The present and future of IR space-based observations of high-z galaxies: Spitzer and JWST

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Outline

- What can we learn from (high spatial optical and near-IR observations of) Local LIRGs?

- Spitzer Cosmological Surveys for high-z galaxies:
  - Mid-Infrared Number Counts
  - Photometric Redshifts for z>1 galaxies
  - Properties of star-forming galaxies
  - How many hidden AGN can be confused with star-forming galaxies?

- Future Prospects with JWST/MIRI

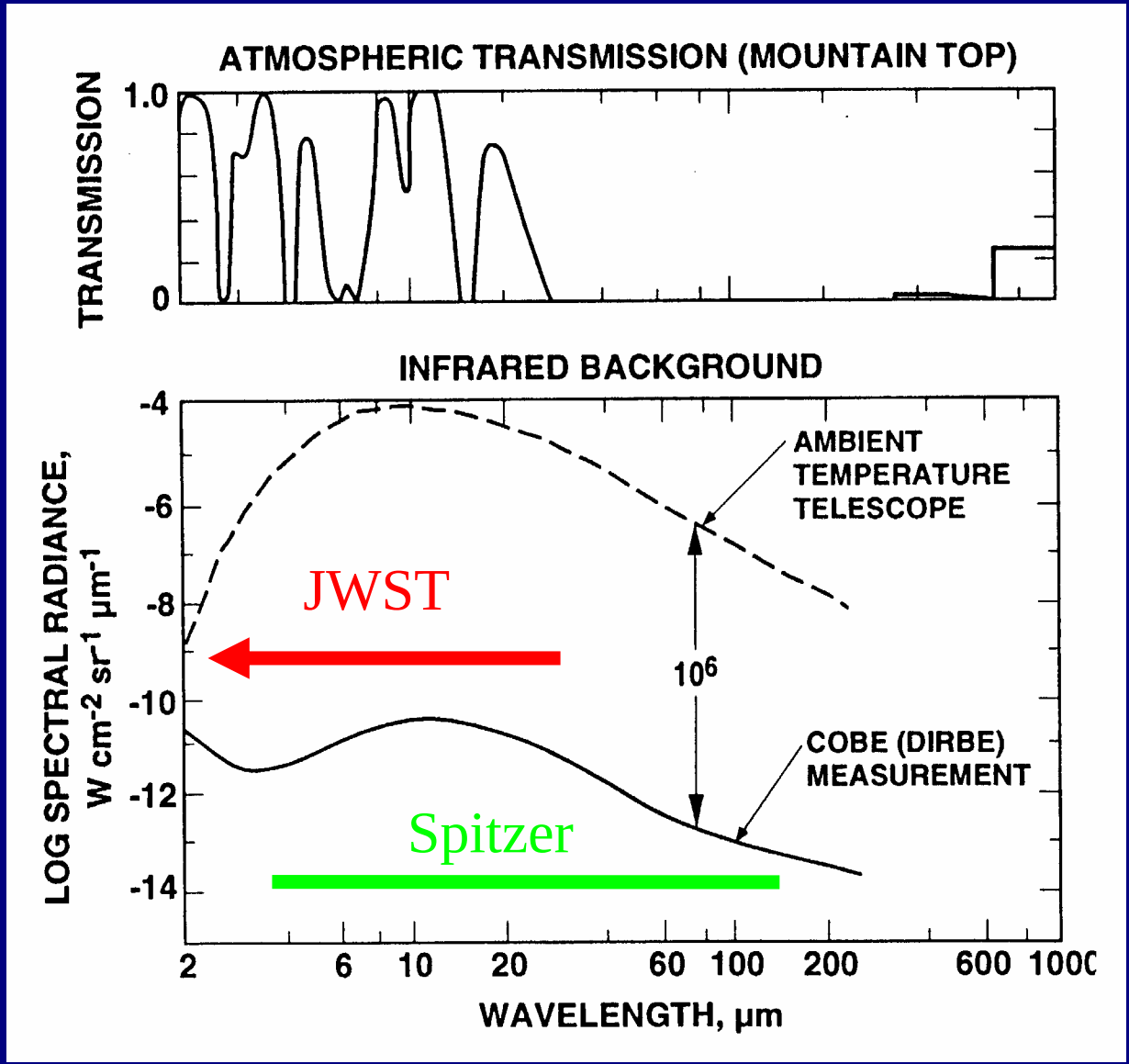
¡JULIÁN!



Advantages of IR Observations from Space:

100% Transmission and a One-Million Fold Decrease in Sky Brightness

Spitzer:
IRAC: 3-8μm imaging
IRS: 5-40μm spectroscopy
MIPS: 24, 70 and 160μm imaging



Luminous and Ultraluminous IR galaxies (LIRGs and ULIRGs) in the Local Universe

Brief Summary of Properties (Sanders & Mirabel 1996)

IR Luminosity: 8-1000μm
LIRGs: $L_{IR}=10^{11}$-$10^{12}L_{\odot}$
ULIRGs: $L_{IR}=10^{12}$-$10^{13}L_{\odot}$
(Hyper Luminous IR galaxies) HyLIRGs: $L_{IR}>10^{13}L_{\odot}$
Cool ULIRGs: $f_{25}/f_{60}<0.3$
Warm ULIRGs: $f_{25}/f_{60}>0.3$ (mostly QSO)

Morphology: Spirals, close pairs, mergers. # mergers increases with L_{IR}
Nuclear Activity: HII, LINER, Seyfert. Fraction of AGN increases with L_{IR}, at $L_{IR}>10^{12}L_{\odot}$ AGN fraction ~70%
Nuclear gas concentrations of up to $10^{10}M_{\odot}$ within 0.5kpc!
If LIRGs, ULIRGs powered by star formation: SFR of up to $1000M_{\odot}$/yr

What can we learn from Local LIRGs?

Selection criteria:

- IRAS Revised Bright Galaxy Sample (RBGS. Sanders et al. 2003)
- Volume-limited sample: 2500<v<5200km/s (d<75Mpc) so Paα (λ_{rest}=1.87μm) observed with NICMOS

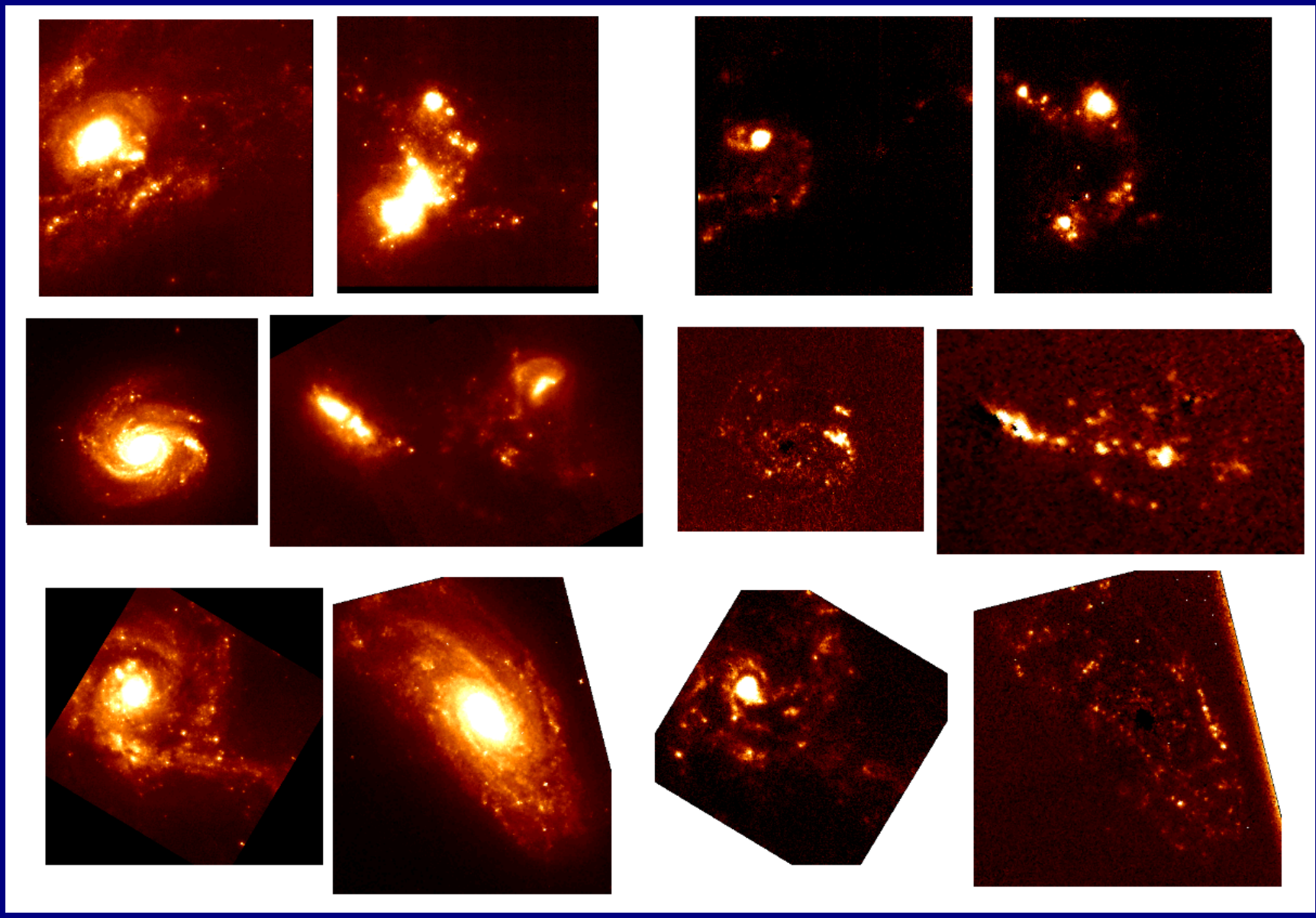
Properties of sample:

- 30 systems (34 galaxies), 80% complete and unbiased
- L_{IR}=11.05-11.88$L_{\odot}$
- Morphology: isolated galaxies, groups, interacting and mergers
- Solar Metallicity
- AGN (Seyfert and LINER) fraction: ~25% (spectroscopy)

Observations: HST/NICMOS contiuum 1.2-1.9μm, narrow-band Paα + on-going optical and near-IR Integral Field Spectroscopy

Alonso-Herrero et al. 2000, 2001 for detailed studies of Arp299 and NGC1614 with NICMOS

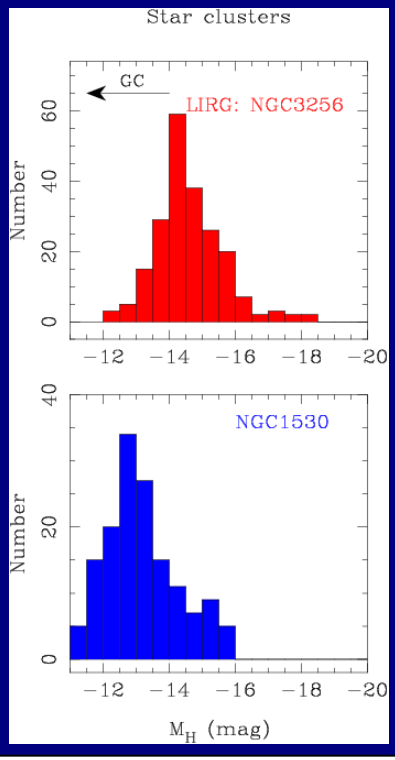
Stellar and ionized gas morphology of Local LIRGs



H-band (1.6μm)

Pa-α line emission

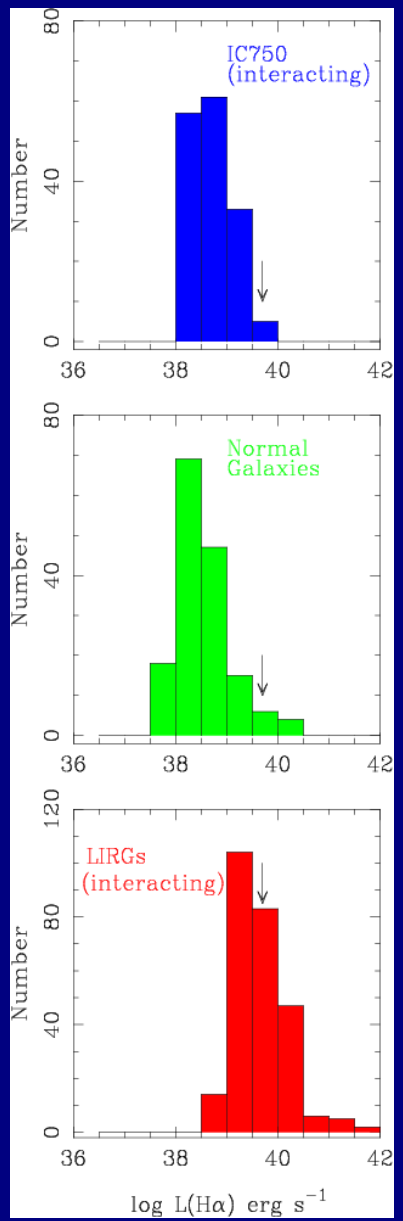
Properties of star clusters and HII regions of LIRGs



(Spatial resolutions of 10-30pc!)

Super Star Clusters

Giant HII Regions
L(Hα)>39.6erg/s
(30 Dor)



Observed distributions of clusters and HII regions

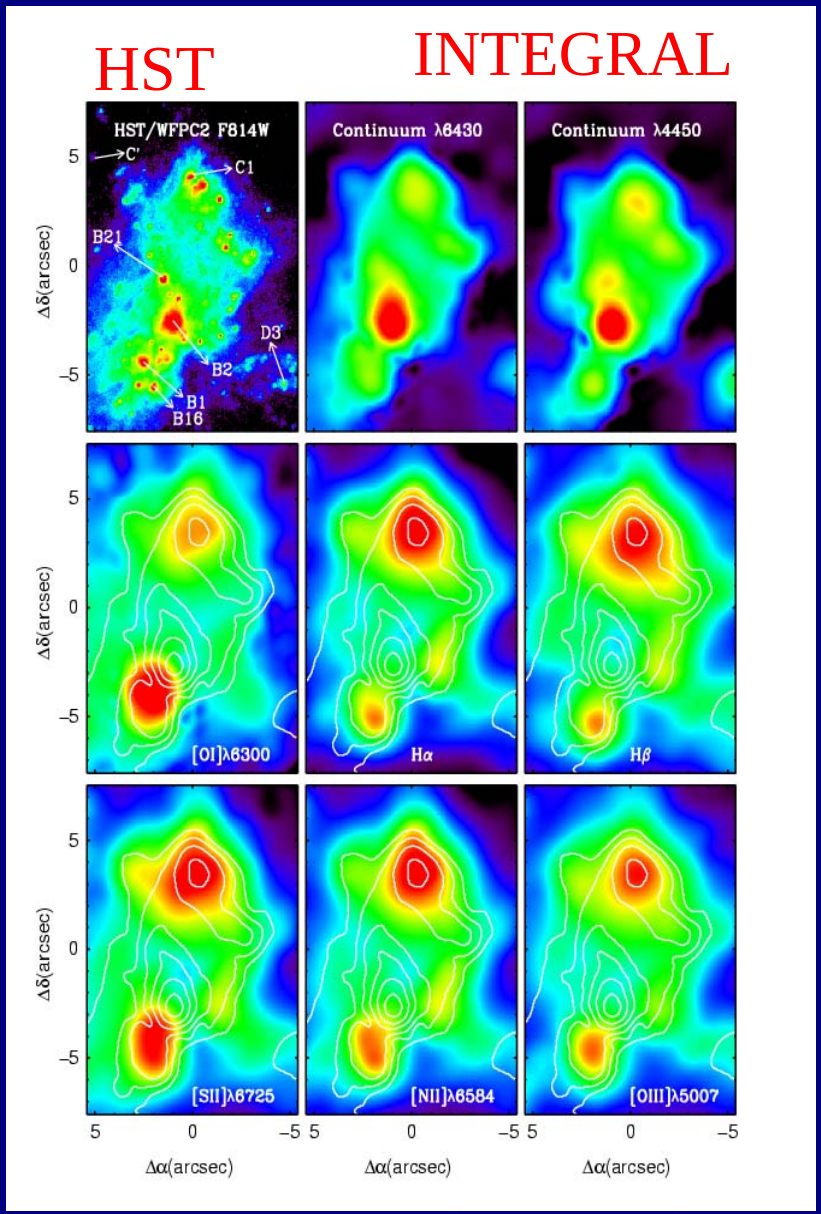
	Only HII	HII+contin.	Only cotinuum
	<5Myr	<7Myr	7-40Myr
NGC3256	37-39%	10-7%	53-54%
NGC3690	25-27%	10-7%	65-66%
IC694	33-34%	6-4%	61-62%

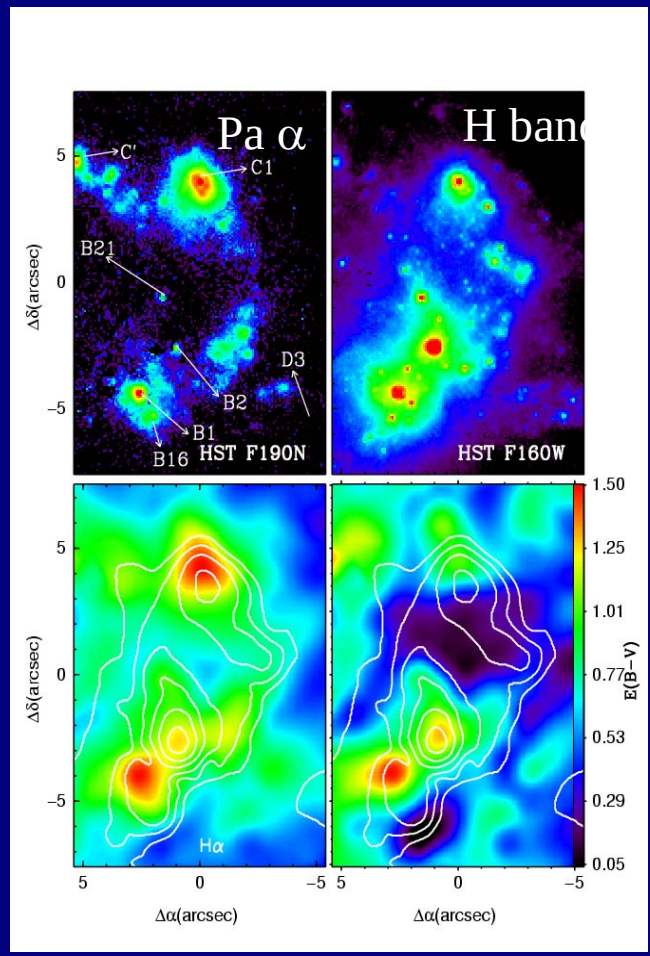
most massive
~$10^6 M_\odot$

10^4-$10^5 M_\odot$

Alonso-Herrero et al. 2002

Arp299: NICMOS + INTEGRAL IFS





DETAILED STUDIES OF INDIVIDUAL REGIONS

Ages ranging between 3.4 and 7.5 x 10^6 yr

Stellar mass content: 6 to 655 x 10^6 $M_\odot$

Extinction: 2-6mag

SFR ranging between 0.1 to 12 $M_\odot$/yr

García-Marín et al. 2006

Accurate SFR can be determined from MIR data alone

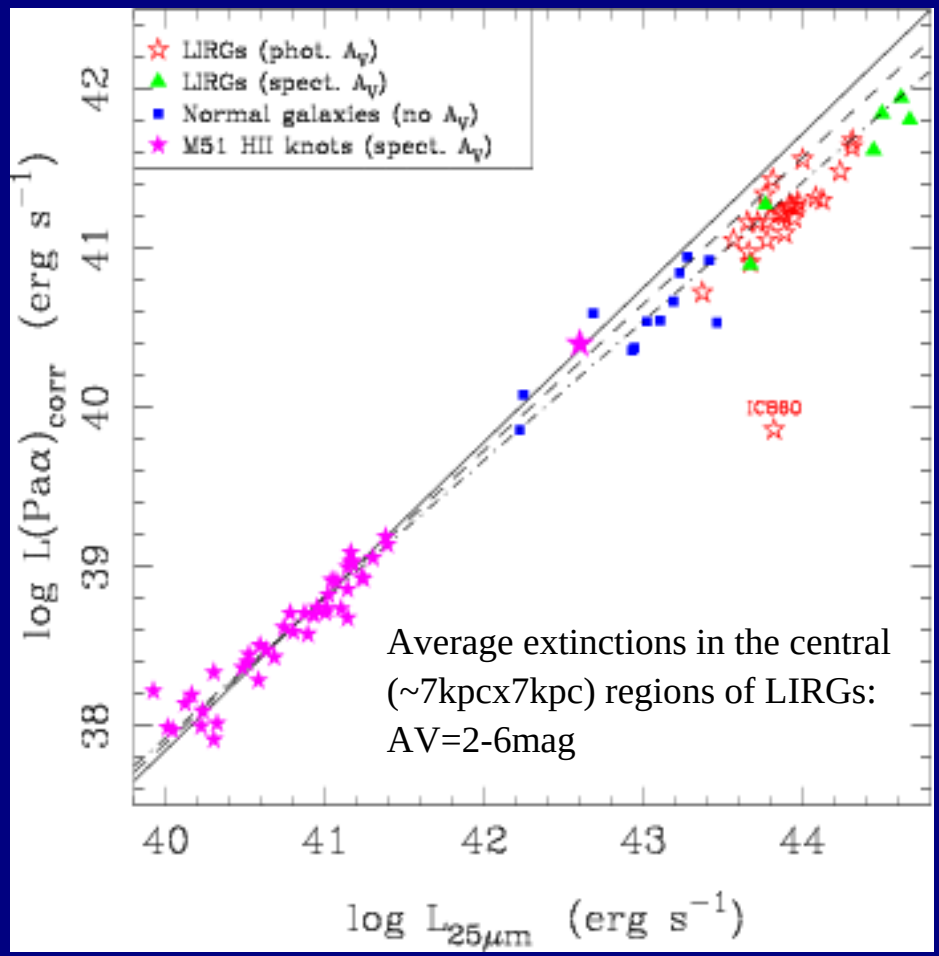
A tight correlation is seen between extinction-corrected Pa-α and 25μm (from IRAS) or 24μm (from Spitzer) flux density for:

M51 HII knots (Calzetti et al. 2005)
normal galaxies
LIRGs (at least up to 5 X 10^{11} $L_{\odot}$)

A similar correlation is seen at 12μm.

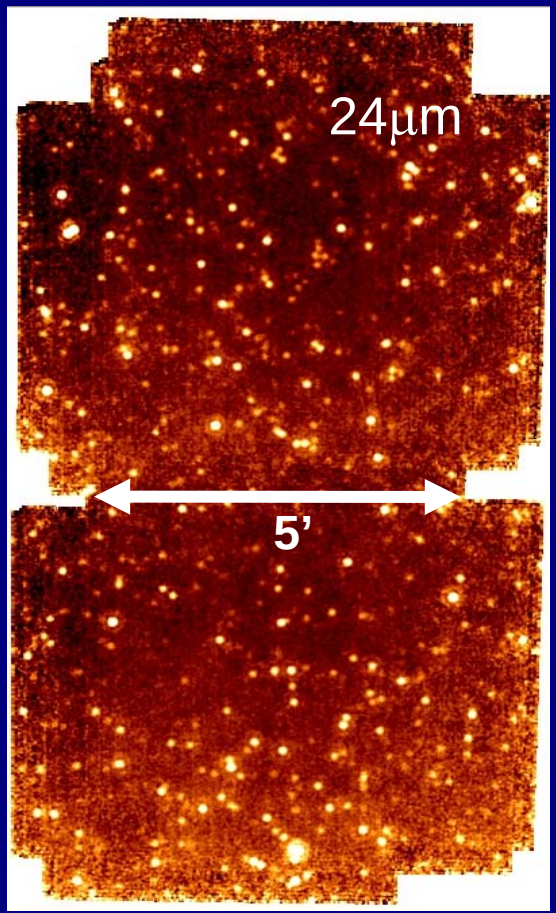
- 12-70μm emission is powered by young stars
- >70μm emission is diffuse interstellar radiation field powered by modest-age stars (from MIPS observations of nearby galaxies, eg. Hinz et al. 2004)

Alonso-Herrero et al. 2006

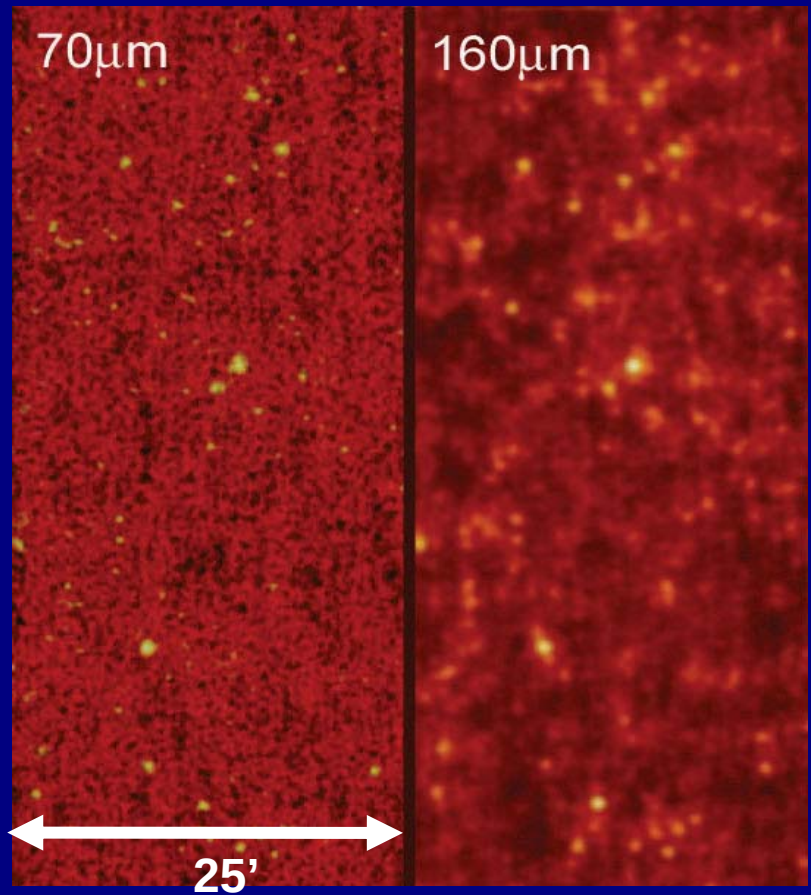


Spitzer Cosmological Surveys

Spitzer sees high-z galaxies as point sources!



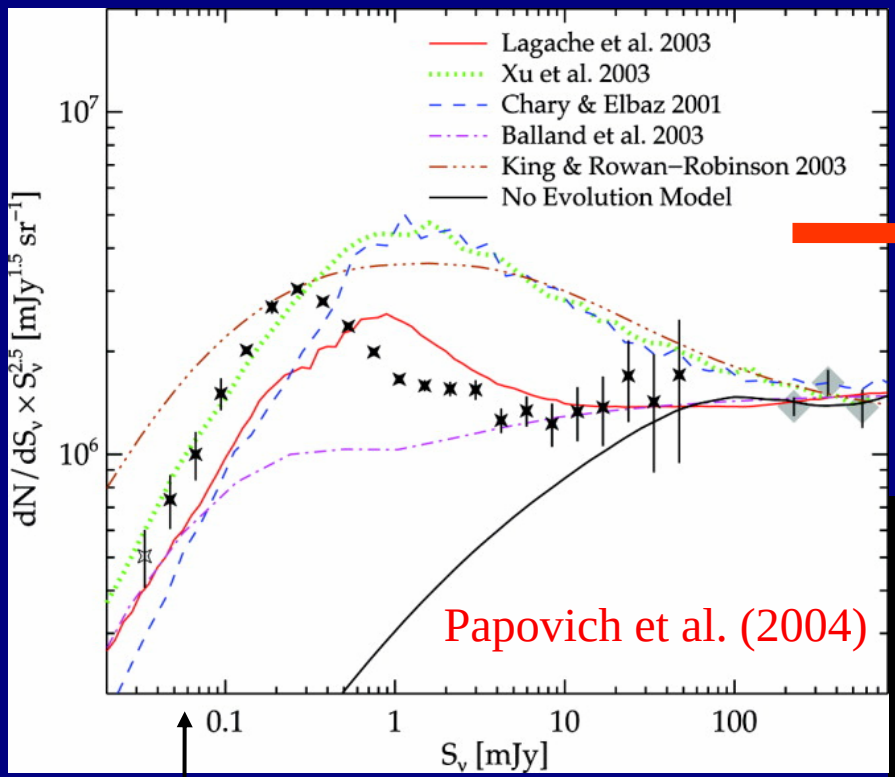
~ 4000 s



~ 600 s

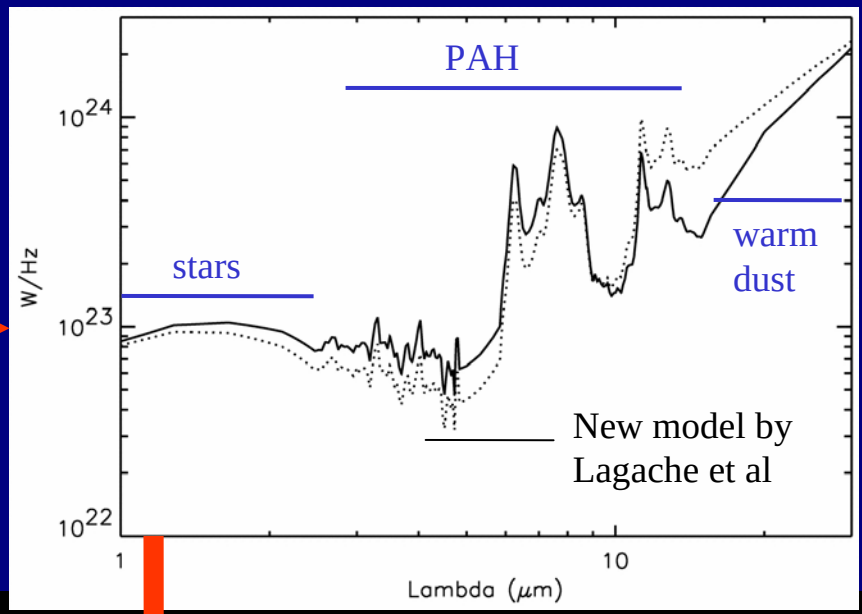
~ 100 s

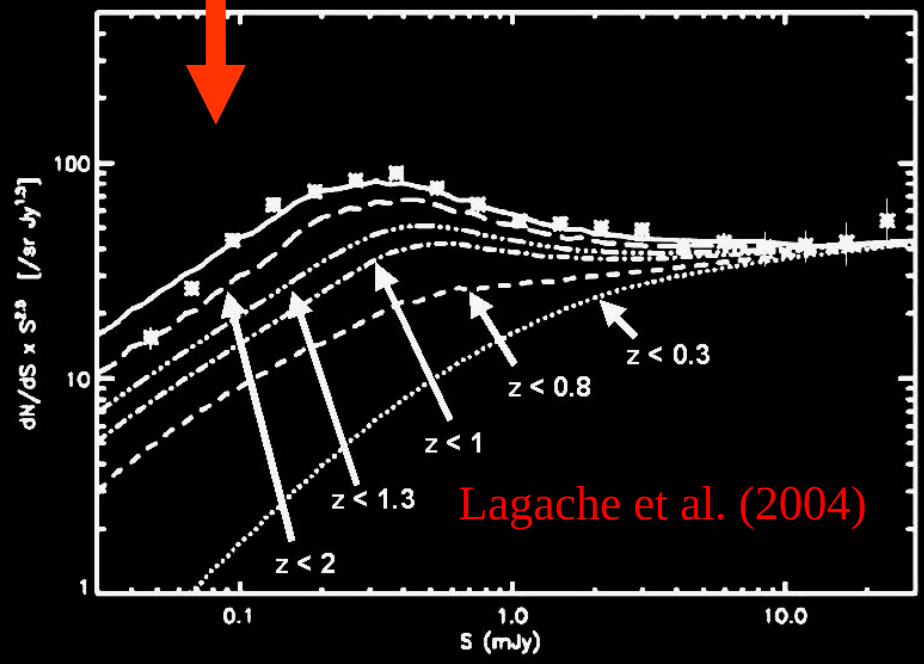
Spitzer 24μm Number Counts



Papovich et al. (2004)

80% (4-5σ) completeness limit is at 83μJy for ~1500s



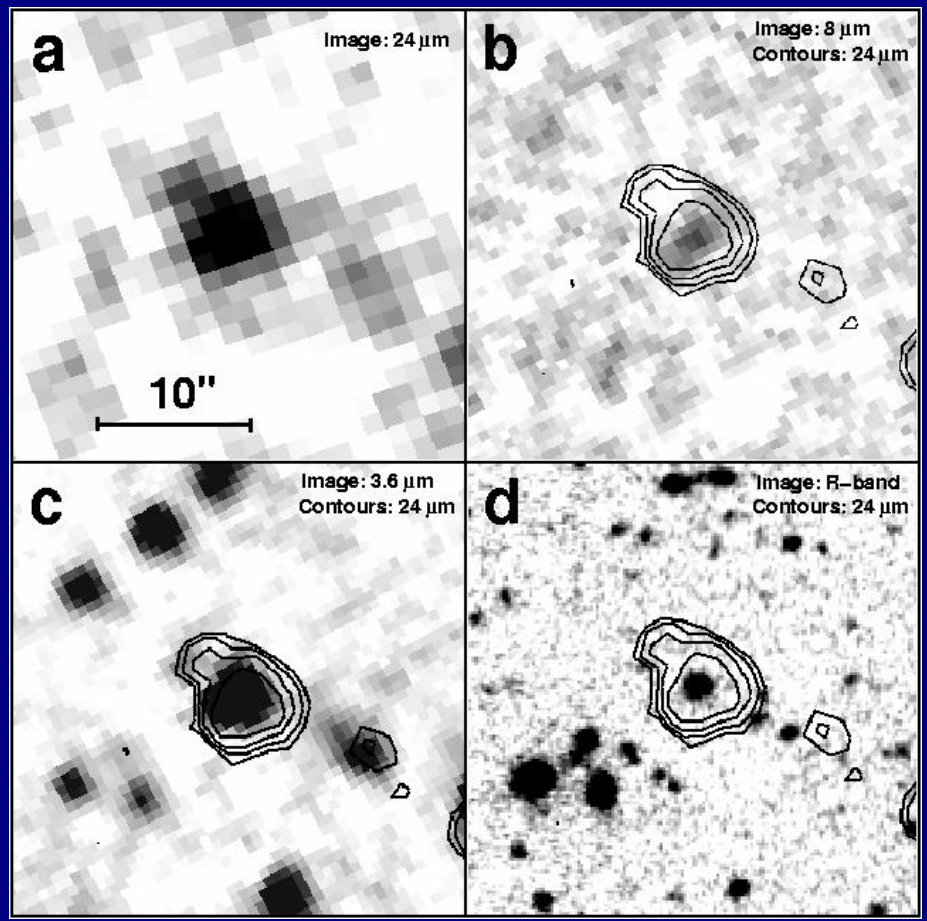


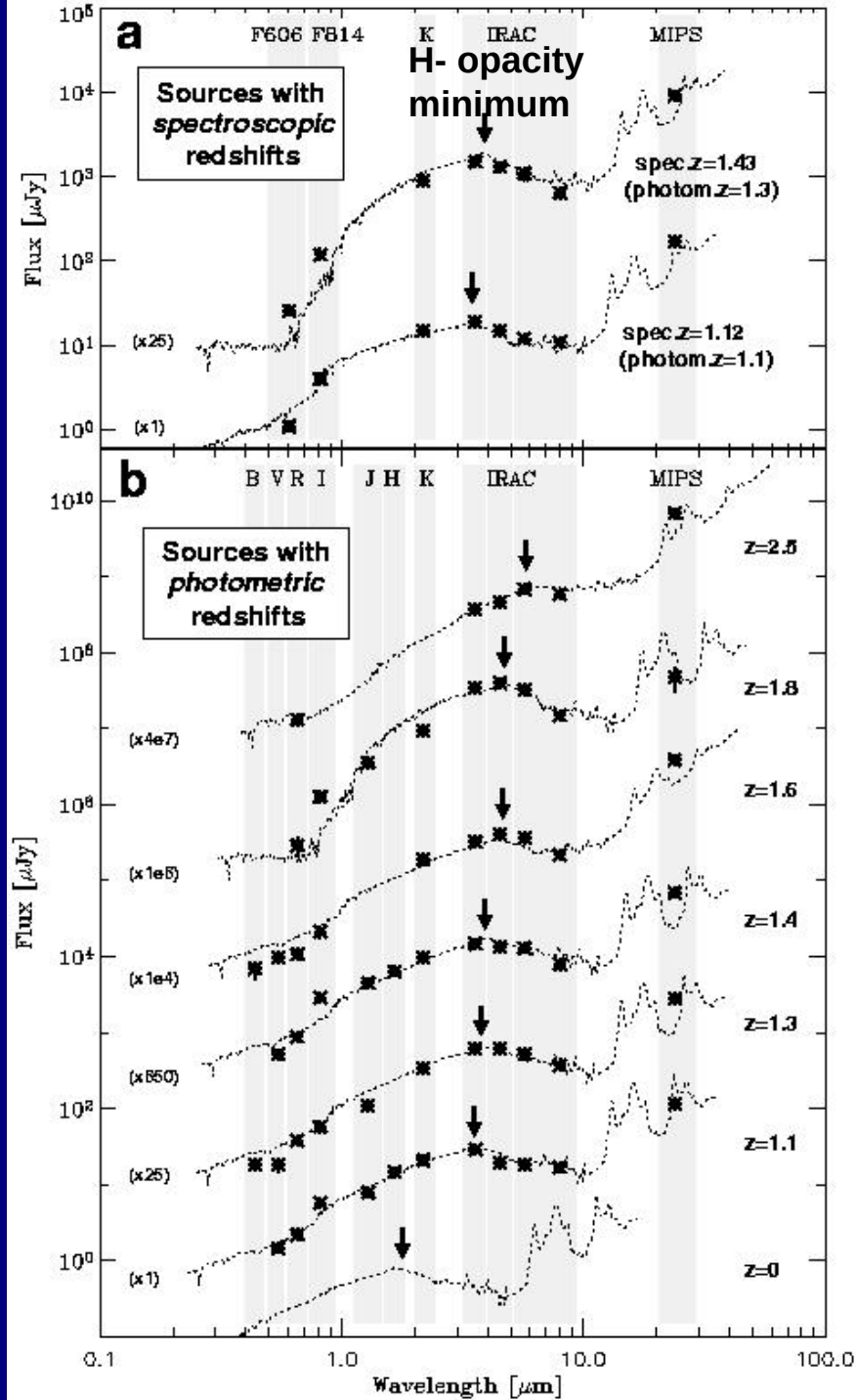
Lagache et al. (2004)

Photometric Redshifts

Spitzer + optical and nearIR data allow determination of phot **z up to z~3**

Lockman Hole Galaxies (Le Floc´h et al. 2004)

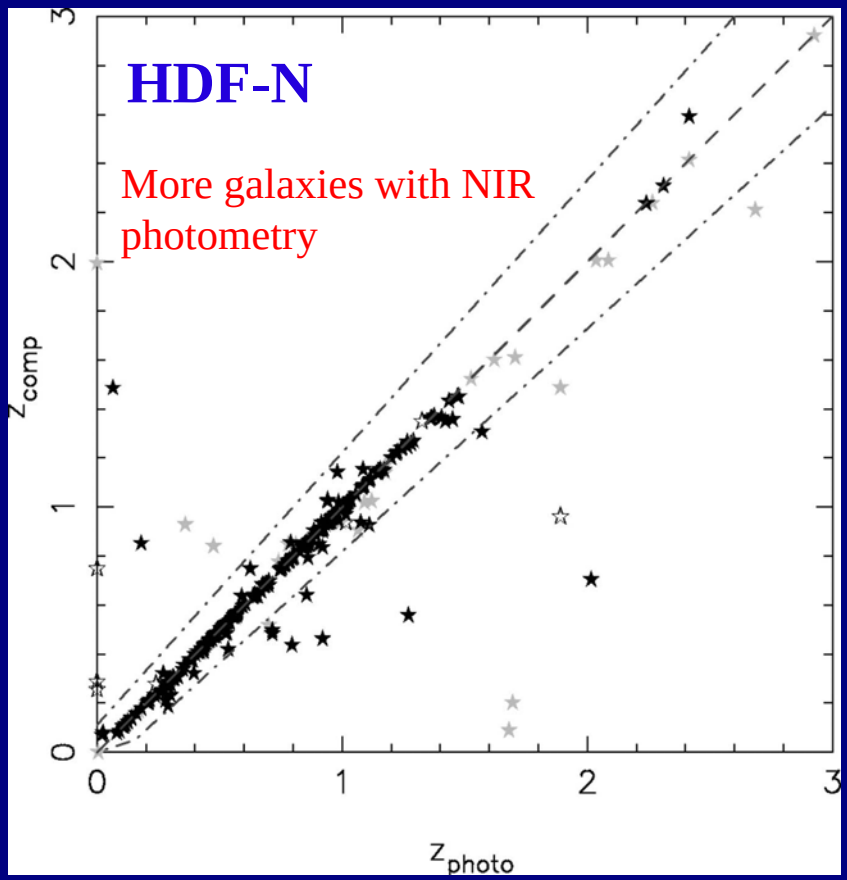


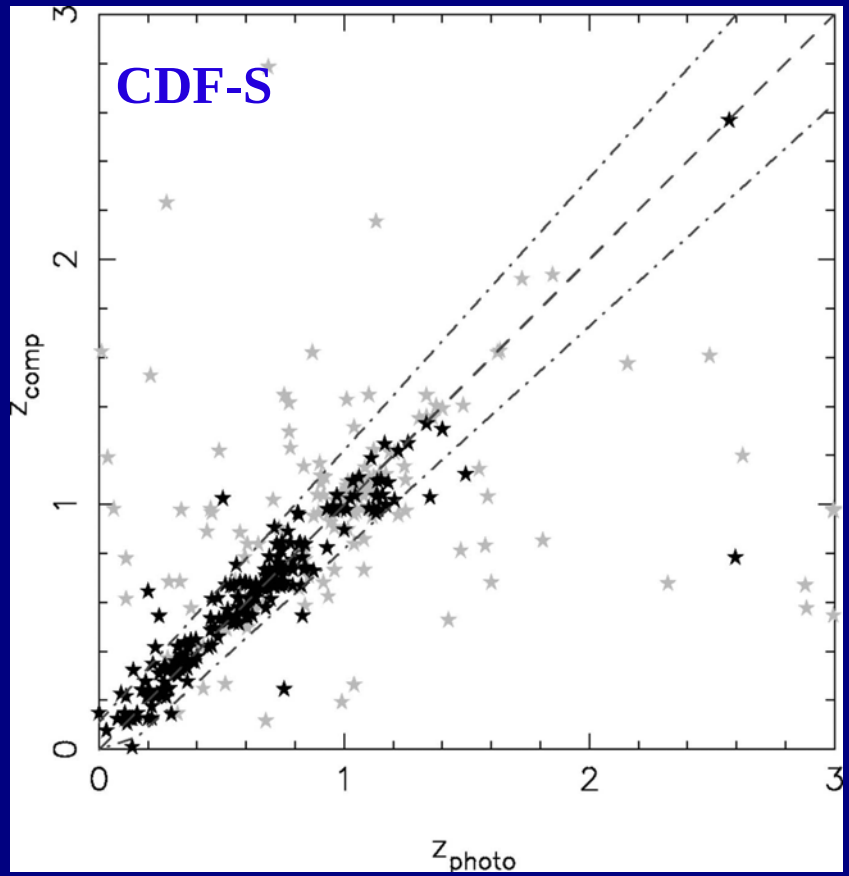


Photometric Redshifts: Pérez-González et al. 2005

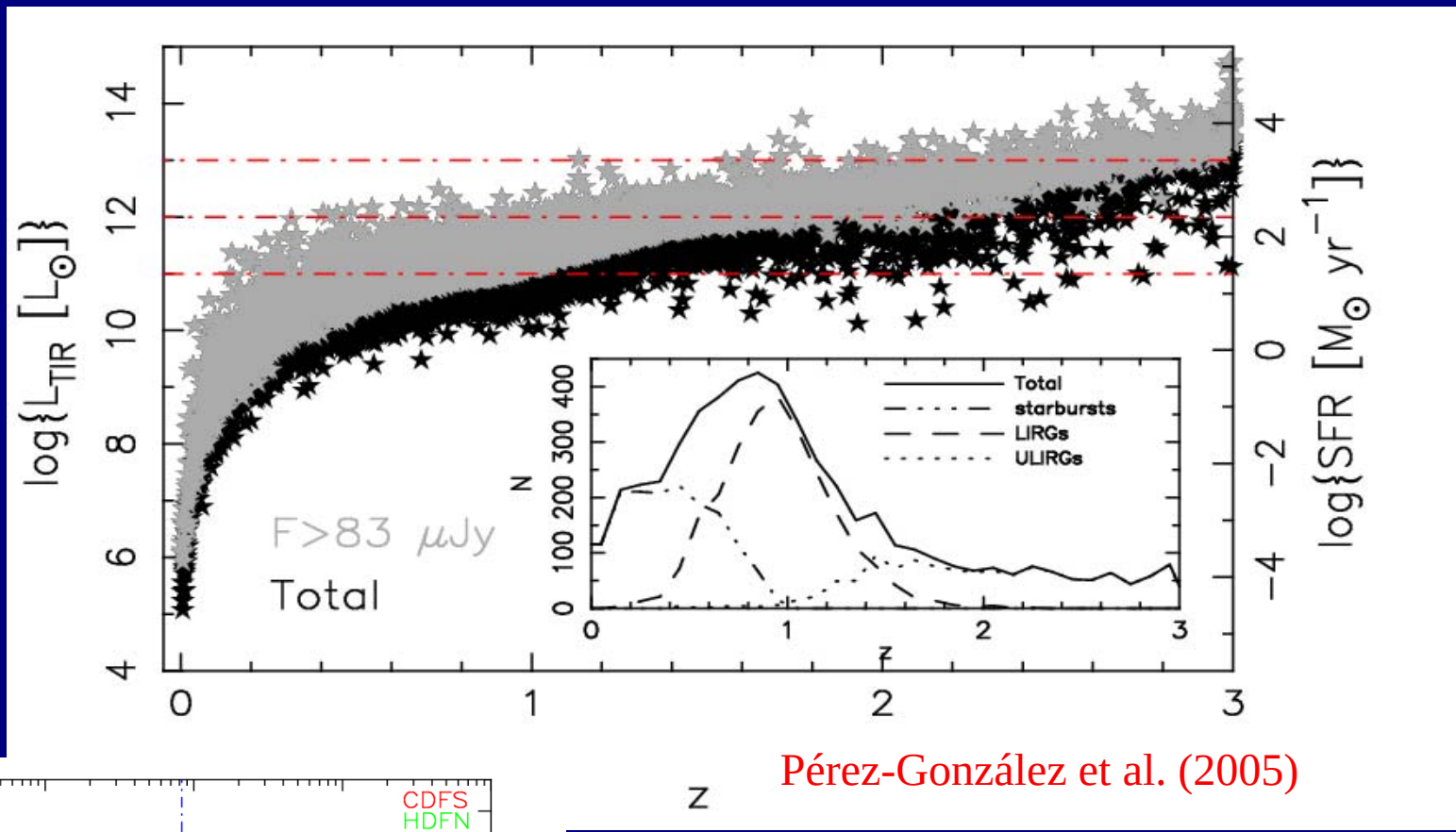
Sample of 24μm selected sample of high-z galaxies. Comparison with spectroscopic redshifts yields an accuracy:

$\sigma_z/(1+z)<0.2$ for 90% of objects

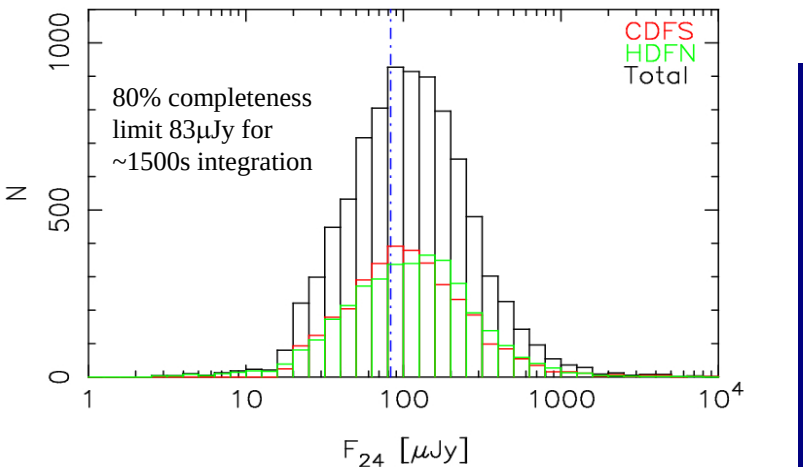




Star-forming galaxies: IR luminosities and SFRs



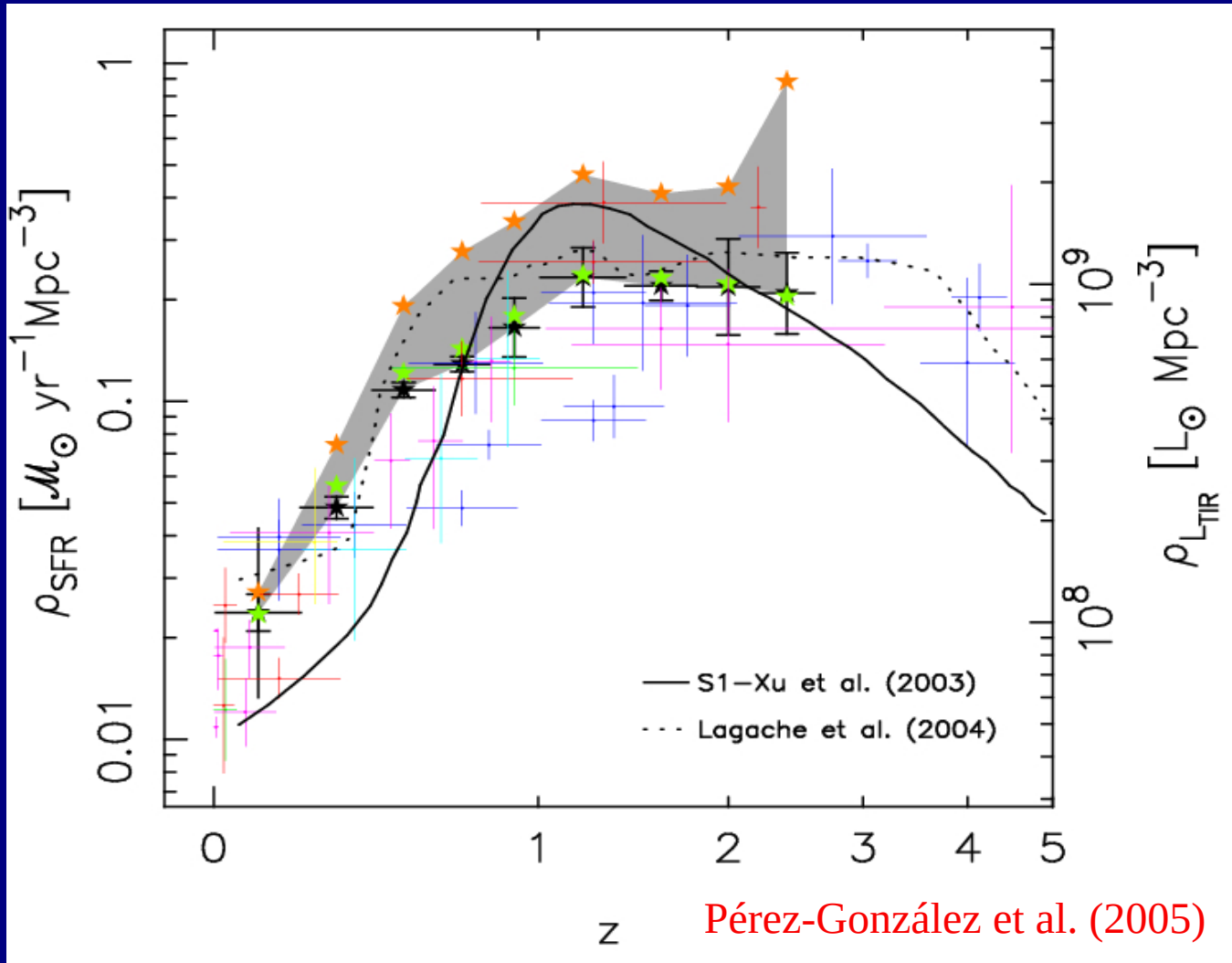
Pérez-González et al. (2005)



- Galaxies with moderate SFRs detected @ z<1
- Few ULIRGs @ z<1 because of low density
- 1<z<2 ~50% are LIRGs and 50% are ULIRGs
- z>2 population of HyLIRGs

Star Formation Rate Density of the Universe

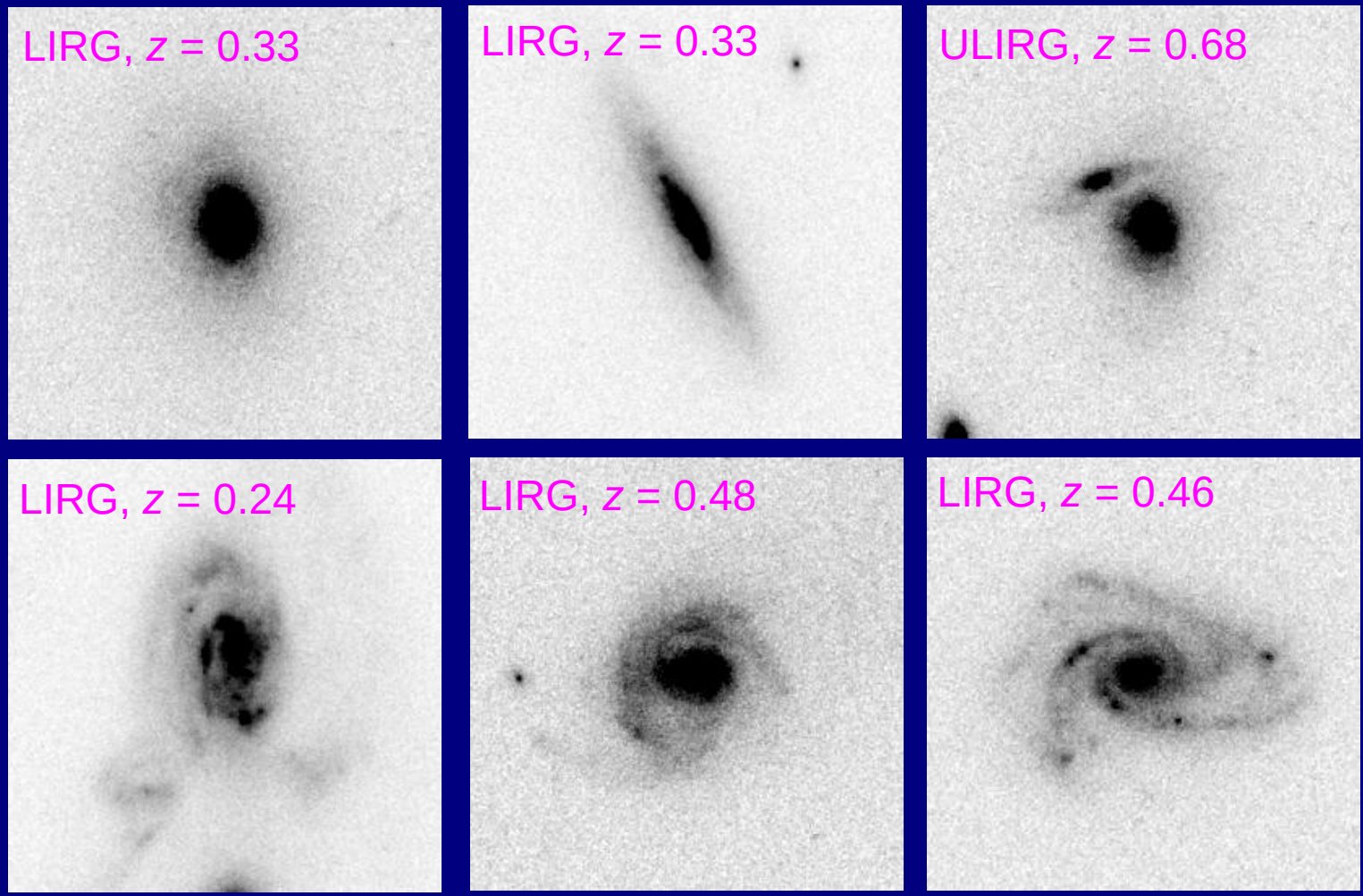
Star formation rate density from 24μm data (grey shaded area) is slightly higher, but generally in agreement with that from reddening-corrected UV/optical studies out to z ~ 1.5



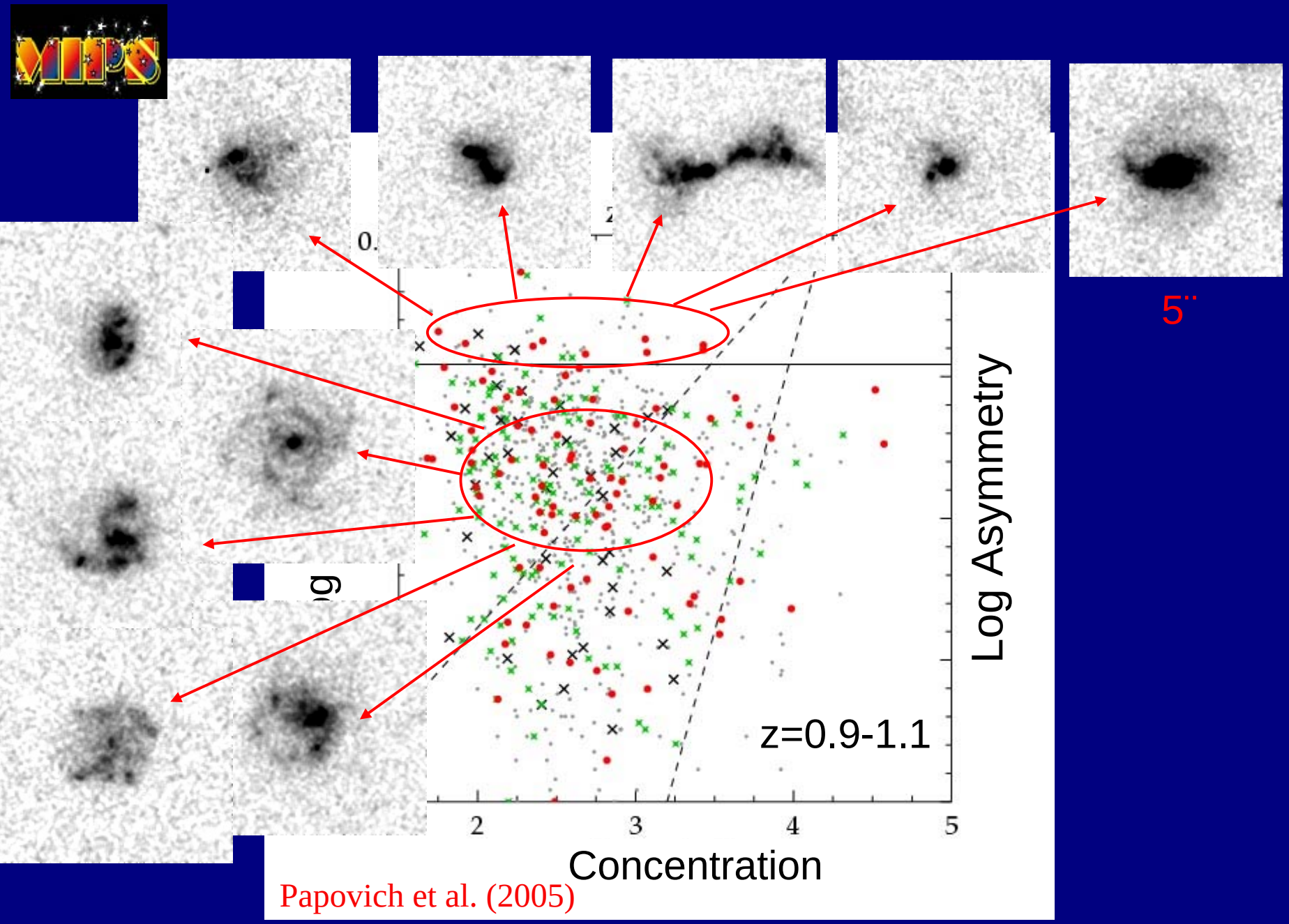
Pérez-González et al. (2005)

Morphological Studies of LIRGs and ULIRGs at z<1

HST/ACS imaging from GEMS (~rest-frame B-band)



Papovich, Rix, Bell, McIntosh, Jogee (private comunication)



Papovich et al. (2005)

Even the most IR luminous galaxies show a range of rest-frame B-band morphologies

How many hidden AGN can be confused with star-forming galaxies?

High-z AGN are routinely selected from deep X-ray (<10keV) exposures (Chandra, XMM).

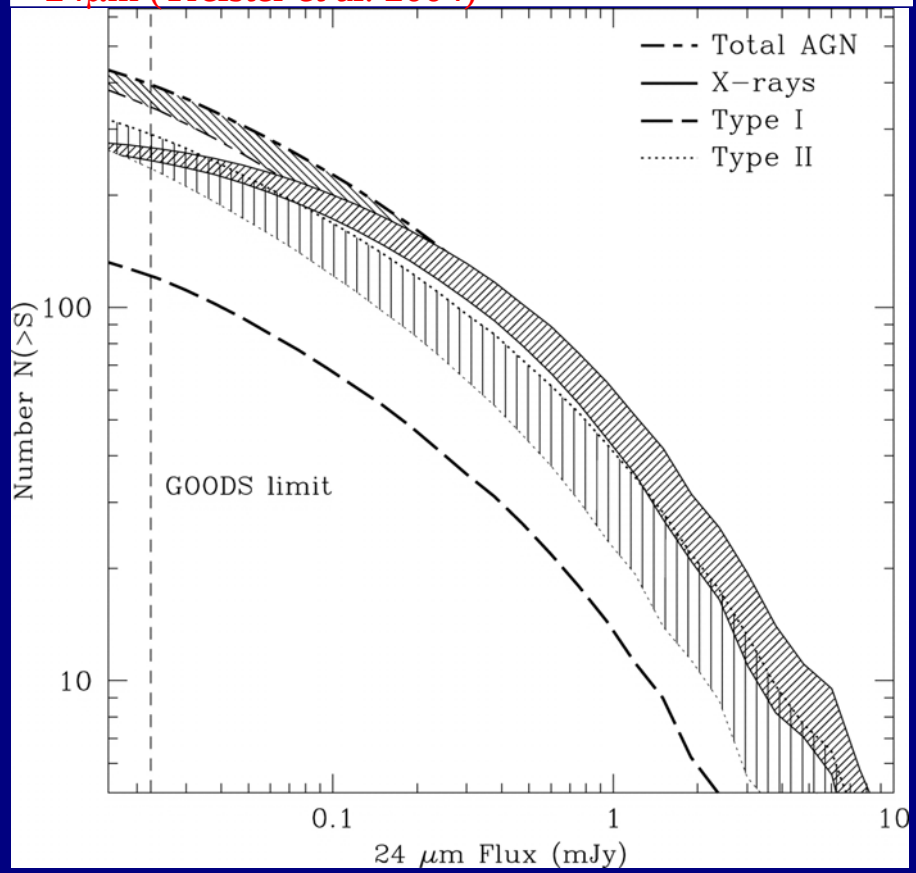
Compton-thick (obscured) AGN make a major contribution to the X-ray background and might not be detected in X-rays.

From deep X-ray Chandra observations observed ratio of obscured to unobscured AGN is 1:1 for objects detected in hard X-rays.

Models predict ratio of obscured to unobscured AGN 2:1 to 3:1 →

Where are the "missing" obscured AGN? Can we use mid-IR observations to find them?

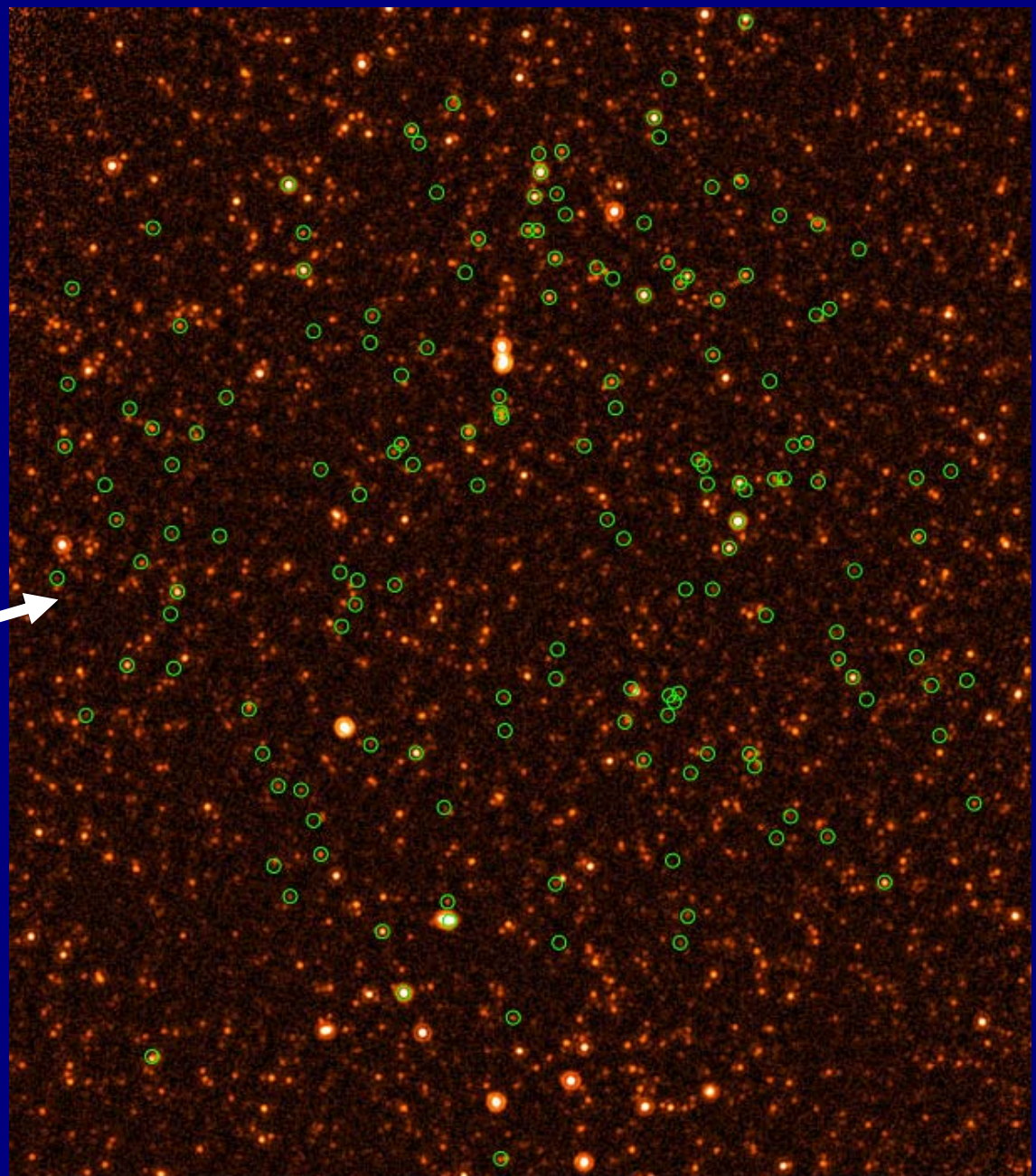
Predictions for unobscured and obscured AGN at 24μm (Treister et al. 2004)



Nature of Infrared Luminous AGN selected in X-rays

Models of the X-ray background predict a large population of obscured AGN that should be bright in the IR

Sources from Chandra Deep Field - South 1Ms exposure (green circles) superimposed on the MIPS 24μm image of Chandra Deep Field-South:
62% of hard X-ray sources are detected at 24μm



Rigby et al. (2004)

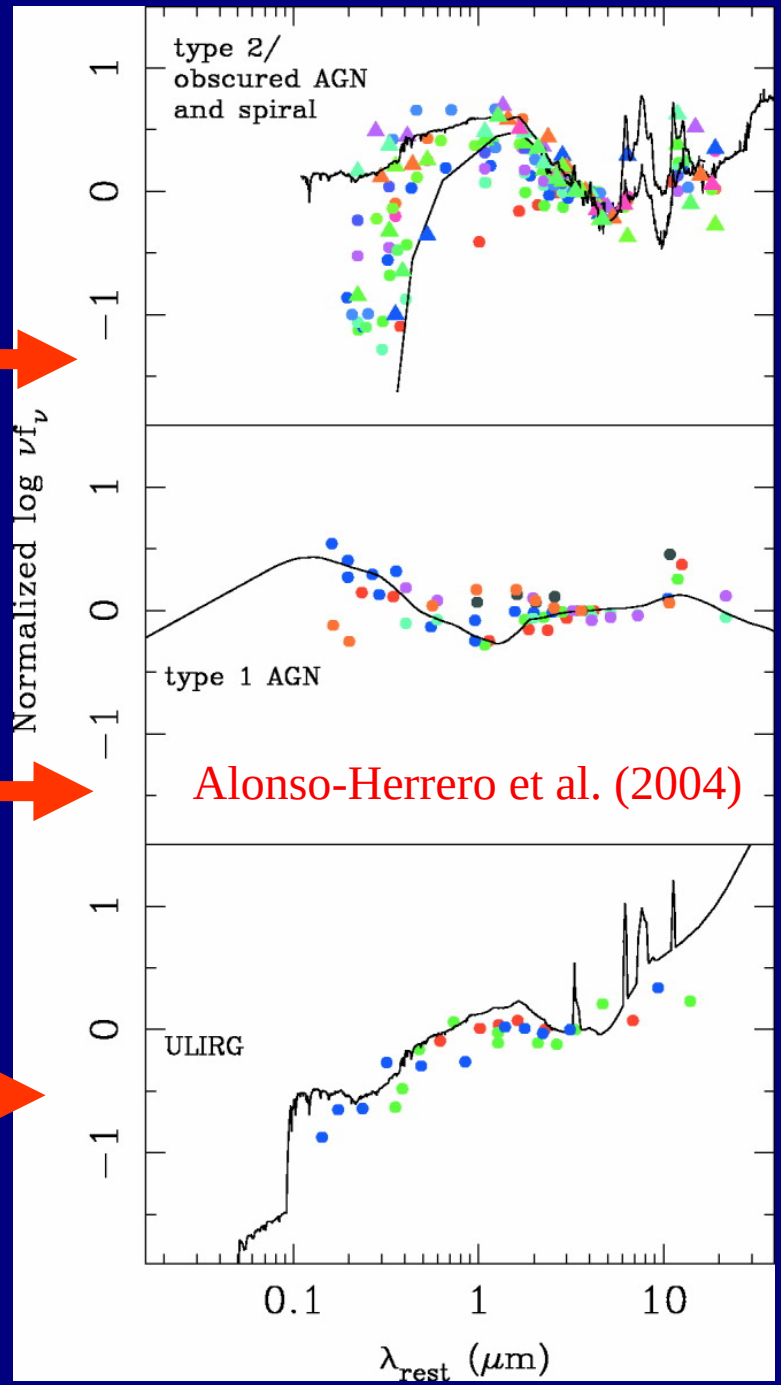
SEDs of IR Luminous AGN selected in hard X-ray

>50% have SEDs resembling those of type2/obscured galaxies and spiral galaxies (ie, SEDs dominated by STELLAR EMISSION)

25% have SEDs similar to type 1 AGN (eg, Elvis et al. 1994 QSO)

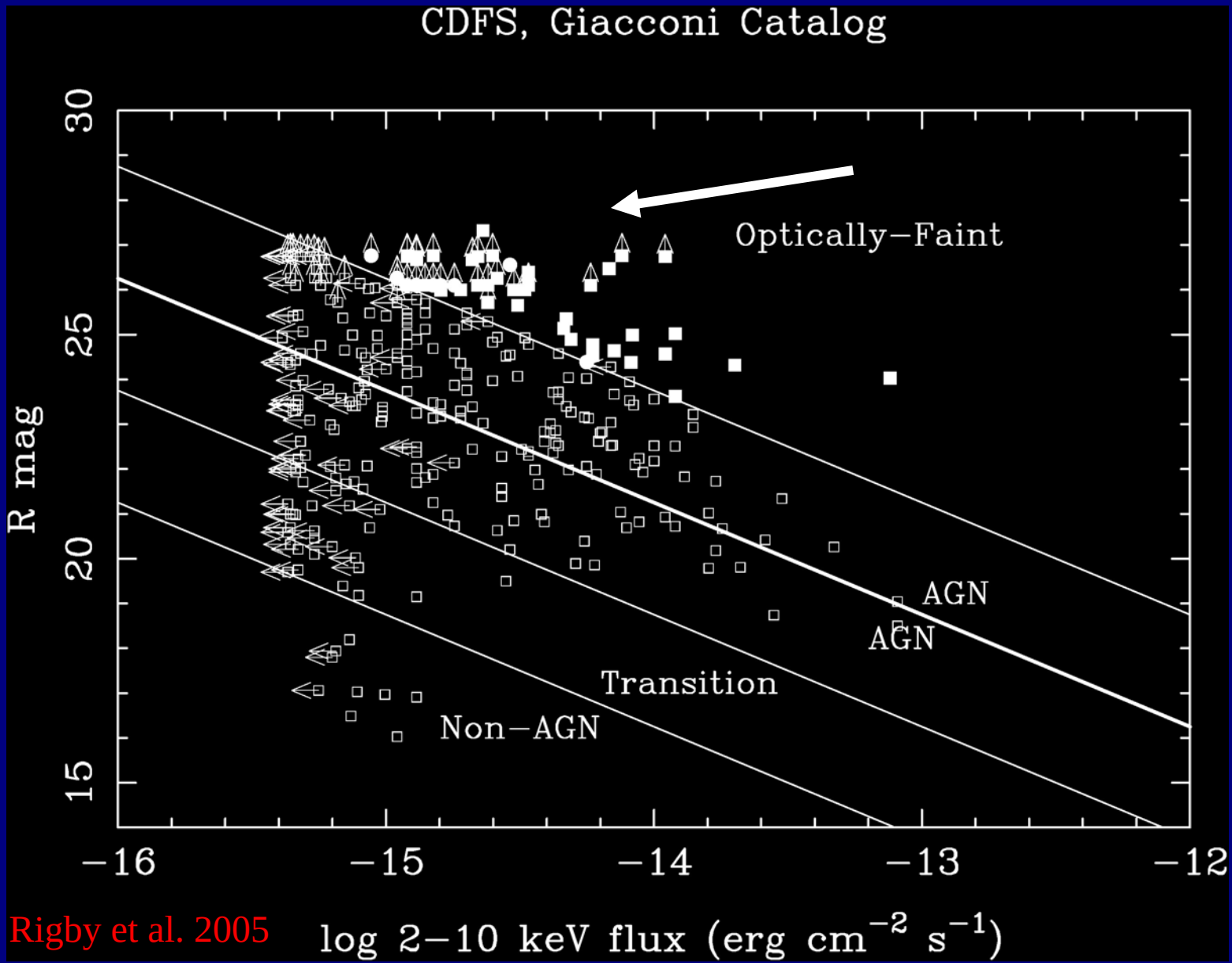
Small fraction have SEDs similar to those of warm ULIRGs in the Local Universe

About 30% of hard X-ray sources do NOT have a 24μm counterpart



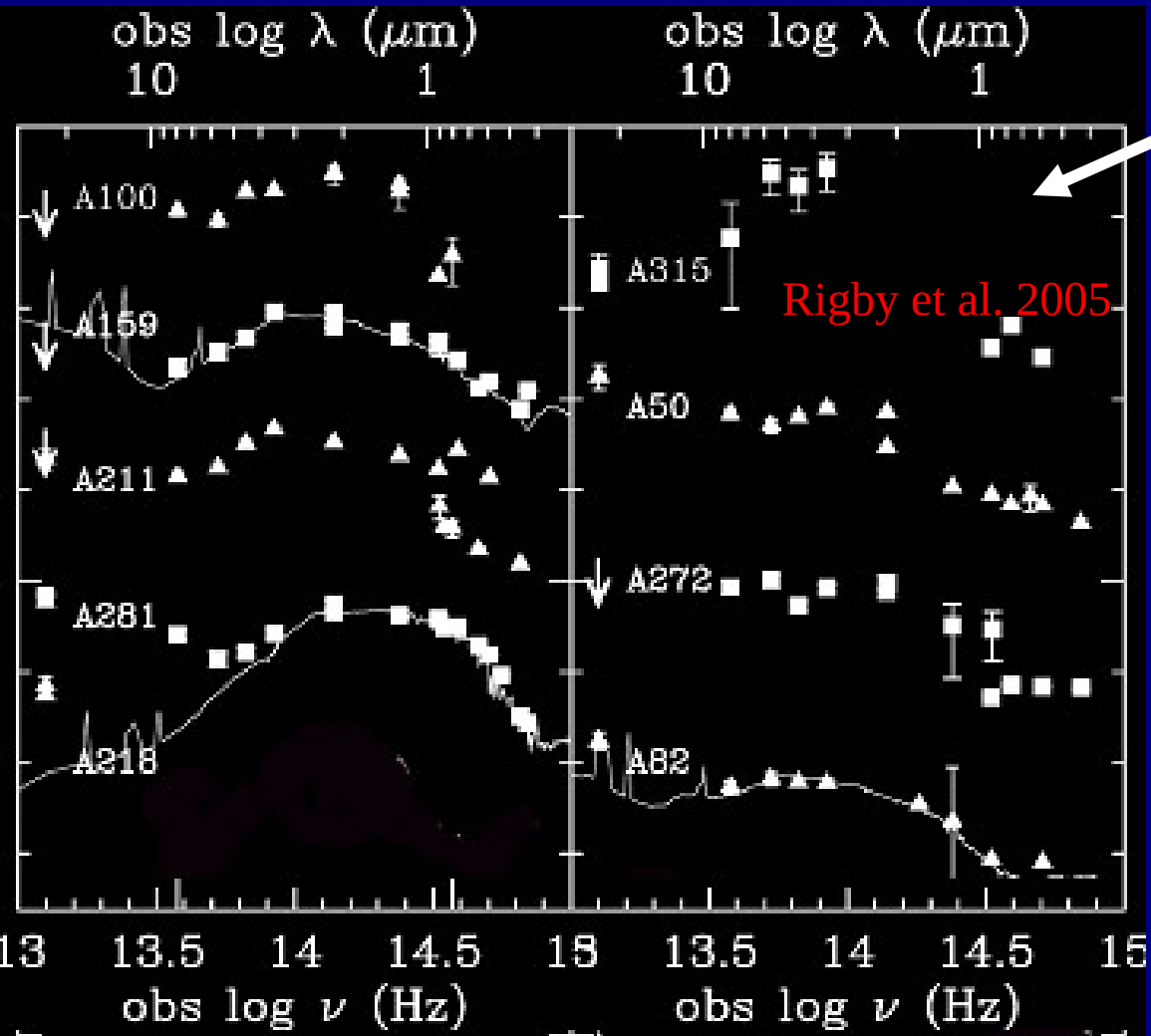
Alonso-Herrero et al. (2004)

Optically faint X-ray sources in the CDFS

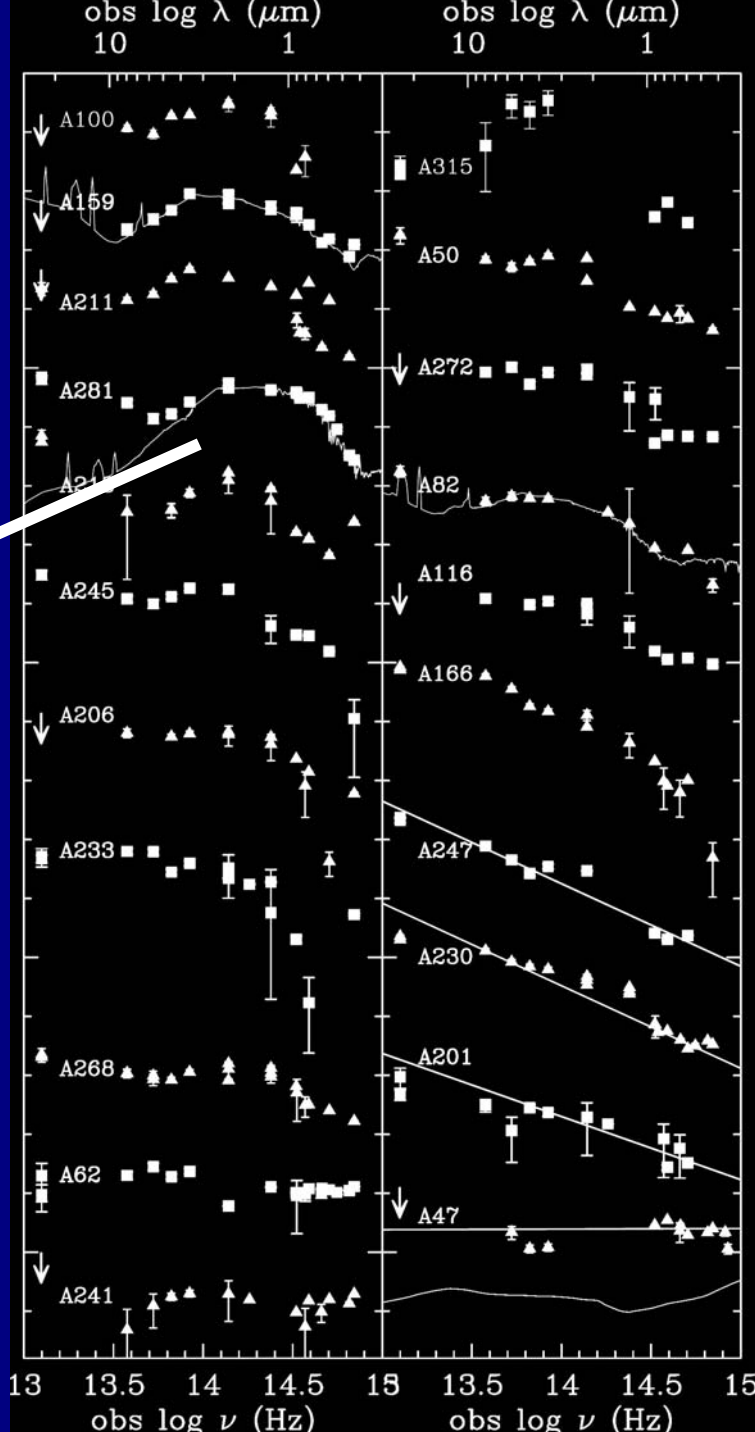


Rigby et al. 2005

Many have prominent rest-frame near-IR stellar peaks at typical QSO redshifts, z~1-2.5, not at the very high redshifts hypothesized by others



Rigby et al. 2005

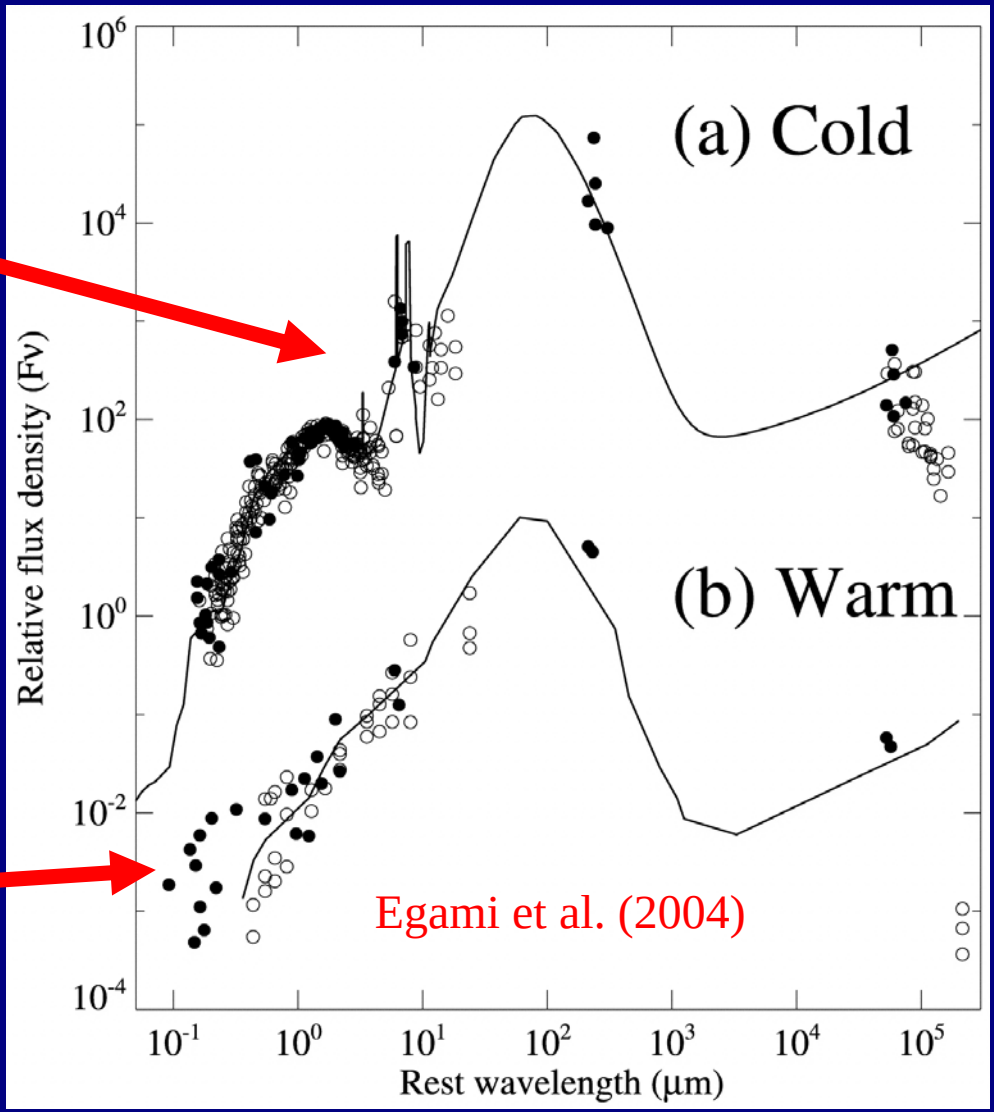


SEDs of SCUBA/VLA sources in the Lockman Hole

Individually Detected ULIRGs have SEDs Like Local Ones

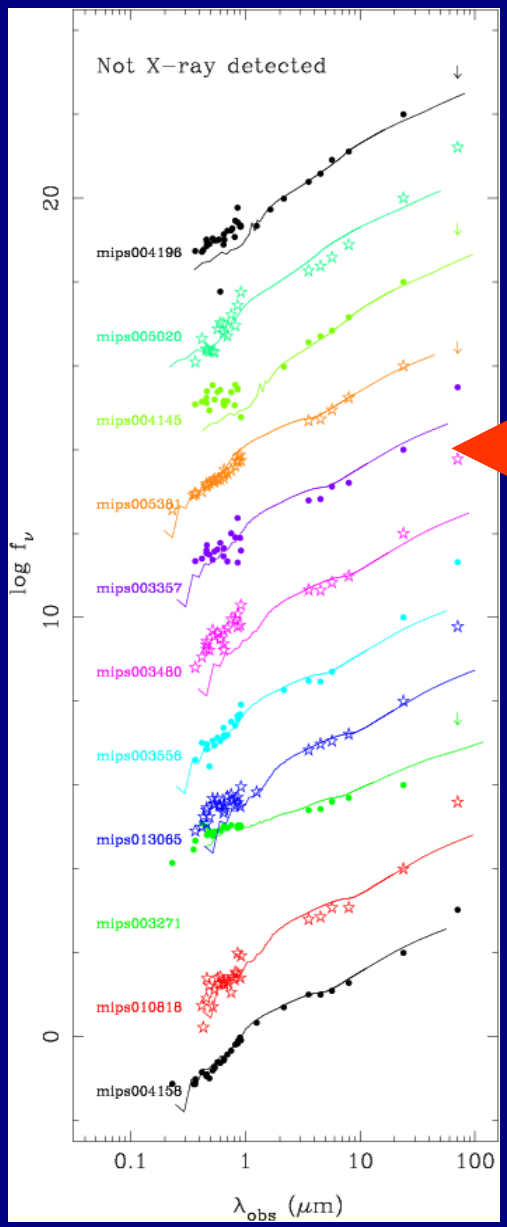
"PAH" features dominate rest frame SED, ~ 7 to ~ 9μm. Hence, dominates Spitzer 24μm signals for $1 < z < 3$

PAH missing in AGN



Nature of IR Power Law Galaxies in the CDFS

Alonso-Herrero et al. (2006)

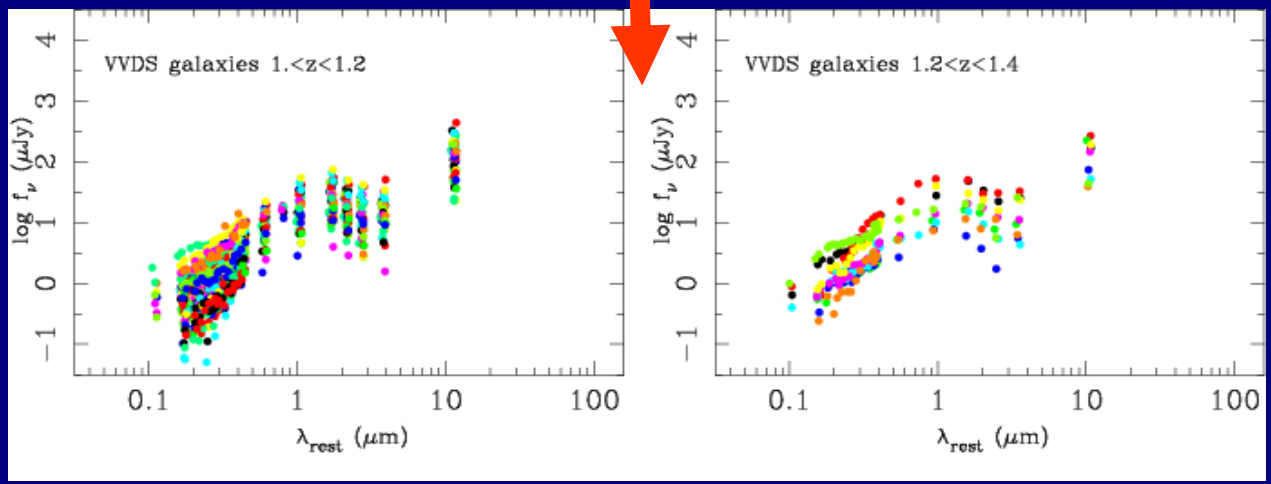


24μm (down to 83μJy) galaxies with IRAC power laws are candidates to AGN. Selection criteria:
$f_\nu \sim \nu^\alpha$, $\alpha < -0.5$ over 3-8μm

~45% are NOT detected in any Chandra X-ray band

SEDs of the galaxies not detected in X-rays are similar to those of warm ULIRGs (eg Mkn231) or obscured AGN and have z_{phot}~1 to 3

Compare with VVDS massive star-forming galaxies



Nature of IR Power Law Galaxies in the CDFS

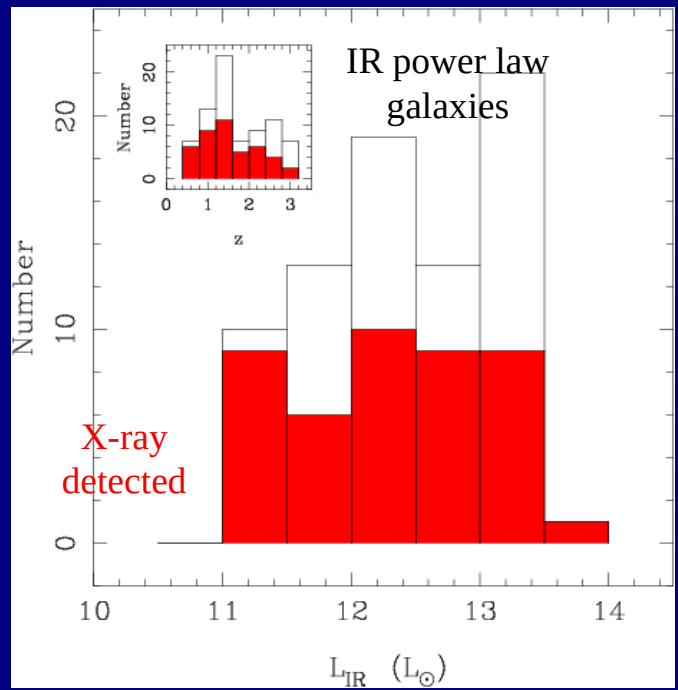
IR power law galaxies NOT detected in any Chandra X-ray band have X-ray upper limits $L_{0.5\text{-}8keV}<10^{42}\text{-}10^{44}$ erg/s (consistent with containing obscured AGN)

Sources NOT detected in X-rays have $L_{IR}>10^{12}L_{\odot}$ and X-ray to IR flux ratios typical of warm (AGN dominated) ULIRGs, and constitute good candidates to X-ray absorbed AGN.

Sources detected in X-rays look mostly line broad and narrow line SED AGN, have X-ray luminosities $L_{0.5\text{-}8keV}=10^{42}\text{-}10^{44}$ erg/s

We find a ratio of obscured to unobscured AGN detected at 24mm of 2:1 consistent with the lower range of Treister et al. 2004 predictions.

More obscured AGN can be selected from radio observations



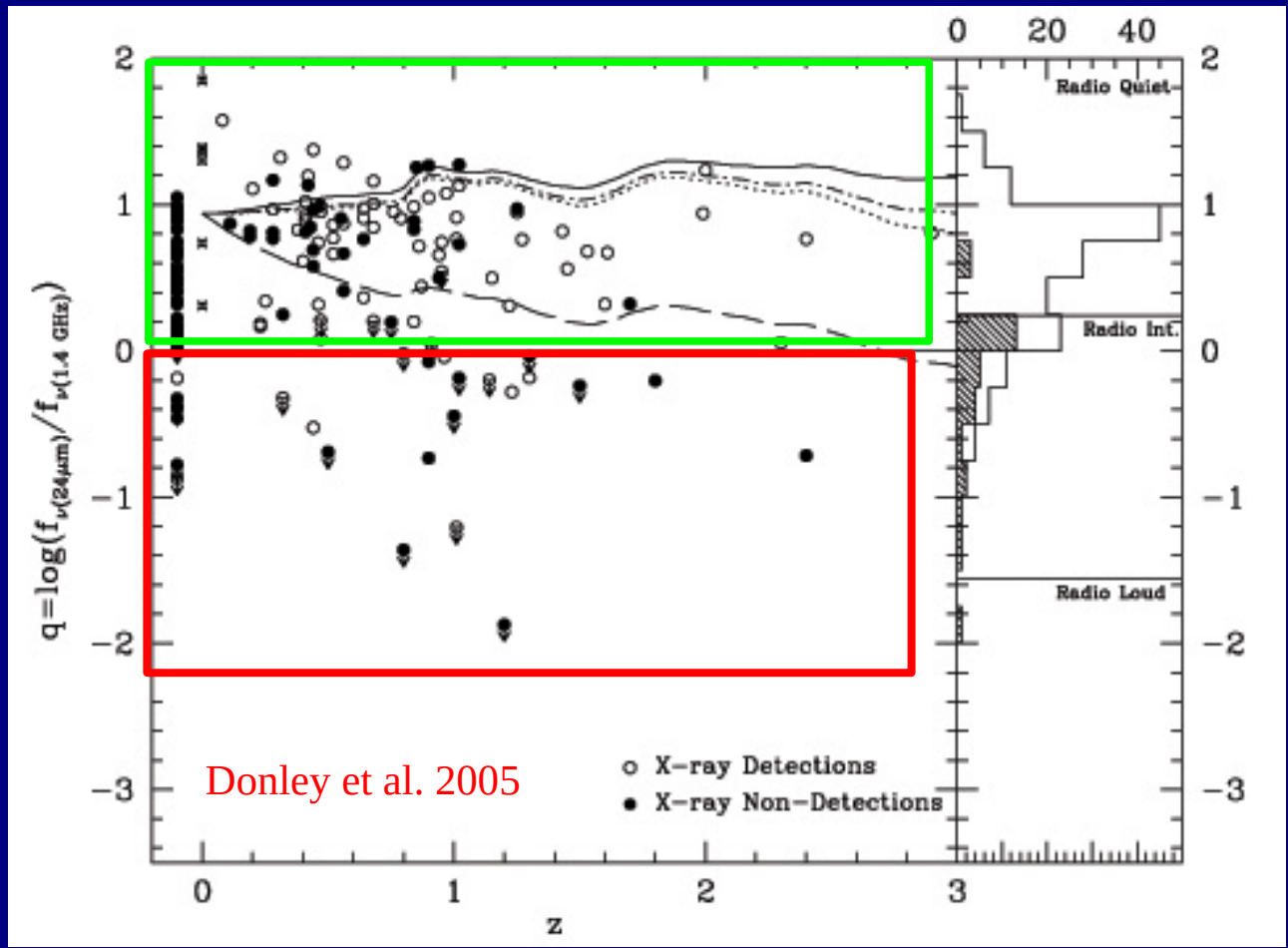
Radio Selection of "X-ray" free AGN

Galaxies are too bright in radio to be star-forming galaxies
Allows identification of AGN samples without using X-ray observations

Star-forming galaxies and Radio-quiet AGN

Radio-loud and radio-intermediate AGN

~30% of radio-loud AGN are not detected in X-rays in CDF-N!

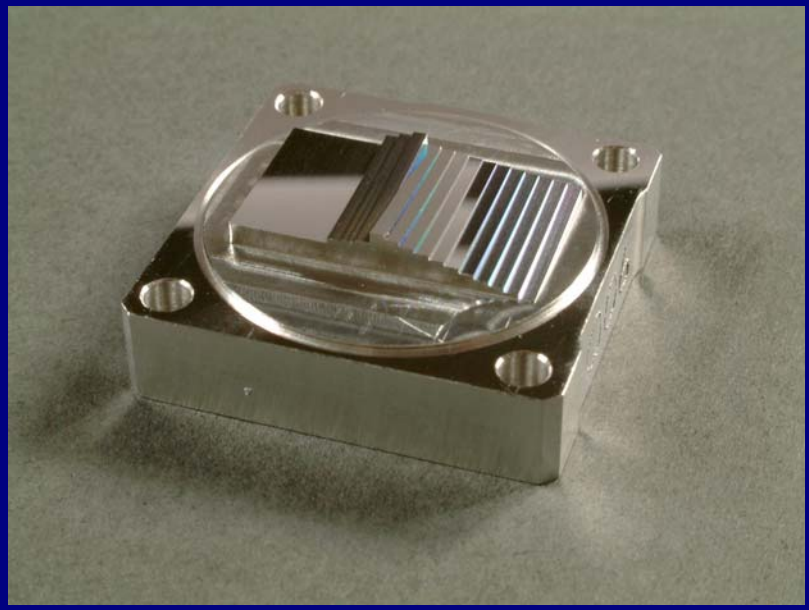




JWST/MIRI

- 6 m. deployable mirror
- Passive cooling
- L2 orbit

Scientific Goals:
First Light Objects
Assembly of galaxies
Birth of stars and planetary systems
Planetary systems and origins of life



MIRI: The Mid-IR instrument for the JWST *(Wright et al. 2004)*

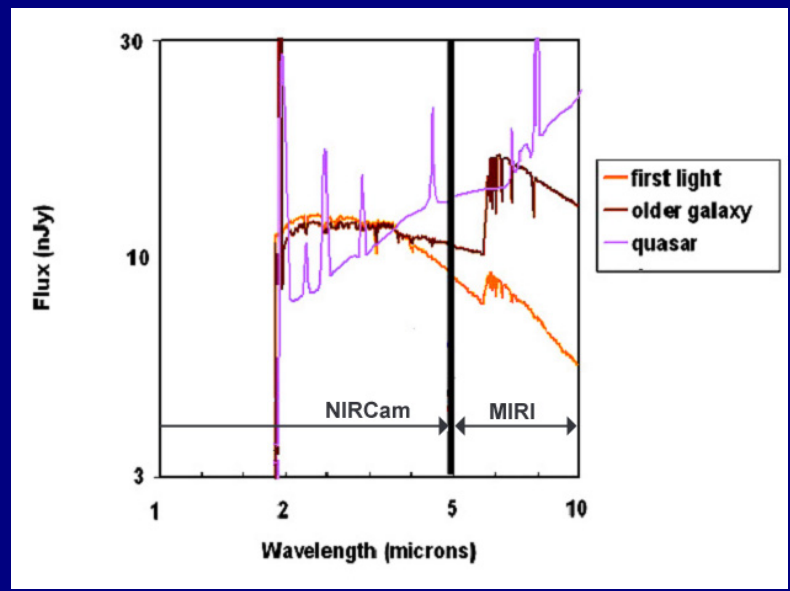
5 – 28 μm
Camera and spectrometer
R ~ 3000
IFUs (image slicers)

JWST/MIRI: Capabilities

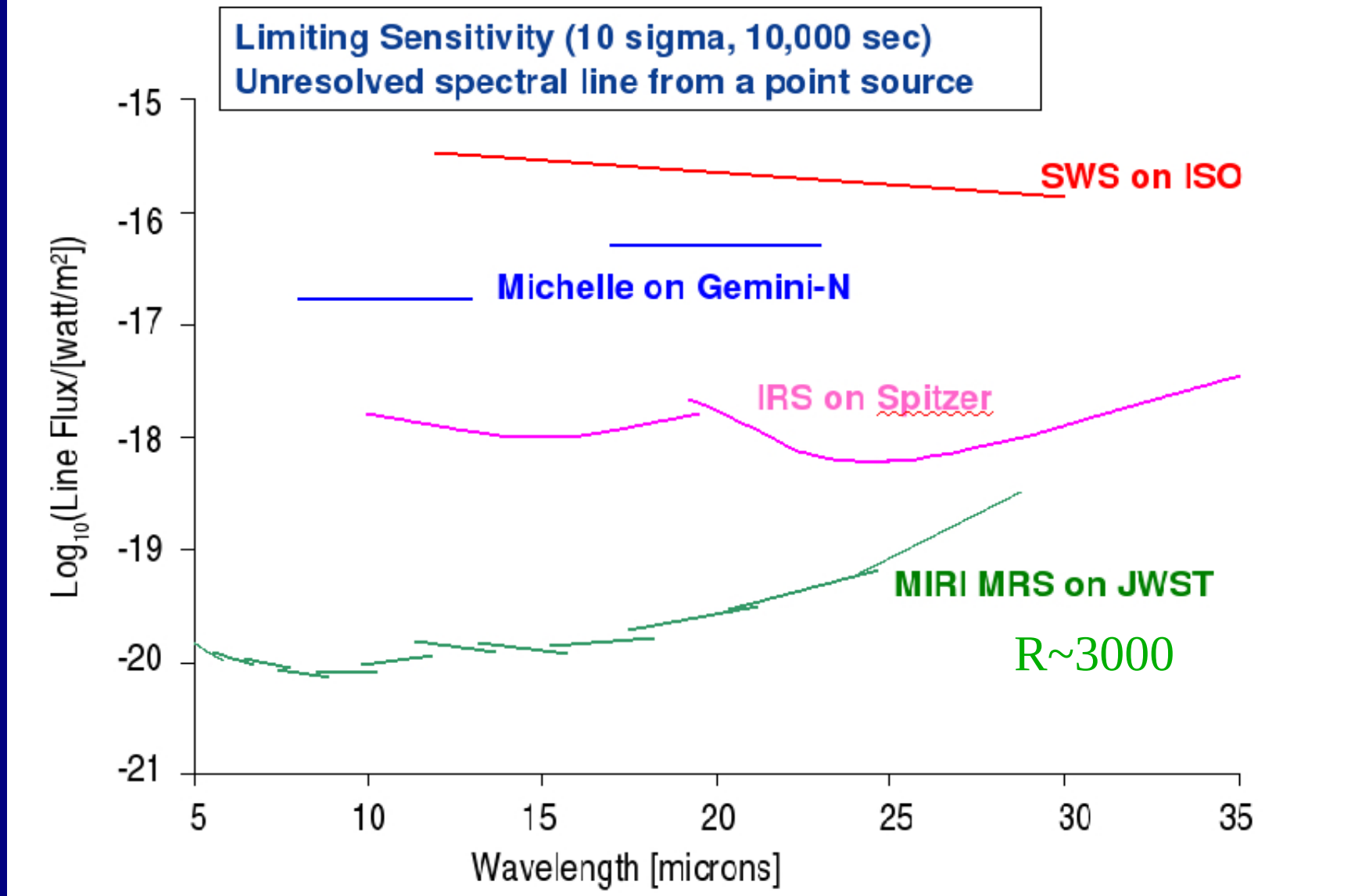
Mode	Wavelengths	Spectral Resolution	Field of View	Comments
Imaging	5.6, 7.7, 10, 11.3, 12.8, 15, 18, 21, and 25.5 μm	. . . = R=5 typical	1.9x1.4 arcmin	Mix of broad and narrow filters
Coronography	10.65, 11.3, 16, and 24 μm	R=10	25x25 arcsec	
Low-resolution spectroscopy	5-11 μm	R=100	5x0.6 arcsec slit	
Medium-res. spectroscopy	5-28.5 μm	R~2000	3.5x3.5 to 7x7 arcsec	Integral field unit

IMAGING

Confirming first light objects requires MIRI.
This plot compares the spectra of a new galaxy ("first light" - slightly reddened by a foreground galaxy) with an older one and a quasar, all placed at high redshift (z = 15).
The three spectra are sufficiently similar in the NIRCAM range that surveys with that instrument will not be able to distinguish them. With the addition of MIRI data at 5.6 and 7.7 μm, the colors of first light objects diverge from the others and they can be properly identified.



JWST/MIRI: Spectroscopic Sensitivity



Integral Field Spectroscopy Unit

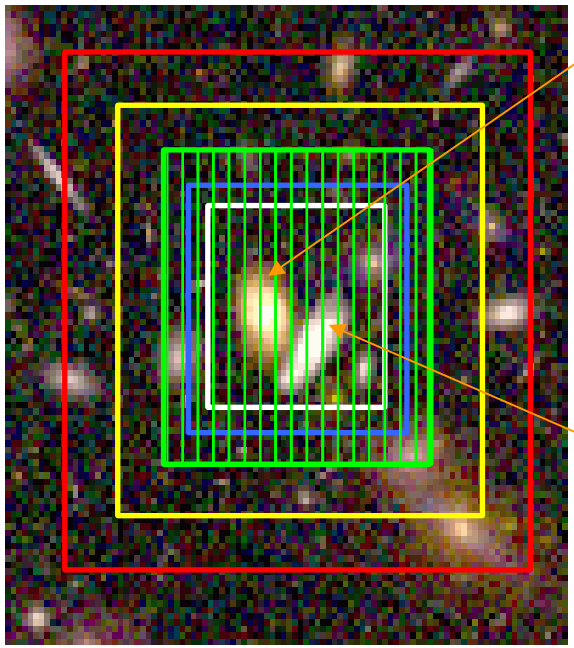
Each channel's field of view is sliced, dispersed and detected.

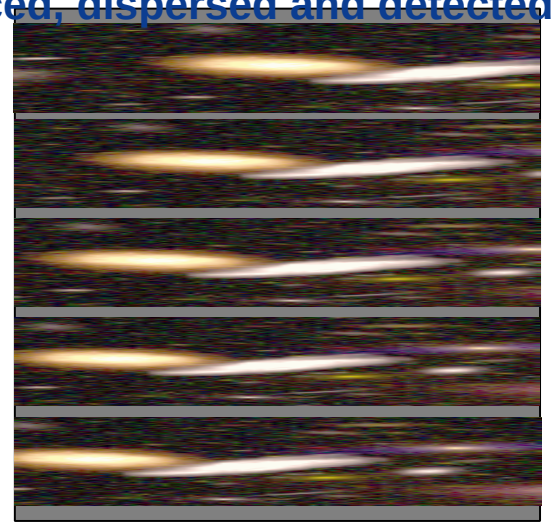
Channel 1
(4.9 - 7.7 μm)
FoV: 3".7x3".7

Channel 2
(7.4 - 11.8 μm)
FoV: 4".7x4".5

Channel 3
(11.4 - 18.2 μm)
FoV: 6".2x6".1

Channel 4
(17.5 - 28.8 μm)
FoV: 7".7x8".9





Wavelength/Velocity

IFU Output Format
Spectrometer input
"slit"