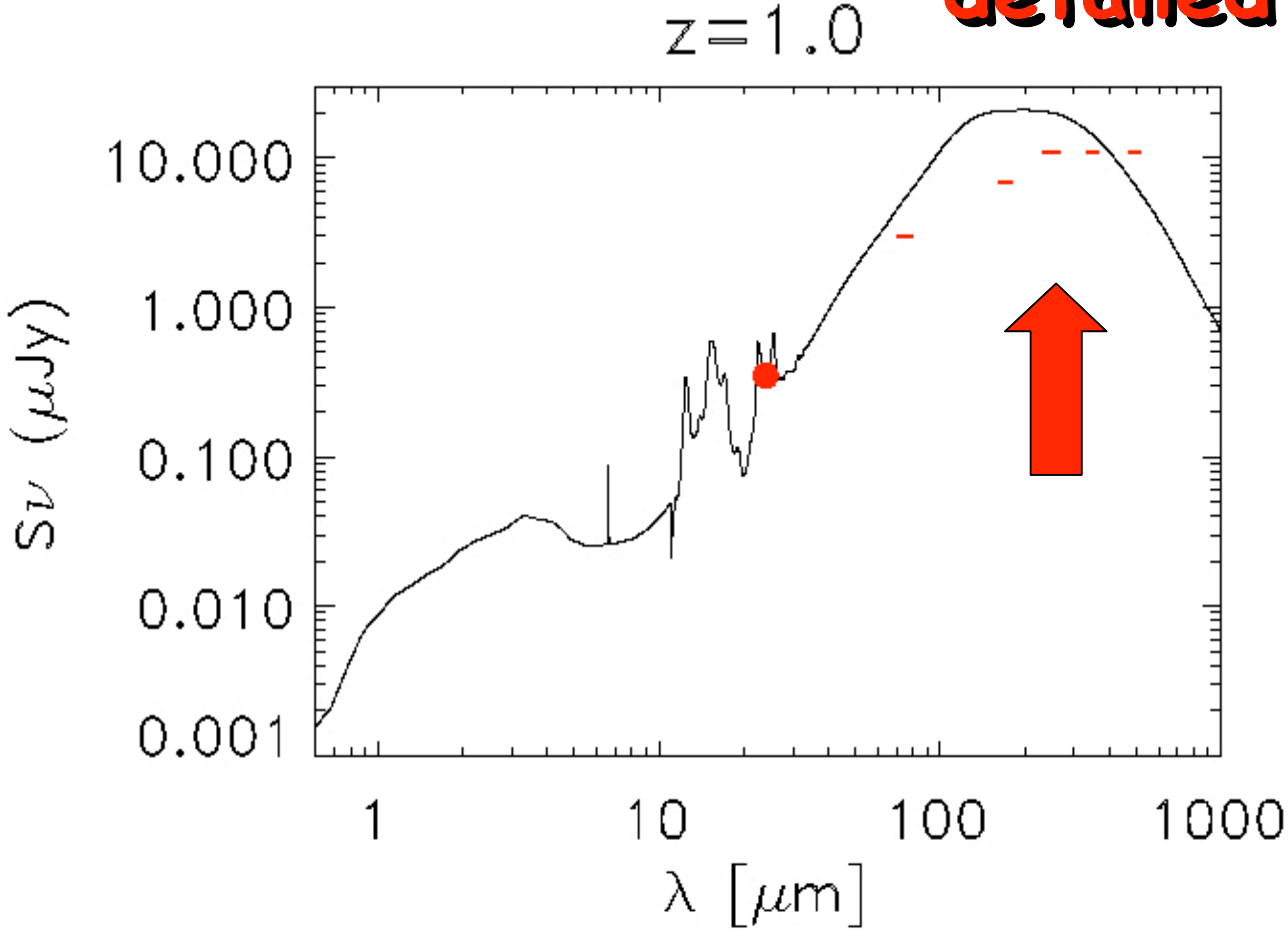
HERSCHEL will operate between 75 and 500 µm ➜ SF up to z=4-5

…need for HERSCHEL?

Locate the peak of dust emission in High-z galaxies ➜ dust Temperature
detailed SEDs in FIR



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Better Galaxy/AGN Separation!