Extragalactic surveys from Spitzer to Herschel

1. Brief presentation of Spitzer extragalactic surveys
2. What have we learnt from them ?
3. What are the key issues raised by Spitzer surveys ?

4. Brief presentation of the Herschel extragalactic surveys
5. What will we learn from them ?
6. What are the key issues that Herschel will not address ?

(see "The Herschel-ALMA Synergies" by Tom Wilson, ESO report, astro-ph)

1- Brief presentation of Spitzer extragalactic surveys

Ultra-deep:

GOODS (Great Observatories Origins Deep Survey, PI M.Dickinson) 2x(10'x15')

2 fields centered on HDFN & CDFS: S(24 μm)= 20 μJy (5σ), S(70 μm)= 2 mJy

New ! FIDEL (Far Infrared Deep Extragalactic Legacy survey)= 0.6 sq. deg.

Extended Groth Strip (10'x90'),CDFS (30'x30'): S(24μm)= 30μJy, S(70μm)= 3mJy

→ *GOODS-S= CDFS = Best region for an ALMA deep field*

Deep:

Guaranteed Time (PI Rieke)

& COSMOS (PI N.Scoville, D.Sanders)

S(24 μm)= 80 μJy, S(70 μm)= 50 mJy

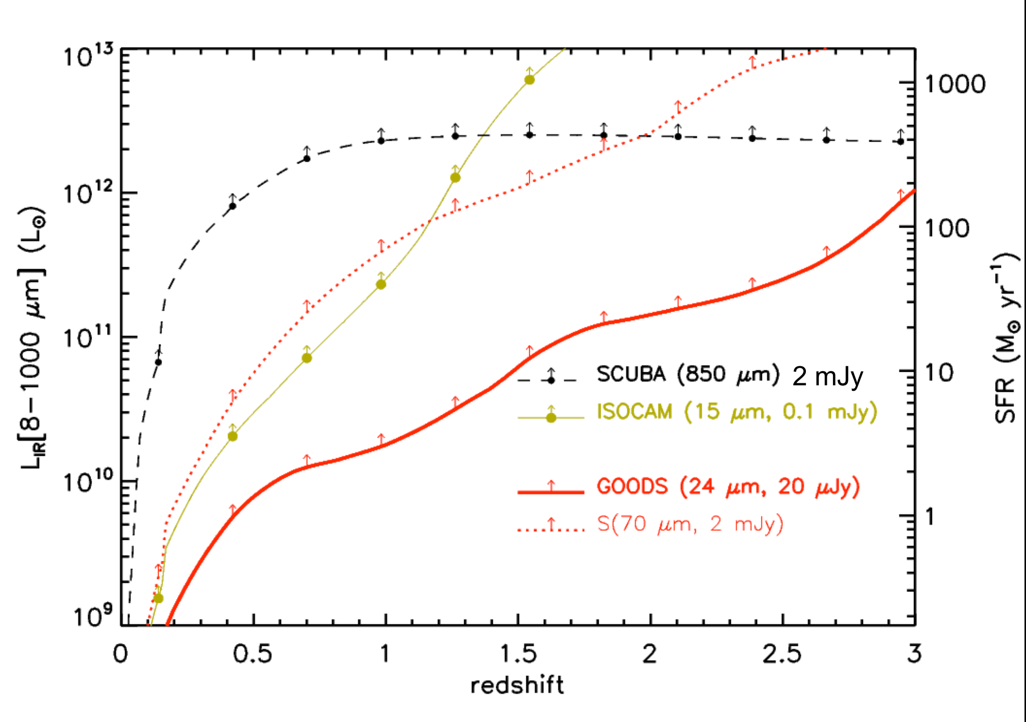
GT (EGS, CDFS,…): 30'x30' fields ;

COSMOS= 1.4° x 1.4° (2sq.deg.)

Shallow:

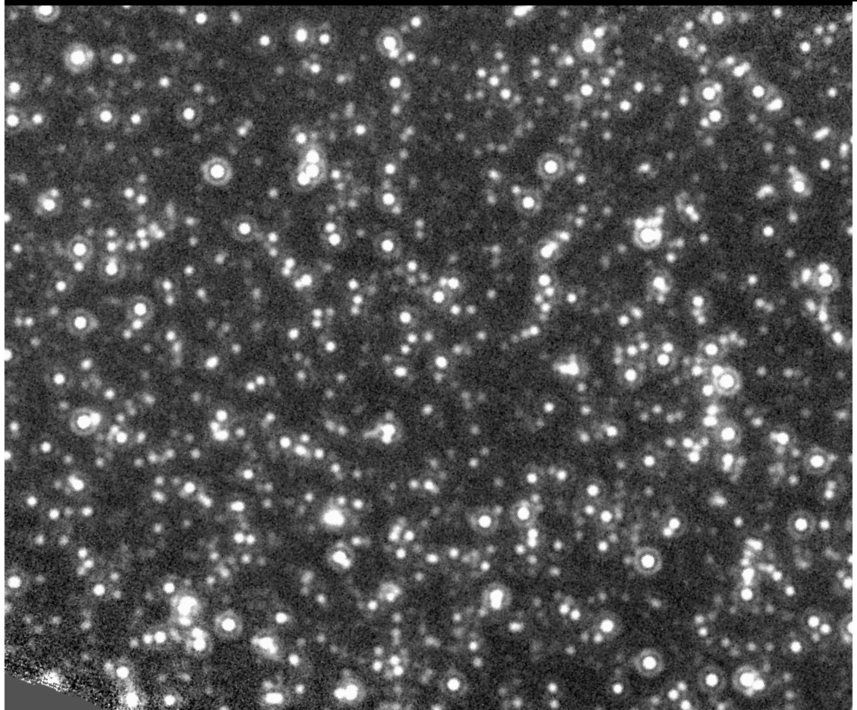
SWIRE fields several sq.deg.

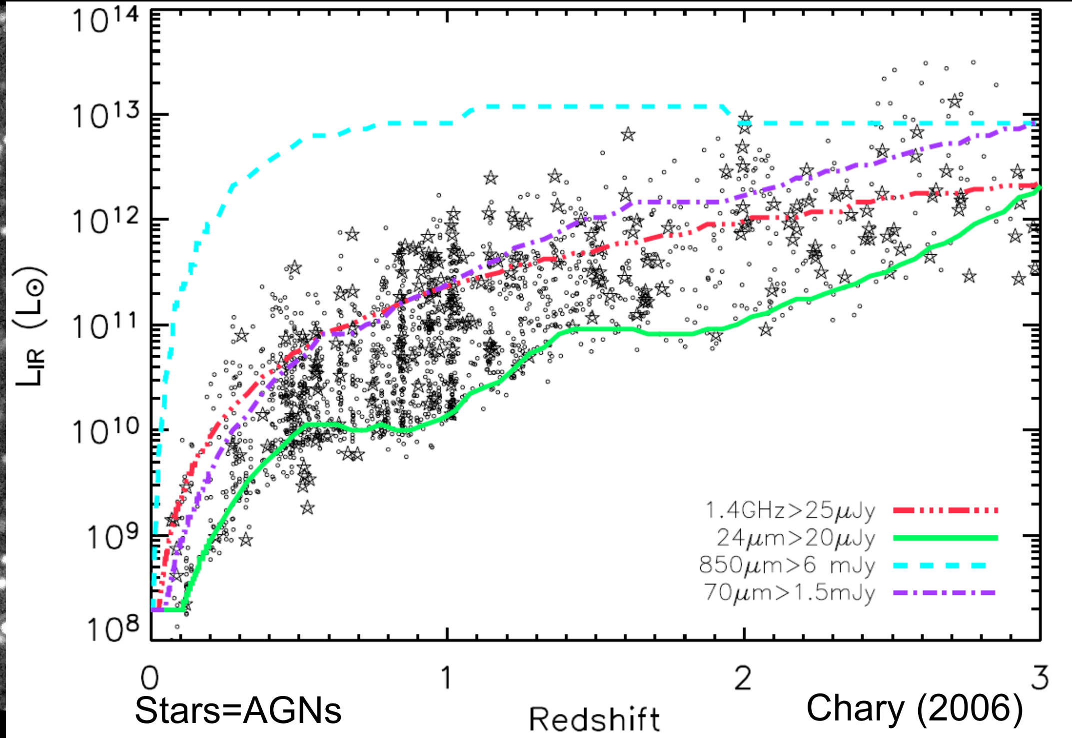
(PI C.Lonsdale)

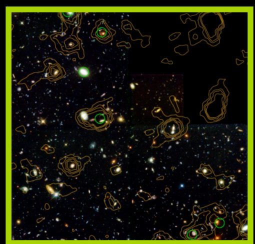


GOODS @ 24 μm: confusion limited ?…

7 beams/src (FWHM=5.7")@ 20μJy
(10 beams/src if 0.8 x FWHM)

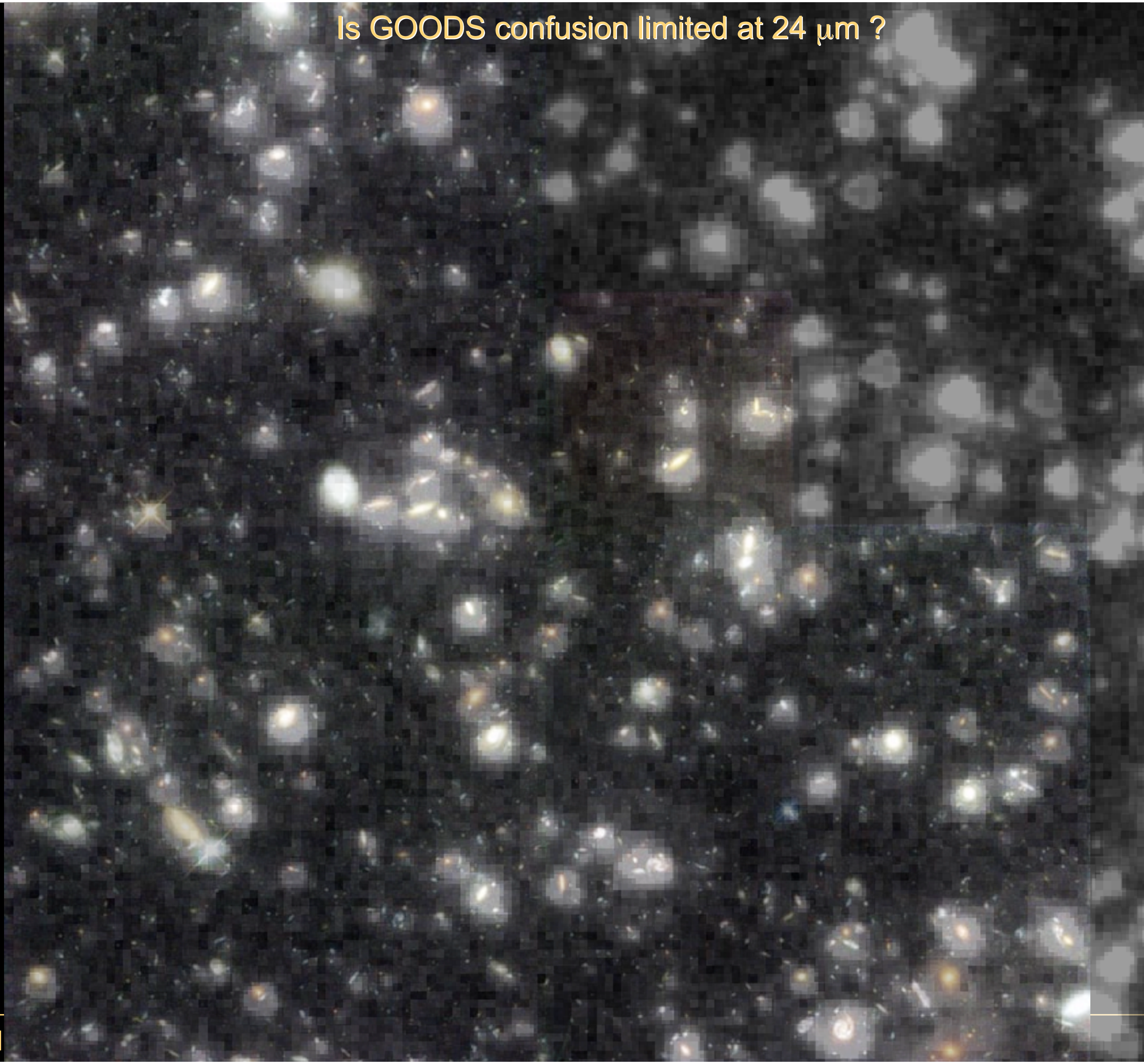


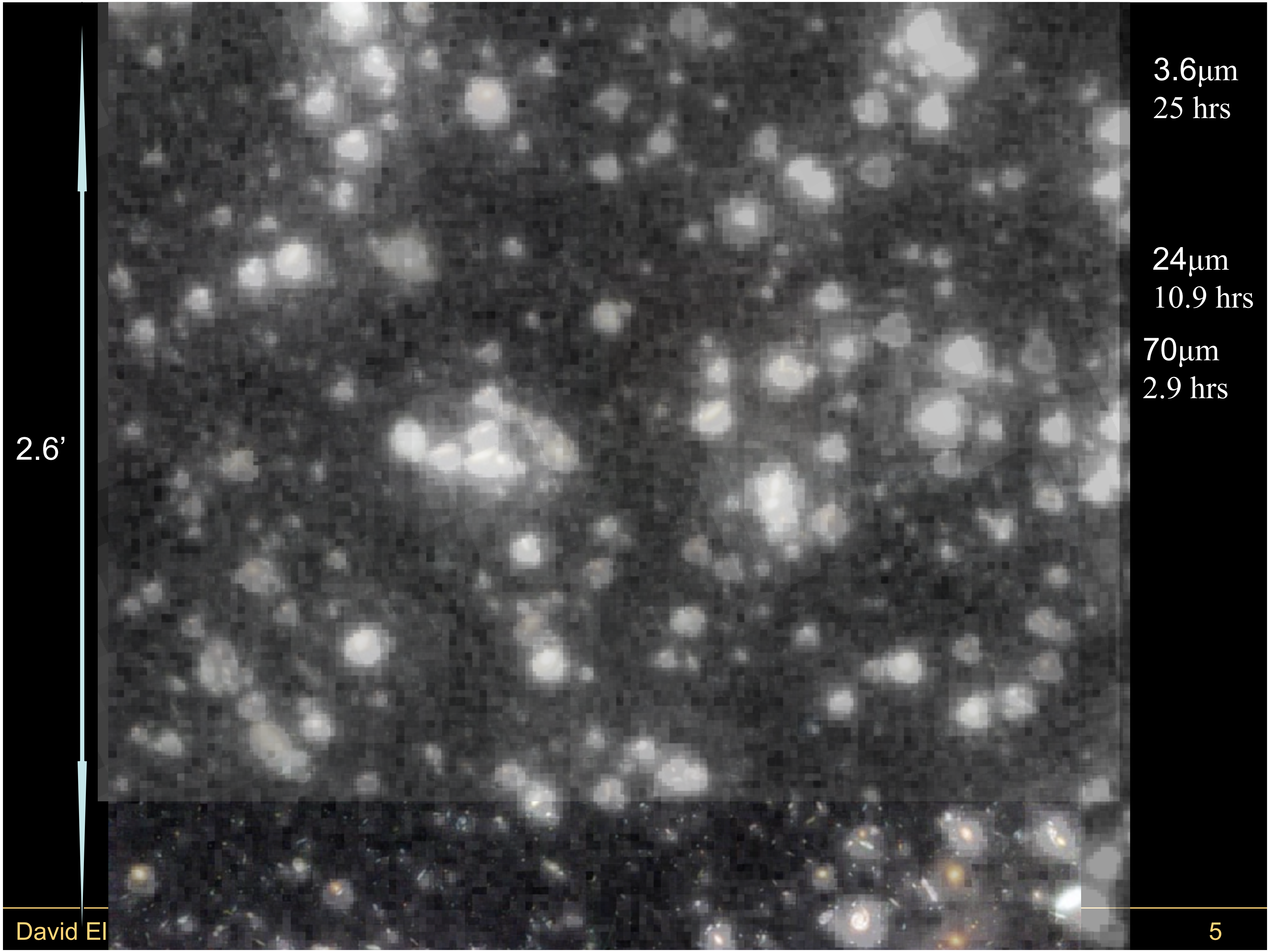


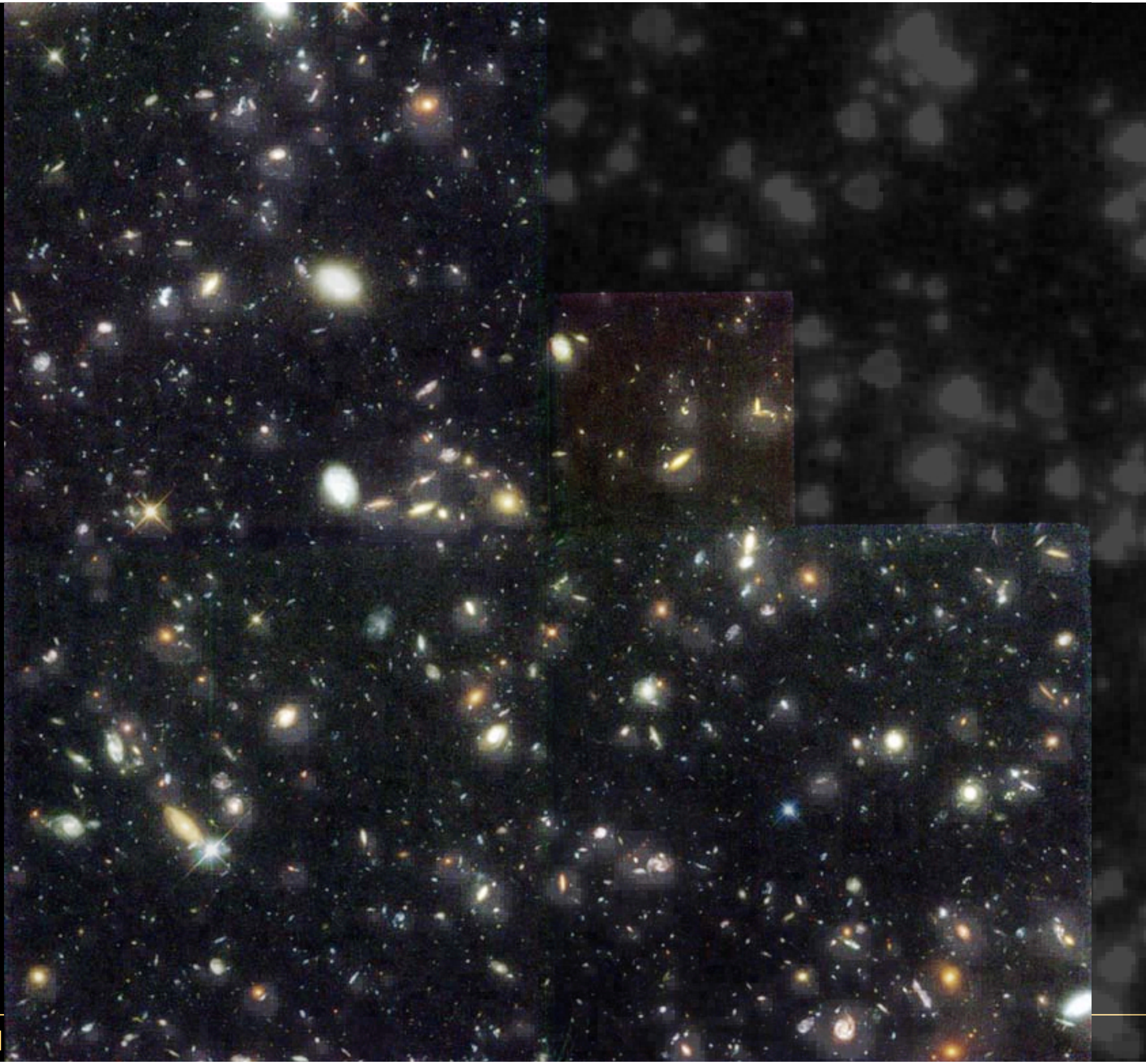


HDFN by ISOCAM @ 15 μm

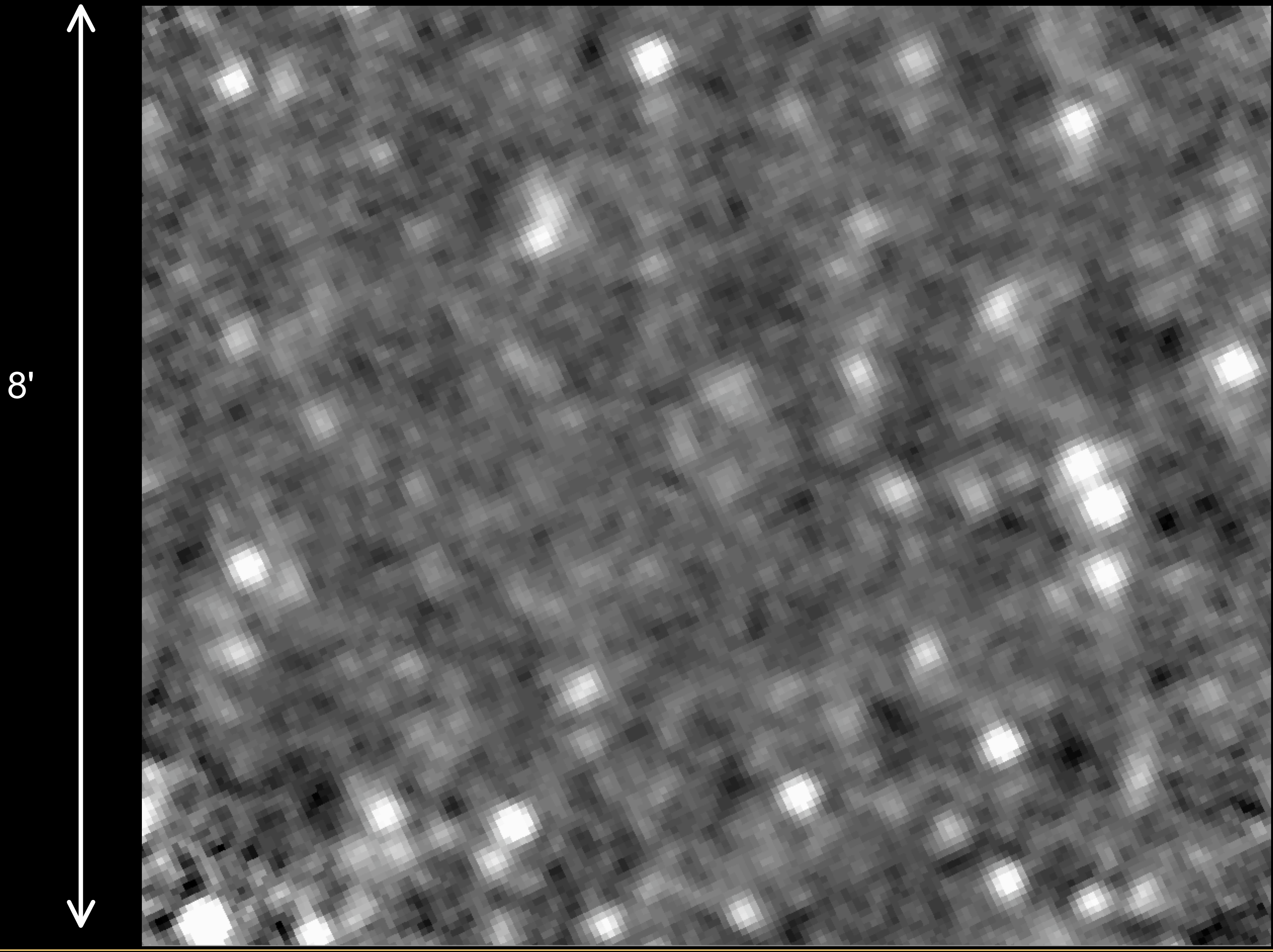
Is GOODS confusion limited at 24 μm ?




3.6µm
25 hrs
24µm
10.9 hrs
70µm
2.9 hrs
2.6'



Spitzer MIPS 24 versus 70 μm (GOODSN + Frayer et al. 06)



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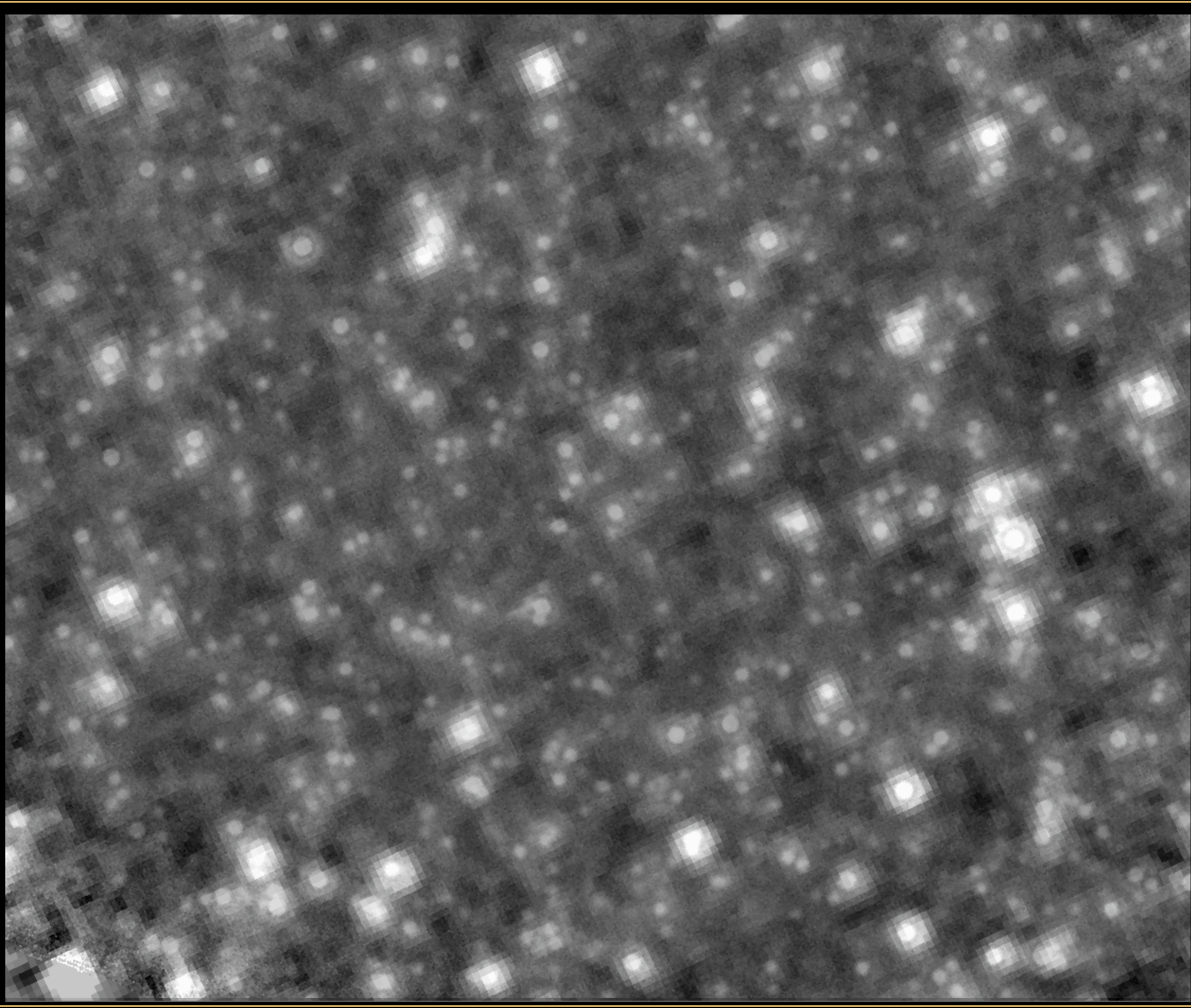
8'



Some key results from Spitzer extragalactic surveys: interpretation and limitations

Deepest Spitzer surveys reach the connection to UV (~3 $M_{\odot} yr^{-1}$) up to z=1

→ complete census on cosmic SFR history, Evolution of 24 & 70 μm LF to z~1 consistent (MIPS reaches 2 mJy at 70μm= close to Herschel, due to warm telescope)

- → But only up to z~1…

Stacking at 70 & 160μm

→ « resolution » of peak of CIRB

- → But only by z~1 galaxies, not the >200 μm one dominated by z>2 galaxies…
- → SCUBA confusion limited surveys at 2 mJy resolves less than ~20% at 850 μm

Morphology /HST-ACS, duty cycle

→ distant LIRGs are different from local ones, not only major mergers !

- → But no idea if star formation is nuclear or extended, quiescent-like mode ?

Complete 3D mapping

→ SFR of galaxies sensitive to the local environment at the 1 Mpc scale

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→ contribution of X-ray and Compton Thick (stacking) AGNs: new population of Compton Thick AGNs identified thanks to the IR !

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→ MIR-FIR OK up to z~1 but obscured AGNs and distant ULIRGs with strong PAHs !

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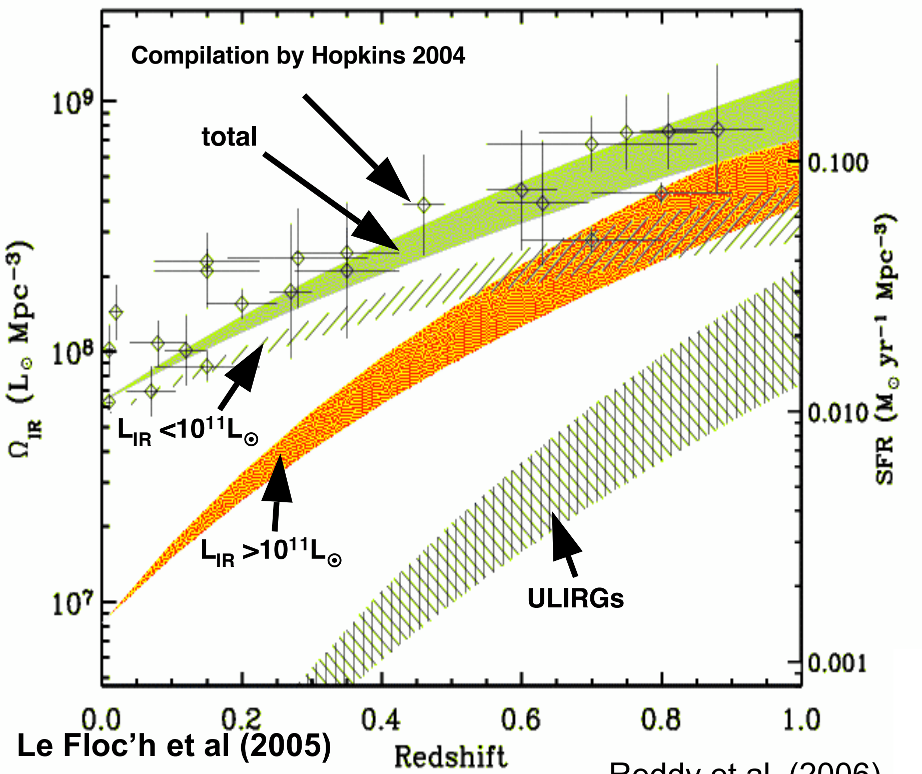

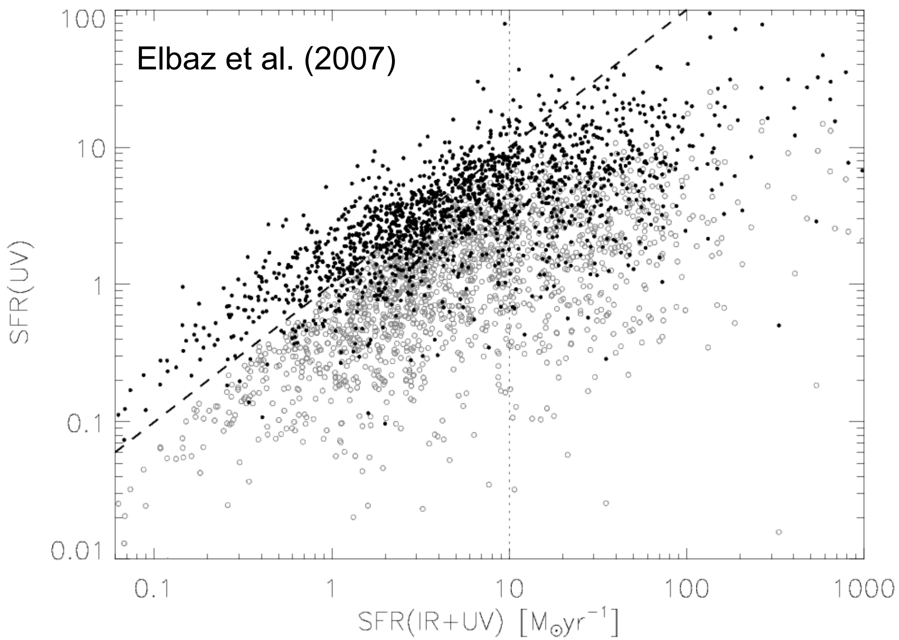

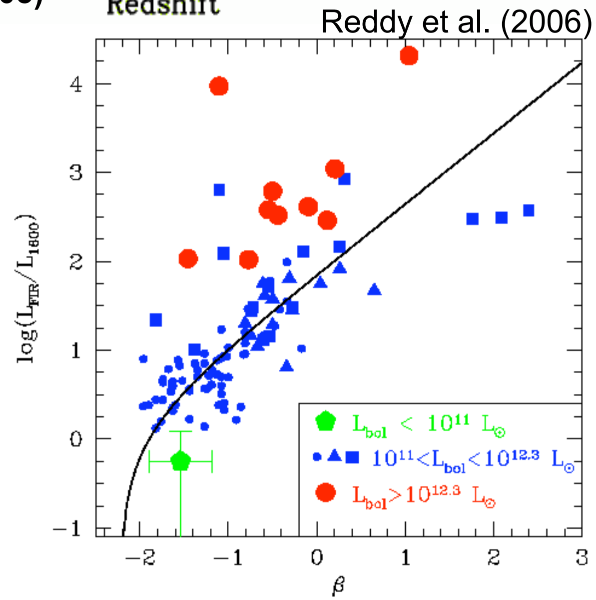

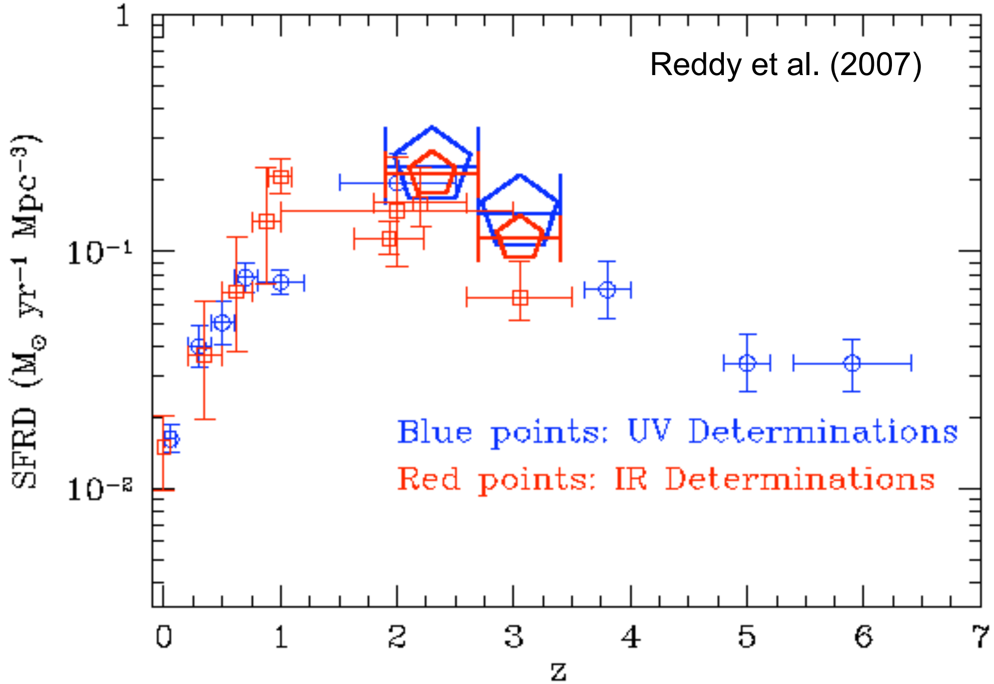

David Elbaz

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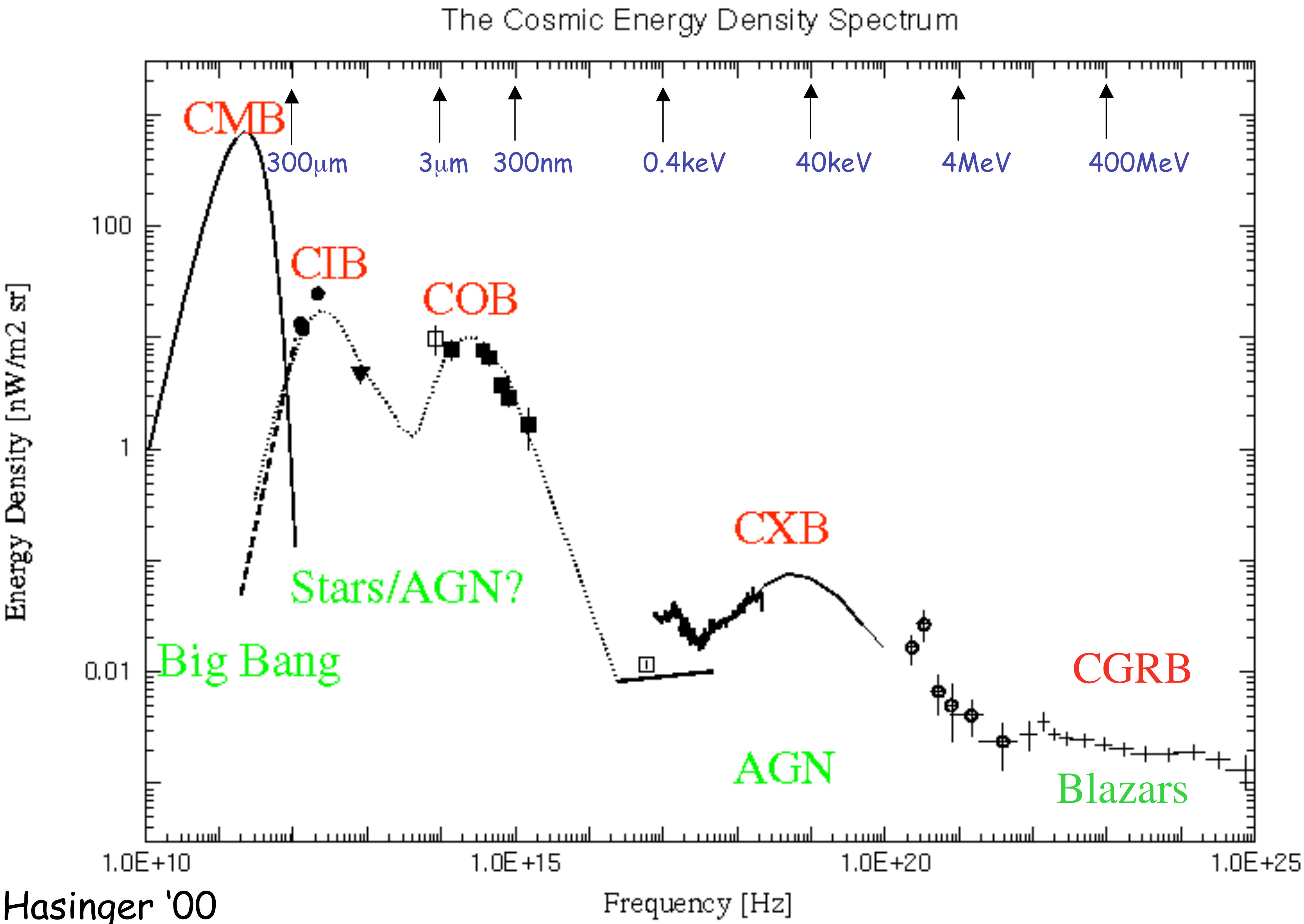
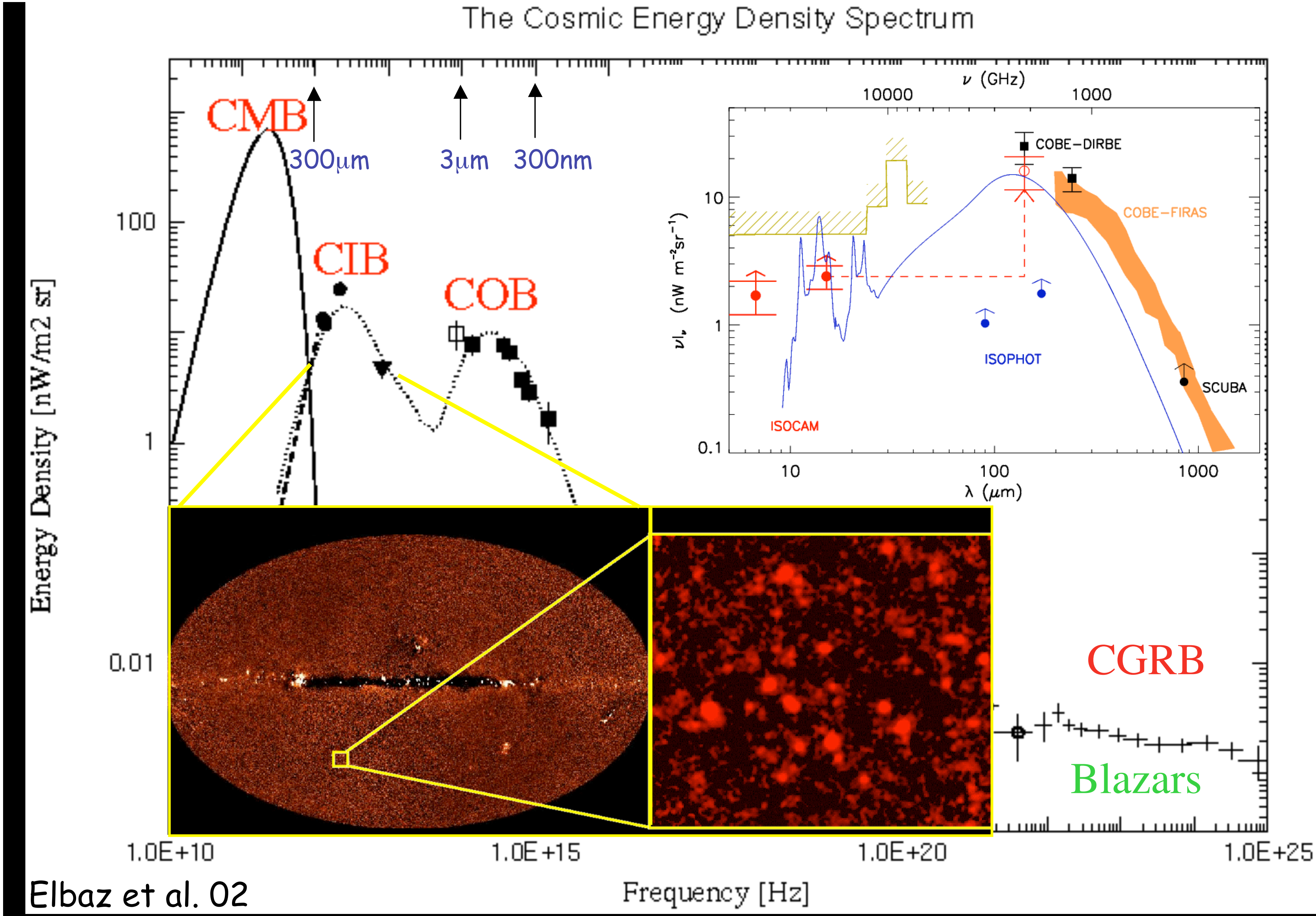


The Cosmic Energy Density Spectrum
CMB
CIB
COB
CXB
CGRB
300µm
3µm
300nm
0.4keV
40keV
4MeV
400MeV
Stars/AGN?
Big Bang
AGN
Blazars
Energy Density [nW/m2 sr]
100
1
0.01
1.0E+10
1.0E+15
1.0E+20
1.0E+25
Frequency [Hz]

Hasinger '00


The Cosmic Energy Density Spectrum
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1.0E+25
Frequency [Hz]
ν (GHz)
10000
1000
νI_ν (nW m^{-2}sr^{-1})
10
1
0.1
λ (μm)
100
COBE−DIRBE
COBE−FIRAS
ISOCAM
ISOPHOT
SCUBA
Elbaz et al. 02

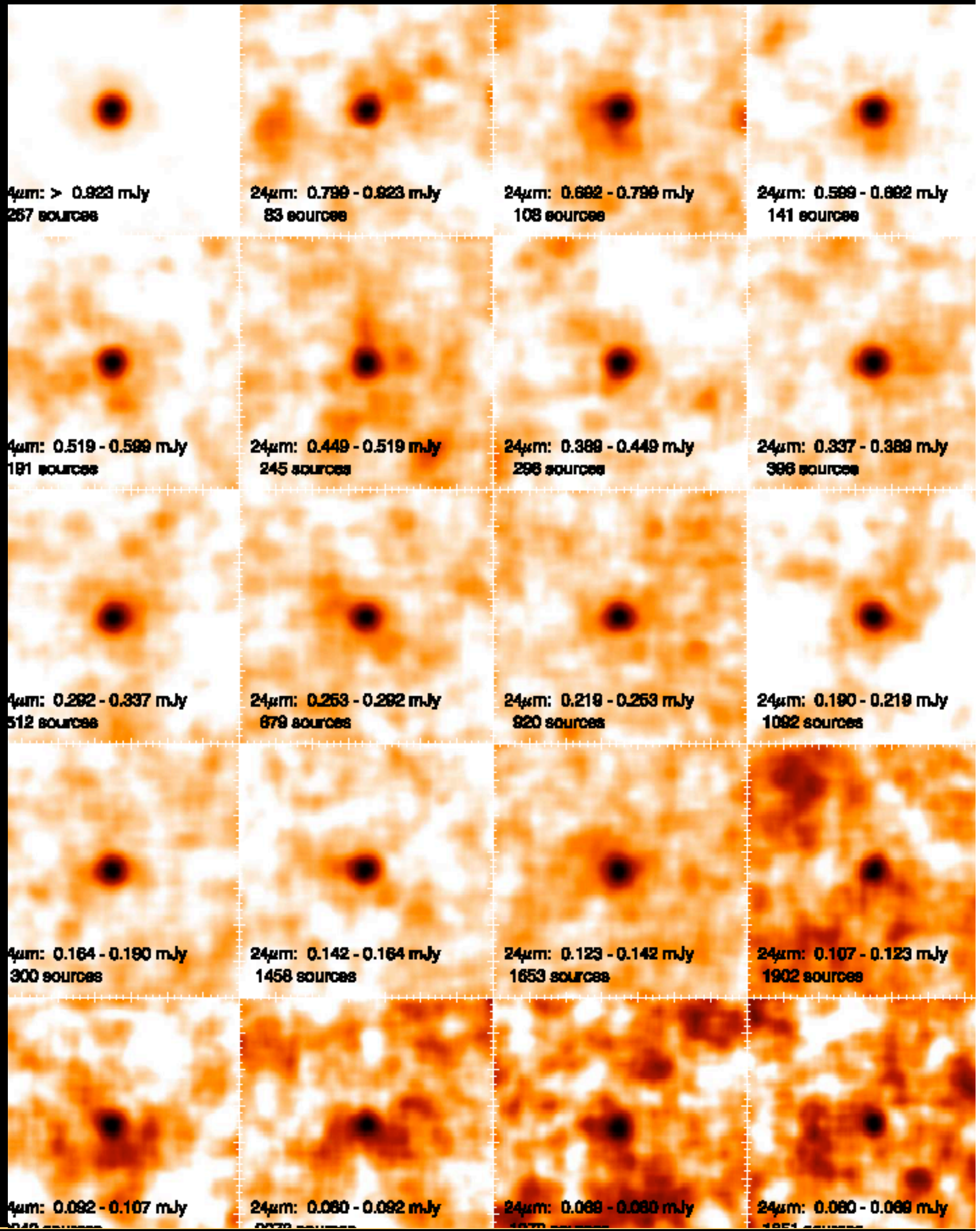
Spitzer 2006: CIRB resolution on statistical basis

Dole et al. 2006 A&A 451, 457:

- ***Statistical*** detection down to S(24μm)-60μJy
- Representing

  70% (80%) of CIB at 160μm (70μm)

- **NB**: Strictly speaking, these percentages refer to the part of the CIB in resolved galaxies, cannot constrain a hypothetical diffuse CIB.
- Errors in COBE absolute CIB are significant at <~100um!



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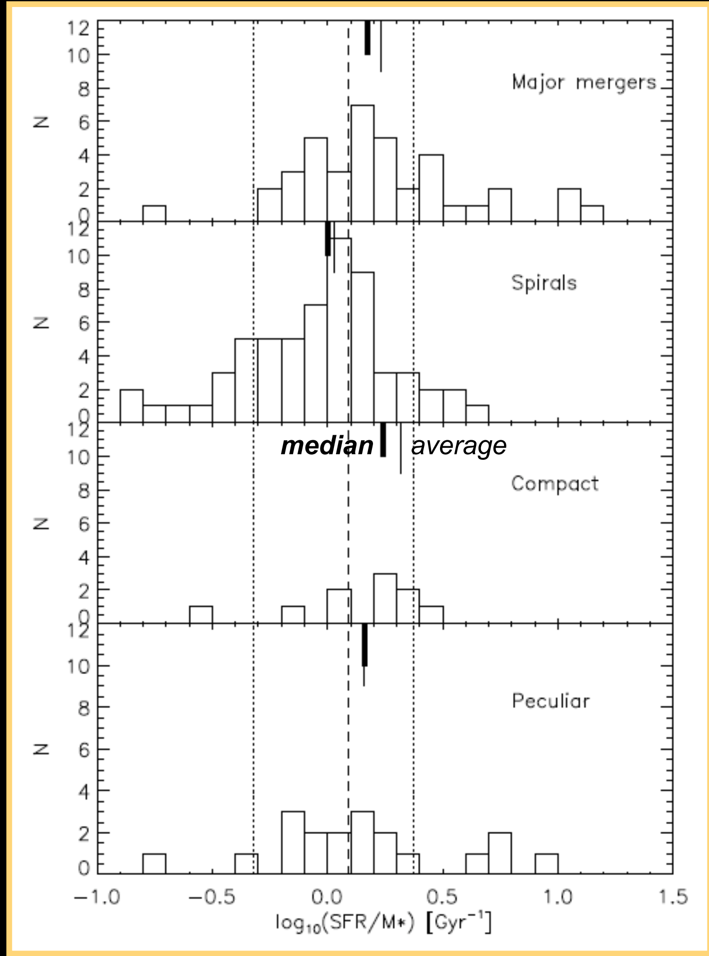
Only ~1/3rd of major mergers in z~1 LIRGs, very ≠ from z~0

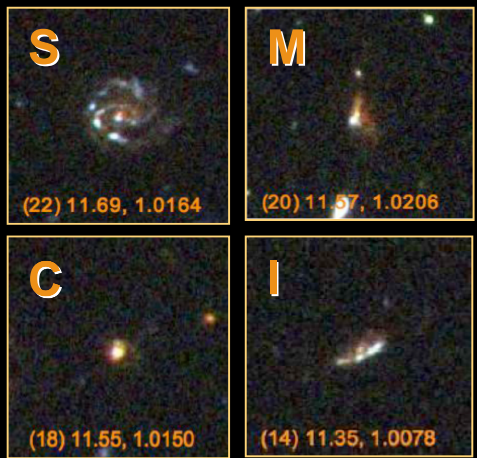
Morphology of LIRGs at 0.8≤z≤1.2:
complete sample of 140 LIRGs from
GOODS-N [S_{24}>25 μJy at 24 μm]

	z~0 Ishida 04	z~0.7 Bell 05	z~1 Elbaz 07
Spiral (S)	26 %	51 %	46 %
Merger (M)	41%+33% +close pair	26 %	31 %
Compact (C)	-	10 %	9 %
Irregular (I)	-	13 %	14 %
interactions		26-39 %	30-45 %



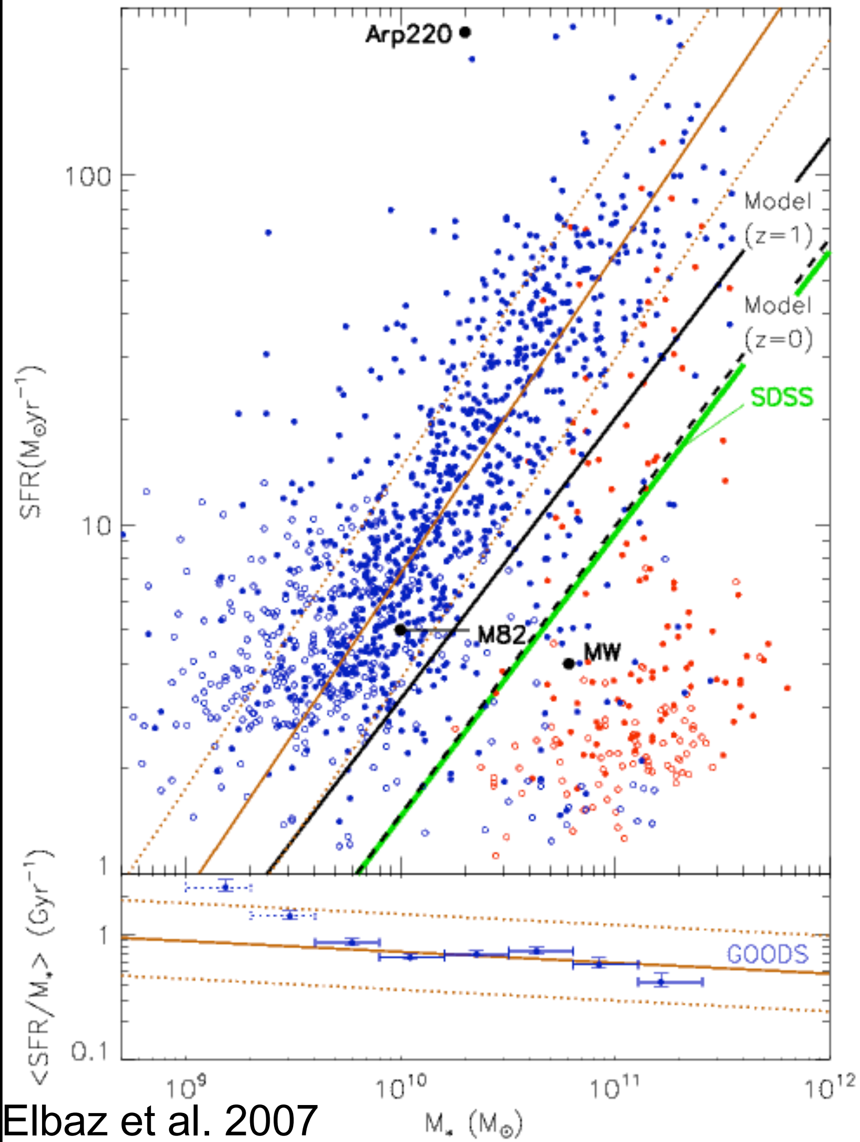
The role of major mergers is not dominant in LIRGs @ z~1

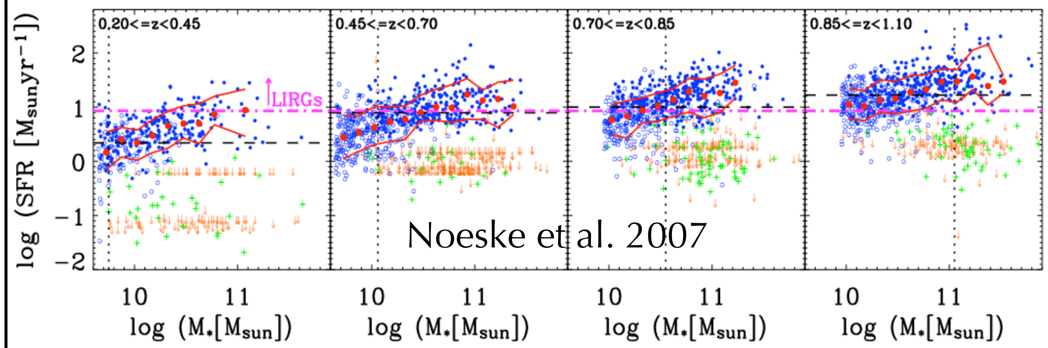
(see also Melbourne, Koo & Le Floc'h 2005)

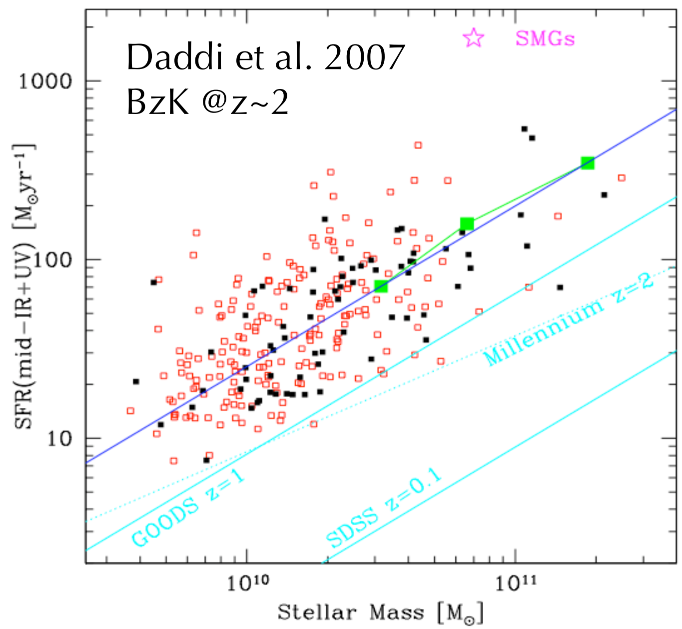


Dist° SFR/M* of mergers ~ isolated galaxies
+ different tails
=> <SFR/M*>(merg.-isol.) ~ 50-70%
consistent with Lin et al. (2007; 90%) DEEP2

The SFR-M* relation:
distant LIRGs are "normal galaxies", with long duty cycles !





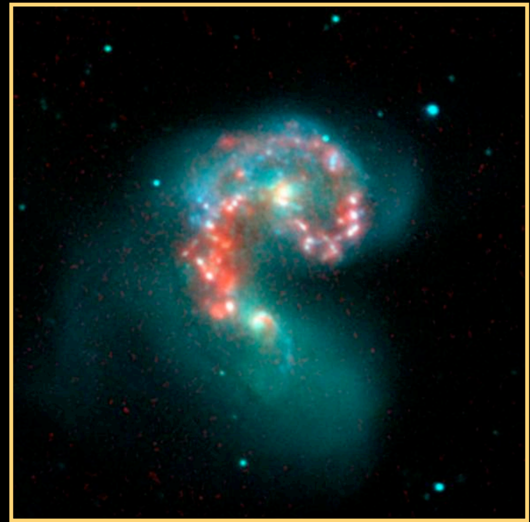


40% of $M_* \geq 10^{11}\ M_\odot$ at z=1.4-2.5 (BzK) are ULIRGs
Δz= 2 Gyr -> long duty cycle (> 400 Myr).
Daddi et al. (2005, 2007)

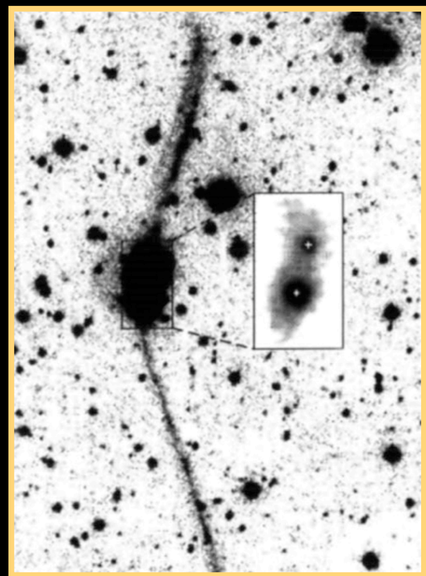
At z~1: $SFR = 7.2\ [-3.6,+7.2] \times (M_*/10^{10} M_\odot)^{0.9}$

The duty cycle of local LIRGs/ULIRGs: < 200 Myr

- The Antennae: (LIRG)
  $L_{IR}=1.1\times10^{11} L_\odot$ --> SFR= 19 $M_\odot yr^{-1}$
  $M(H_2)=3.9\times10^9\ M_\odot$
  Molecular gas exhausted in 200 Myr



- The Super-Antennae: (ULIRG)
  $L_{IR}=1.1\times10^{12}\ L_\odot$ --> SFR= 190 $M_\odot yr^{-1}$
  $M(H_2)=3\times10^{10}\ M_\odot$
  Molecular gas exhausted in 160 Myr



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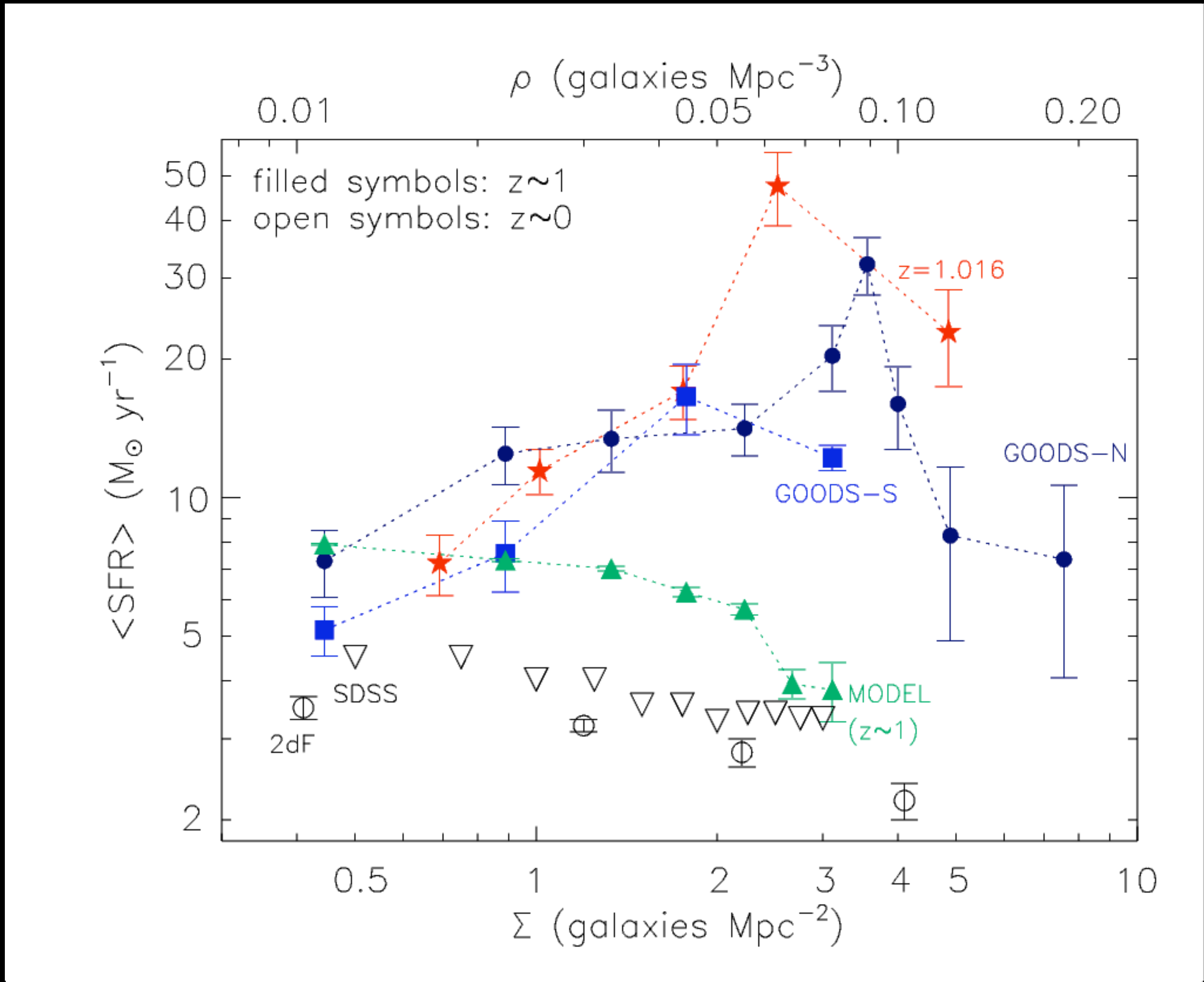
The star formation - galaxy density relation is reversed at z~1
(Elbaz et al. 2007)



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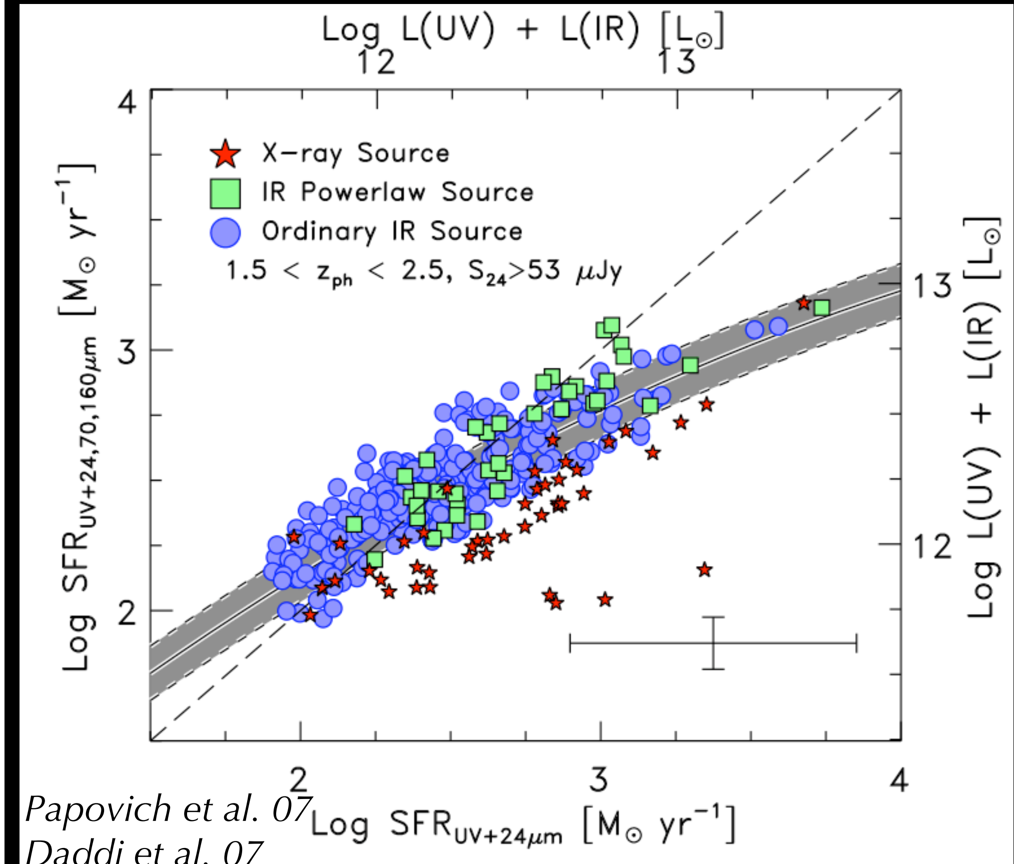
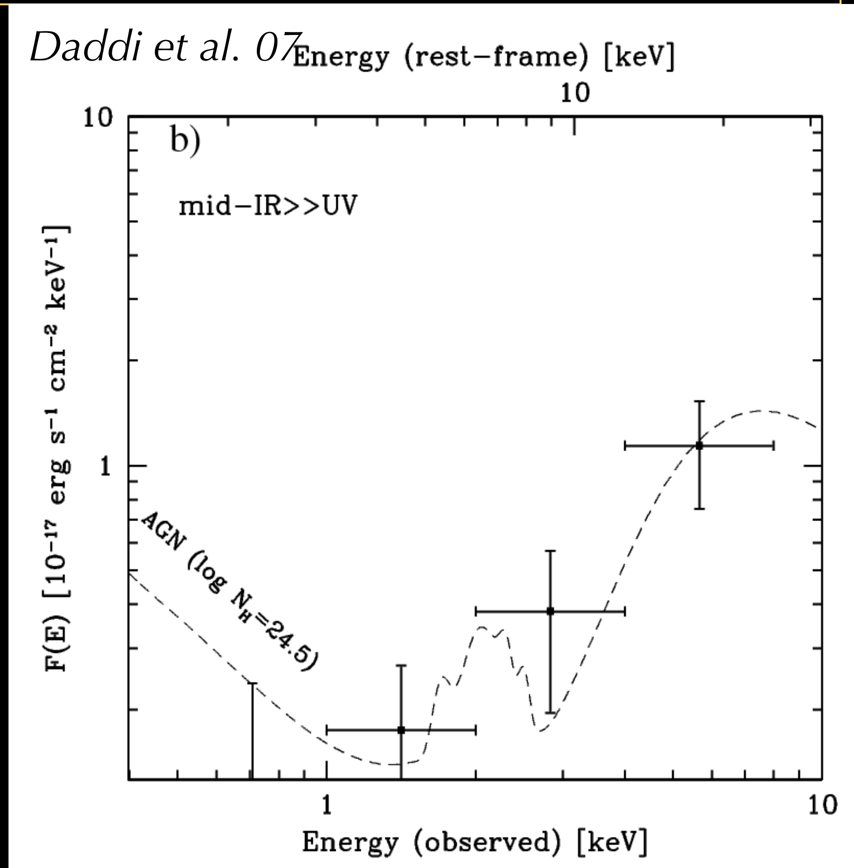
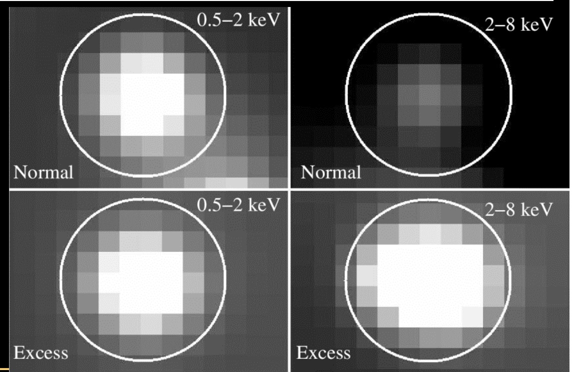
Luminous objects at 8 μm, z~2 present a mid infrared excess inconsistent with a star formation origin…





20-30 % of massive galaxies @z=2 are candidate Compton Thick AGNs ($N_H = 3x10^{24}$ cm^{-2}), this fraction increases with mass up to 50-60% for M*>4x10^{10}M$_{\odot}$, hence this phase is not exceptional !



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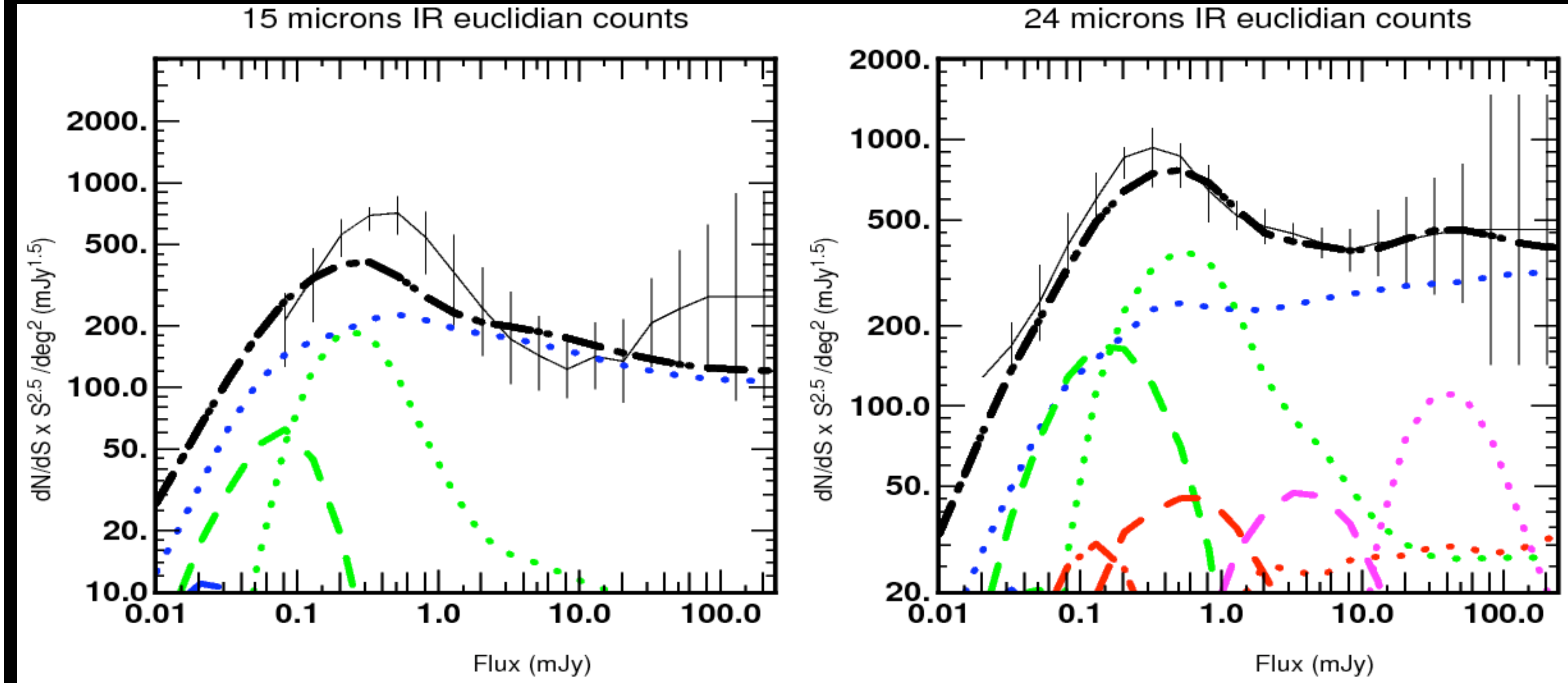
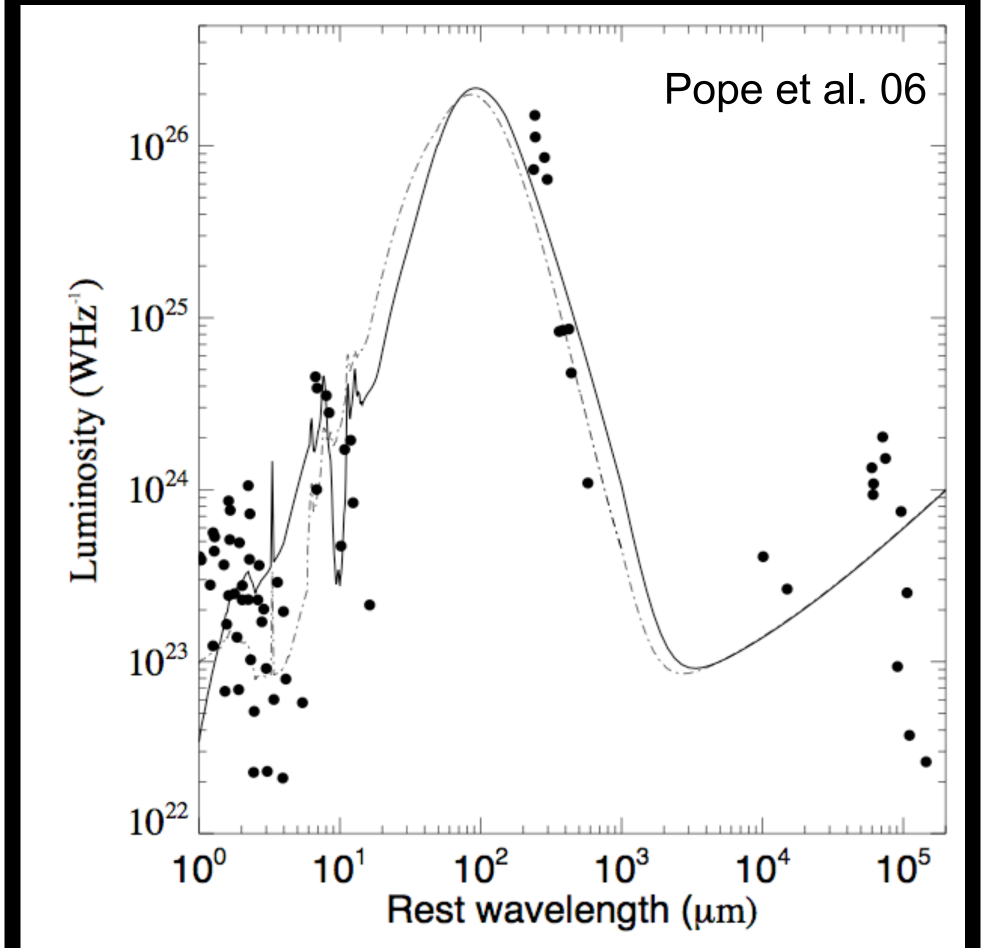
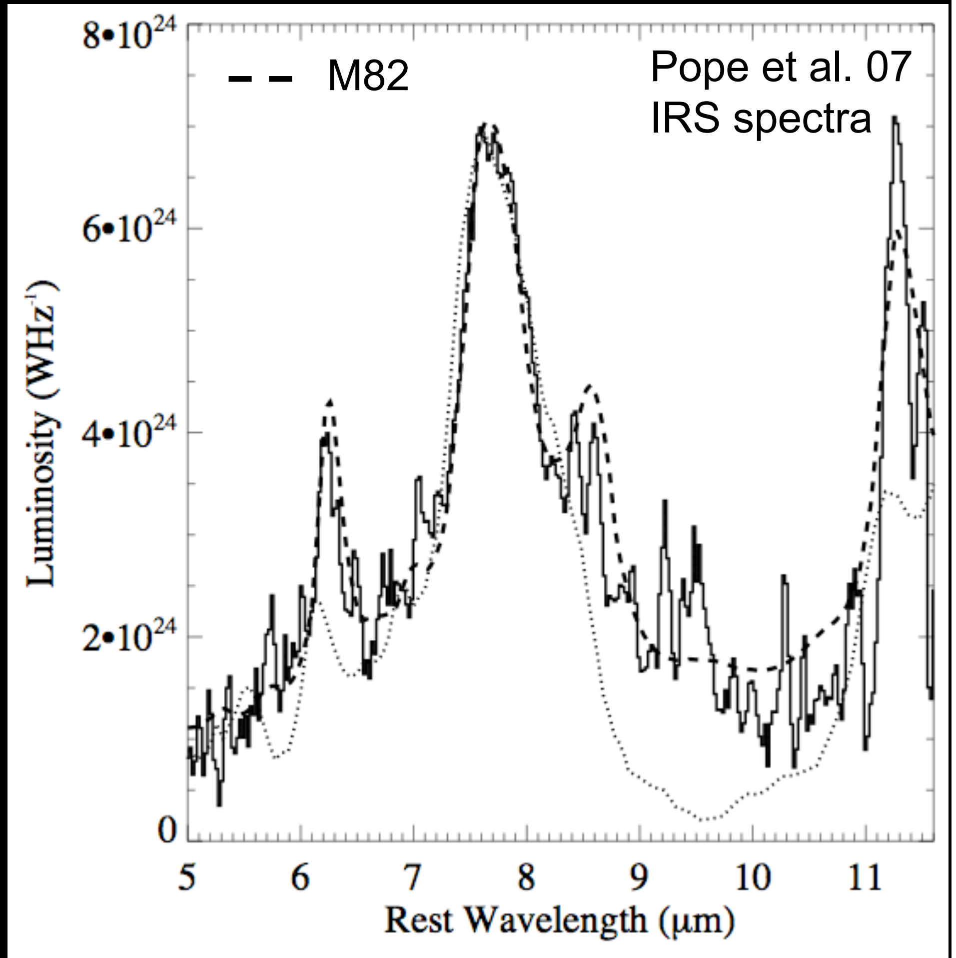
Backward models: marginal fit to the 2 bumps (15 & 24um)
--> evolution of the SEDs …



Average Spitzer-IRS spectrum of 13 z~2 SCUBA galaxies (GOODS-N) strong PAH features --> distant ULIRGs like nearby moderate starbursts

- **high redshift :** **z~2** **(Chapman et al. 2005, Pope et al. 2005)**
- **high SFR :** **SFR~100-1000$M_{\odot}yr^{-1}$** **(Lilly et al. 1999, Chapman et al. 2005)**
- **massive :** **M_{gas}~3x$10^{10}M_{\odot}$ & $M_{\star}$~$10^{11}M_{\odot}$** **(Greve et al. 2005, Borys et al. 2005)**





Some key issues from Spitzer extragalactic surveys

- Distant LIRGs are different from local ones:
  - not dominantly major mergers
  - long duty cycle
  - stronger PAH EW

→ what is causing their star formation ? What is the cause of the fast decline of the cosmic SFR from z~1 to 0 ?

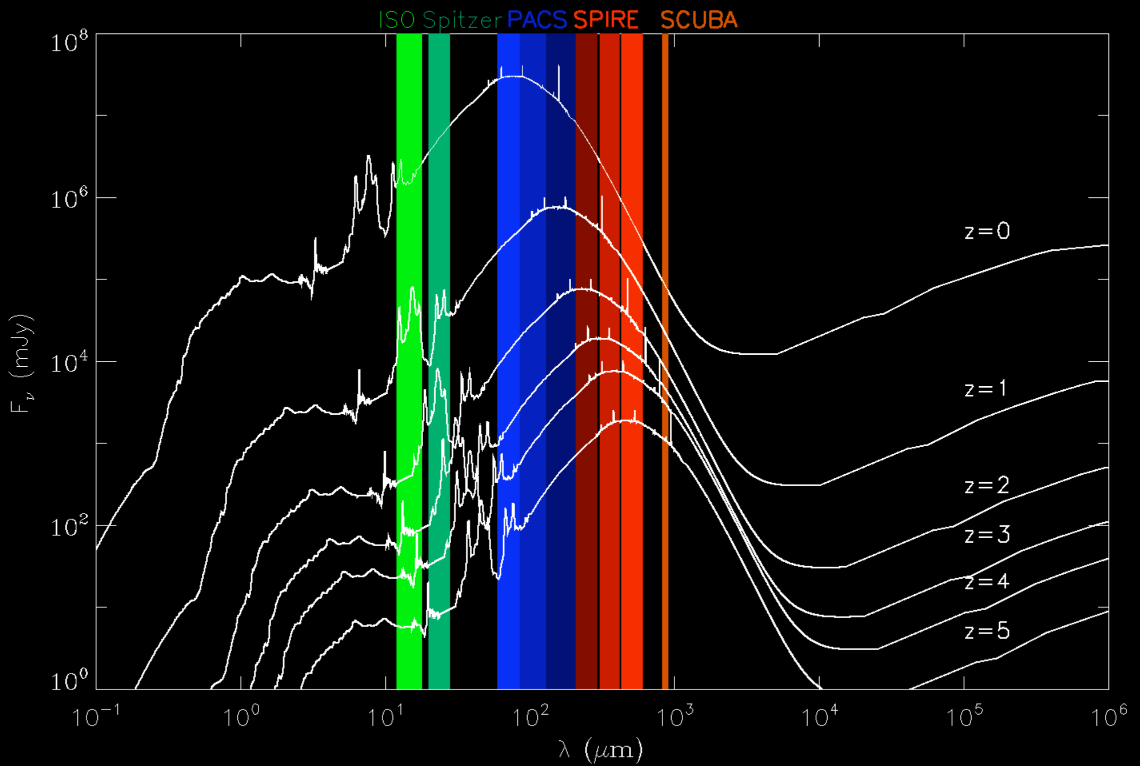
→ what is responsible for the present-day bimodality ? negative feedback or gas exhaustion ?

→ what is the contribution of obscured AGNs ?

(Where are the obscured AGNs producing the X-ray bkg ?)

- What is happening at $z>2$? Not addressed by Spitzer…

Herschel



Will probe the peak of the FIR emission

--> Complete census on cosmic SFR history up to z~3

Will not suffer from AGN contamination to derive SFR

Access to the more distant universe

MIR-FIR photometric redshifts to probe distant obscurded galaxies

Herschel Guaranteed Time extragalactic surveys (1550 h)

PACS 60-210µm
(PI Albrecht Poglitsch)
Scan mapping (unchopped)

PEP: PACS extragalactic probe
(coordinated with SPIRE)

650 h - coordinator: D.Lutz

Steering Group:
Lutz, Elbaz, Andreani, Cepa, Altieri
MPE+CEA+IAC+INAF+ESA
+HSC+M.Harwit

SPIRE 200-670µm
(PI Matt Griffin)
Scan mapping (unchopped)

HERMES : The Herschel Multi-tiered Extragalactic Survey: Measuring the Infrared Galaxy Formation History of the Universe

900 h - coord.: S.Oliver, JBock

SAG1 (Specialist Astronomy Group):
UK + USA + France + Italy + Spain + Canada+ ESA
(http://astronomy.sussex.ac.uk/~sjo/Hermes/)

Coordination Group: Lutz, Bock, Oliver, Poglitsch, Griffin, Elbaz
Letter of agreement between PACS & SPIRE to facilitate collaborative projects between PEP and HERMES members after call cycle -> proposals inside GT

Extragalactic surveys with Herschel Guaranteed Time: Goals…

- Resolve the Cosmic Infrared Background and determine the nature of its constituents

~80-100% @75μm	~25 % @250μm
~ 85 % @110μm	<10 % @350μm
~ 55 % @170μm	< 5 % @500μm

- Determine the cosmic evolution of dusty star formation and of the infrared luminosity function
- Elucidate the relation of far-infrared emission and environment, and determine clustering properties
- Determine the contribution of AGNs
- Determine the infrared emission and energetics of known galaxy populations
- …

Confusion & detection limits

Name	70	100	160	250	350	500	PEP time	PEP size	HERMES (h)	HERMES (°2)
PSF FWHm(")	5.4	8	12	18	25	36				
S(mJy) conf°	1 (0.1)	1	5	11	15	15				
logL(IR)@z~1	11.2 (10.4)	10.8	11.3	11.8	12.2	12.6				
logL(IR)@z~2	12.2 (11.2)	11.8	12.1	12.3	12.5	12.8				
logL(IR)@z~3	12.8 (11.9)	12.2	12.5	12.7	12.8	12.9				
Level 1:							***227.4 h***		***22.9 h***	***250.3 h***
GOODSS		1.72	2.43	4.2	5.7	4.9	113.71h	10'x15'	22.9 h	0.11 sq.deg.
GOODSS	1.61		2.43				113.71h	10'x15'		
Level 2:							***65 h***		***12.3 h***	***77.3 h***
GOODSN		3.33	4.70	8.8	12.0	10.2	30.46h	10'x15'	3.8 h	0.11 sq.deg.
ECDFS		5.88	8.25	8.7	11.9	10.1	34.51 h	30'x30'	8.5 h	30'x30'
Level 3 *(4 fields)*							***69.4 h***		***16.7****+61.5* ***h***	***147.6 h***
Lockman Hole		4.9	6.8	11.1	15.2	12.9	34.9h	24'x24'	3.15 h	30'x30'
EGS		5.44	7.75	11.1	15.2	12.9	34.53 h	10'x67'	3.75 h	10'x90'
Level 4 *(4 fields)*							***212.75 h***		***61.1****+85.3* ***h***	***359.1 h***
COSMOS		6.13	8.63	10.8	14.7	12.5	212.75h	85'x85'	44.15 h	1.4°x1.4°
Bootes-SCUBA2		20.4	29.3	14.0	19.3	16.3	No			2 sq deg
NDWFS/Bootes		38.2	54.8	26.2	36.1	30.4	No			8 sq deg
Level 5 *(6 fields)*	***18***	***31.3***	***35.7***	***10.9***	***15.2***	***12.8***	***No***		***328.1 h***	***18.3 sq deg***
Level 6 *(7 fields)*	***18***	***70***	***80***	***24.4***	***33.9***	***28.6***	***No***		***165.8 h***	***50.3 sq deg***
Clusters							***74.6 h***		***147 h***	***221.6 h***
Lensing clusters		2.6	4.0	3.4	4.7	4.0			147 h	0.01 sq.deg
TOTAL							***650 h***		***900 h***	***1550 h***
								797h PACS	753h SPIRE	

Herschel Level 1 extragalactic surveys

Name	70	100	160	250	350	500	PEP time	PEP size	HERMES (h)	HERMES (°2)
PSF FWHm(")	5.4	8	12	18	25	36				
S(mJy) conf°	1 (0.1)	1	5	11	15	15				
logL(IR)@z~1	11.2 (10.4)	10.8	11.3	11.8	12.2	12.6				
logL(IR)@z~2	12.2 (11.2)	11.8	12.1	12.3	12.5	12.8				
logL(IR)@z~3	12.8 (11.9)	12.2	12.5	12.7	12.8	12.9				
Level 1:							***227.4 h***		***22.9 h***	***250.3 h***
GOODSS		1.72	2.43	4.2	5.7	4.9	113.71h	10'x15'	22.9 h	0.11 sq.deg.
GOODSS	1.61		2.43				113.71h	10'x15'		
Level 2:							***65 h***		***12.3 h***	***77.3 h***
GOODSN		3.33	4.70	8.8	12.0	10.2	30.46h	10'x15'	3.8 h	0.11 sq.deg.
ECDFS		5.88	8.25	8.7	11.9	10.1	34.51 h	30'x30'	8.5 h	30'x30'
Level 3 *(4 fields)*							***69.4 h***		***16.7**+**61.5 h***	***147.6 h***
Lockman Hole		4.9	6.8	11.1	15.2	12.9	34.9h	24'x24'	3.15 h	30'x30'
EGS		5.44	7.75	11.1	15.2	12.9	34.53 h	10'x67'	3.75 h	10'x90'
Level 4 *(4 fields)*							***212.75 h***		***61.1**+**85.3 h***	***359.1 h***
COSMOS		6.13	8.63	10.8	14.7	12.5	212.75h	85'x85'	44.15 h	1.4°x1.4°
Bootes-SCUBA2		20.4	29.3	14.0	19.3	16.3	No			2 sq deg
NDWFS/Bootes		38.2	54.8	26.2	36.1	30.4	No			8 sq deg
Level 5 *(6 fields)*	***18***	***31.3***	***35.7***	***10.9***	***15.2***	***12.8***	***No***		***328.1 h***	***18.3 sq deg***
Level 6 *(7 fields)*	***18***	***70***	***80***	***24.4***	***33.9***	***28.6***	***No***		***165.8 h***	***50.3 sq deg***
Clusters							***74.6 h***		***147 h***	***221.6 h***
Lensing clusters		2.6	4.0	3.4	4.7	4.0			147 h	0.01 sq.deg
TOTAL							***650 h***		***900 h***	***1550 h***
								797h PACS	753h SPIRE	

Herschel Level 2 extragalactic surveys

Name	70	100	160	250	350	500	PEP time	PEP size	HERMES (h)	HERMES (°2)
PSF FWHm(")	5.4	8	12	18	25	36				
S(mJy) conf°	1 (0.1)	1	5	11	15	15				
logL(IR)@z~1	11.2 (10.4)	10.8	11.3	11.8	12.2	12.6				
logL(IR)@z~2	12.2 (11.2)	11.8	12.1	12.3	12.5	12.8				
logL(IR)@z~3	12.8 (11.9)	12.2	12.5	12.7	12.8	12.9				
Level 1:							***227.4 h***		***22.9 h***	***250.3 h***
GOODSS		1.72	2.43	4.2	5.7	4.9	113.71h	10'x15'	22.9 h	0.11 sq.deg.
GOODSS	1.61		2.43				113.71h	10'x15'		
Level 2:							***65 h***		***12.3 h***	***77.3 h***
GOODSN		3.33	4.70	8.8	12.0	10.2	30.46h	10'x15'	3.8 h	0.11 sq.deg.
ECDFS		5.88	8.25	8.7	11.9	10.1	34.51 h	30'x30'	8.5 h	30'x30'
Level 3 *(4 fields)*							***69.4 h***		***16.7****+61.5* ***h***	***147.6 h***
Lockman Hole		4.9	6.8	11.1	15.2	12.9	34.9h	24'x24'	3.15 h	30'x30'
EGS		5.44	7.75	11.1	15.2	12.9	34.53 h	10'x67'	3.75 h	10'x90'
Level 4 *(4 fields)*							***212.75 h***		***61.1****+85.3* ***h***	***359.1 h***
COSMOS		6.13	8.63	10.8	14.7	12.5	212.75h	85'x85'	44.15 h	1.4°x1.4°
Bootes-SCUBA2		20.4	29.3	14.0	19.3	16.3	No			2 sq deg
NDWFS/Bootes		38.2	54.8	26.2	36.1	30.4	No			8 sq deg
Level 5 *(6 fields)*	***18***	***31.3***	***35.7***	***10.9***	***15.2***	***12.8***	***No***		***328.1 h***	***18.3 sq deg***
Level 6 *(7 fields)*	***18***	***70***	***80***	***24.4***	***33.9***	***28.6***	***No***		***165.8 h***	***50.3 sq deg***
Clusters							***74.6 h***		***147 h***	***221.6 h***
Lensing clusters		2.6	4.0	3.4	4.7	4.0			147 h	0.01 sq.deg
TOTAL							***650 h***		***900 h***	***1550 h***
								797h PACS	753h SPIRE	

Herschel Level 3 extragalactic surveys

Name	70	100	160	250	350	500	PEP time	PEP size	HERMES (h)	HERMES (°2)
PSF FWHm(")	5.4	8	12	18	25	36				
S(mJy) conf°	1 (0.1)	1	5	11	15	15				
logL(IR)@z~1	11.2 (10.4)	10.8	11.3	11.8	12.2	12.6				
logL(IR)@z~2	12.2 (11.2)	11.8	12.1	12.3	12.5	12.8				
logL(IR)@z~3	12.8 (11.9)	12.2	12.5	12.7	12.8	12.9				
Level 1:							***227.4 h***		***22.9 h***	***250.3 h***
GOODSS		1.72	2.43	4.2	5.7	4.9	113.71h	10'x15'	22.9 h	0.11 sq.deg.
GOODSS	1.61		2.43				113.71h	10'x15'		
Level 2:							***65 h***		***12.3 h***	***77.3 h***
GOODSN		3.33	4.70	8.8	12.0	10.2	30.46h	10'x15'	3.8 h	0.11 sq.deg.
ECDFS		5.88	8.25	8.7	11.9	10.1	34.51 h	30'x30'	8.5 h	30'x30'
Level 3 *(4 fields)*							***69.4 h***		***16.7****+61.5* ***h***	***147.6 h***
Lockman Hole		4.9	6.8	11.1	15.2	12.9	34.9h	24'x24'	3.15 h	30'x30'
EGS		5.44	7.75	11.1	15.2	12.9	34.53 h	10'x67'	3.75 h	10'x90'
Level 4 *(4 fields)*							***212.75 h***		***61.1****+85.3* ***h***	***359.1 h***
COSMOS		6.13	8.63	10.8	14.7	12.5	212.75h	85'x85'	44.15 h	1.4°x1.4°
Bootes-SCUBA2		20.4	29.3	14.0	19.3	16.3	No			2 sq deg
NDWFS/Bootes		38.2	54.8	26.2	36.1	30.4	No			8 sq deg
Level 5 *(6 fields)*	***18***	***31.3***	***35.7***	***10.9***	***15.2***	***12.8***	***No***		***328.1 h***	***18.3 sq deg***
Level 6 *(7 fields)*	***18***	***70***	***80***	***24.4***	***33.9***	***28.6***	***No***		***165.8 h***	***50.3 sq deg***
Clusters							***74.6 h***		***147 h***	***221.6 h***
Lensing clusters		2.6	4.0	3.4	4.7	4.0			147 h	0.01 sq.deg
TOTAL							***650 h***		***900 h***	***1550 h***
								797h PACS	753h SPIRE	

Herschel Level 3 extragalactic surveys

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PSF FWHm(")	5.4	8	12	18	25	36				
S(mJy) conf°	1 (0.1)	1	5	11	15	15				
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logL(IR)@z~2	12.2 (11.2)	11.8	12.1	12.3	12.5	12.8				
logL(IR)@z~3	12.8 (11.9)	12.2	12.5	12.7	12.8	12.9				
Level 1:							***227.4 h***		***22.9 h***	***250.3 h***
GOODSS		1.72	2.43	4.2	5.7	4.9	113.71h	10'x15'	22.9 h	0.11 sq.deg.
GOODSS	1.61		2.43				113.71h	10'x15'		
Level 2:							***65 h***		***12.3 h***	***77.3 h***
GOODSN		3.33	4.70	8.8	12.0	10.2	30.46h	10'x15'	3.8 h	0.11 sq.deg.
ECDFS		5.88	8.25	8.7	11.9	10.1	34.51 h	30'x30'	8.5 h	30'x30'
Level 3 *(4 fields)*							***69.4 h***		***16.7****+61.5* ***h***	***147.6 h***
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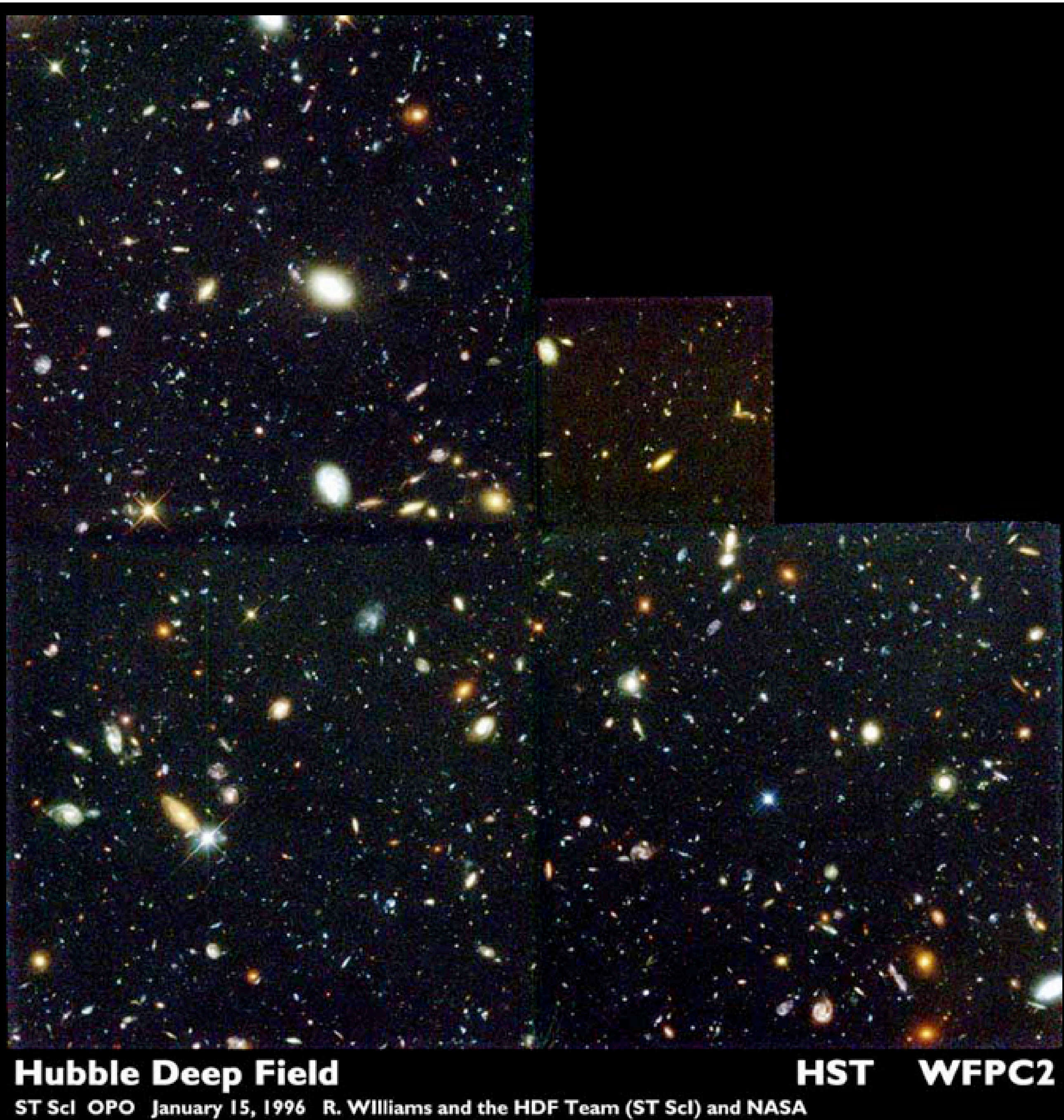
EGS		5.44	7.75	11.1	15.2	12.9	34.53 h	10'x67'	3.75 h	10'x90'
Level 4 *(4 fields)*							***212.75 h***		***61.1****+85.3* ***h***	***359.1 h***
COSMOS		6.13	8.63	10.8	14.7	12.5	212.75h	85'x85'	44.15 h	1.4°x1.4°
Bootes-SCUBA2		20.4	29.3	14.0	19.3	16.3	No			2 sq deg
NDWFS/Bootes		38.2	54.8	26.2	36.1	30.4	No			8 sq deg
Level 5 *(6 fields)*	***18***	***31.3***	***35.7***	***10.9***	***15.2***	***12.8***	***No***		***328.1 h***	***18.3 sq deg***
Level 6 *(7 fields)*	***18***	***70***	***80***	***24.4***	***33.9***	***28.6***	***No***		***165.8 h***	***50.3 sq deg***
Clusters							***74.6 h***		***147 h***	***221.6 h***
Lensing clusters		2.6	4.0	3.4	4.7	4.0			147 h	0.01 sq.deg
TOTAL							***650 h***		***900 h***	***1550 h***
								797h PACS	753h SPIRE	

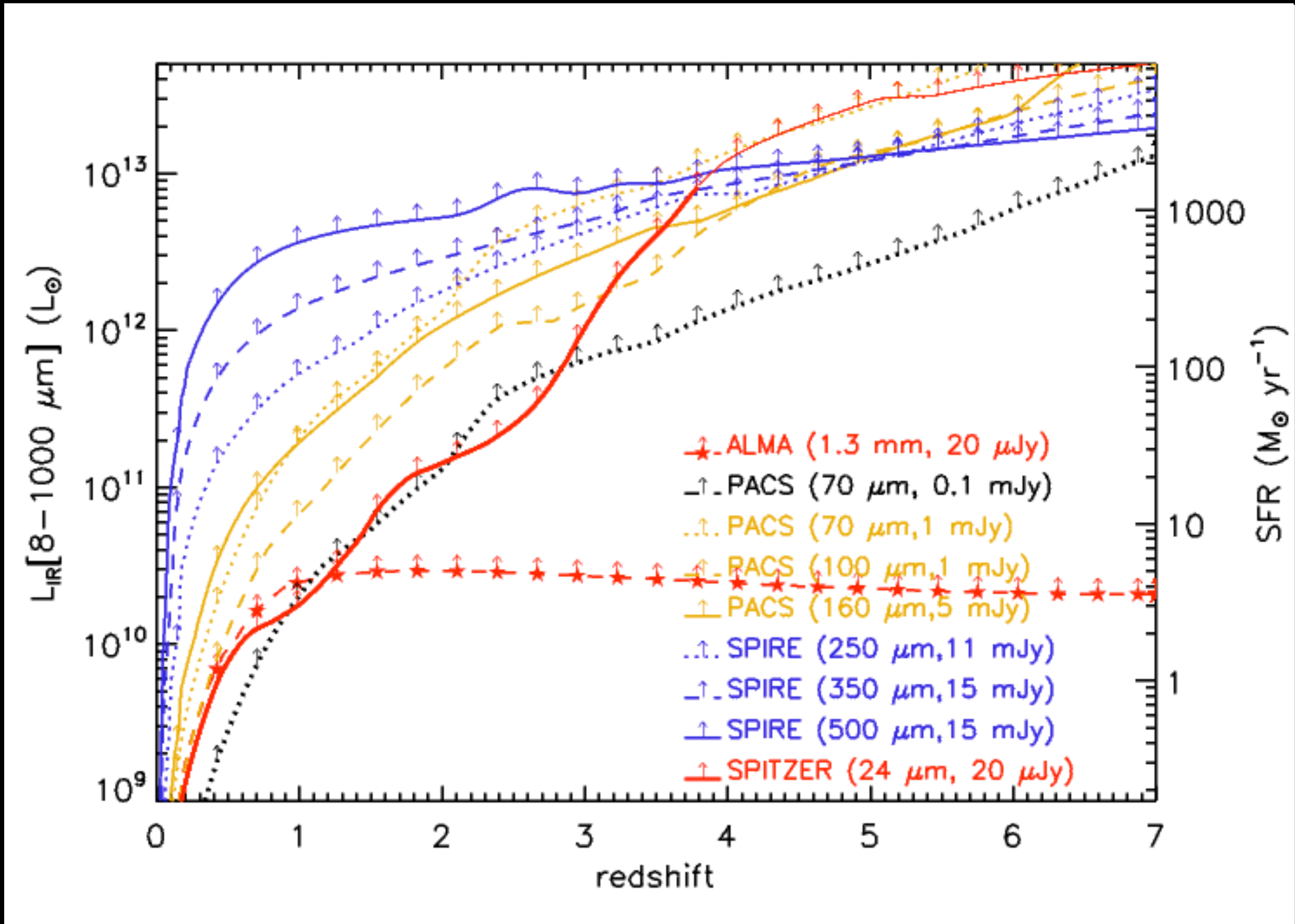
Herschel extragalactic surveys

Name	70	100	160	250	350	500	PEP time	PEP size	HERMES (h)	HERMES (°2)
PSF FWHm(")	5.4	8	12	18	25	36				
S(mJy) conf°	1 (0.1)	1	5	11	15	15				
logL(IR)@z~1	11.2 (10.4)	10.8	11.3	11.8	12.2	12.6				
logL(IR)@z~2	12.2 (11.2)	11.8	12.1	12.3	12.5	12.8				
logL(IR)@z~3	12.8 (11.9)	12.2	12.5	12.7	12.8	12.9				
Level 1:							***227.4 h***		***22.9 h***	***250.3 h***
GOODSS		1.72	2.43	4.2	5.7	4.9	113.71h	10'x15'	22.9 h	0.11 sq.deg.
GOODSS	1.61		2.43				113.71h	10'x15'		
Level 2:							***65 h***		***12.3 h***	***77.3 h***
GOODSN		3.33	4.70	8.8	12.0	10.2	30.46h	10'x15'	3.8 h	0.11 sq.deg.
ECDFS		5.88	8.25	8.7	11.9	10.1	34.51 h	30'x30'	8.5 h	30'x30'
Level 3 *(4 fields)*							***69.4 h***		***16.7****+61.5* ***h***	***147.6 h***
Lockman Hole		4.9	6.8	11.1	15.2	12.9	34.9h	24'x24'	3.15 h	30'x30'
EGS		5.44	7.75	11.1	15.2	12.9	34.53 h	10'x67'	3.75 h	10'x90'
Level 4 *(4 fields)*							***212.75 h***		***61.1****+85.3* ***h***	***359.1 h***
COSMOS		6.13	8.63	10.8	14.7	12.5	212.75h	85'x85'	44.15 h	1.4°x1.4°
Bootes-SCUBA2		20.4	29.3	14.0	19.3	16.3	No			2 sq deg
NDWFS/Bootes		38.2	54.8	26.2	36.1	30.4	No			8 sq deg
Level 5 *(6 fields)*	***18***	***31.3***	***35.7***	***10.9***	***15.2***	***12.8***	***No***		***328.1 h***	***18.3 sq deg***
Level 6 *(7 fields)*	***18***	***70***	***80***	***24.4***	***33.9***	***28.6***	***No***		***165.8 h***	***50.3 sq deg***
Clusters							***74.6 h***		***147 h***	***221.6 h***
Lensing clusters		2.6	4.0	3.4	4.7	4.0			147 h	0.01 sq.deg
TOTAL							***650 h***		***900 h***	***1550 h***
								797h PACS	753h SPIRE	



Wilson 07 ESO-report

Optimum depths from Spitzer to Herschel and ALMA



Confusion limits as in GOODS (e.g. 10 beams/src) or S/N(conf)>3, %blended= 20%

From Herschel to ALMA

Herschel brings the FIR side of galaxies and very distant ULIRGs to HyLIRGs but remains limited to extreme objects…

Hence on the long term, an ultra-deep sub-mm survey with ALMA is key to understand galaxy formation to:

- obtain a complete census on the cosmic SFR history up to z~5 or more (instead of z~1 for Spitzer/Herschel and ~only (U)LIRGs above) by connecting to the UV, i.e. down to 3 $M_{\odot} yr^{-1}$ at all redshifts.
- get a better spatial resolution
  - ⇒ identification of counterparts, z determination, deblending
  - ⇒ map SFR + molecular gas inside galaxies : origin of SF, spatial dist°
- complete SED : dust temperature, L(IR)-> SFR, photometric z.

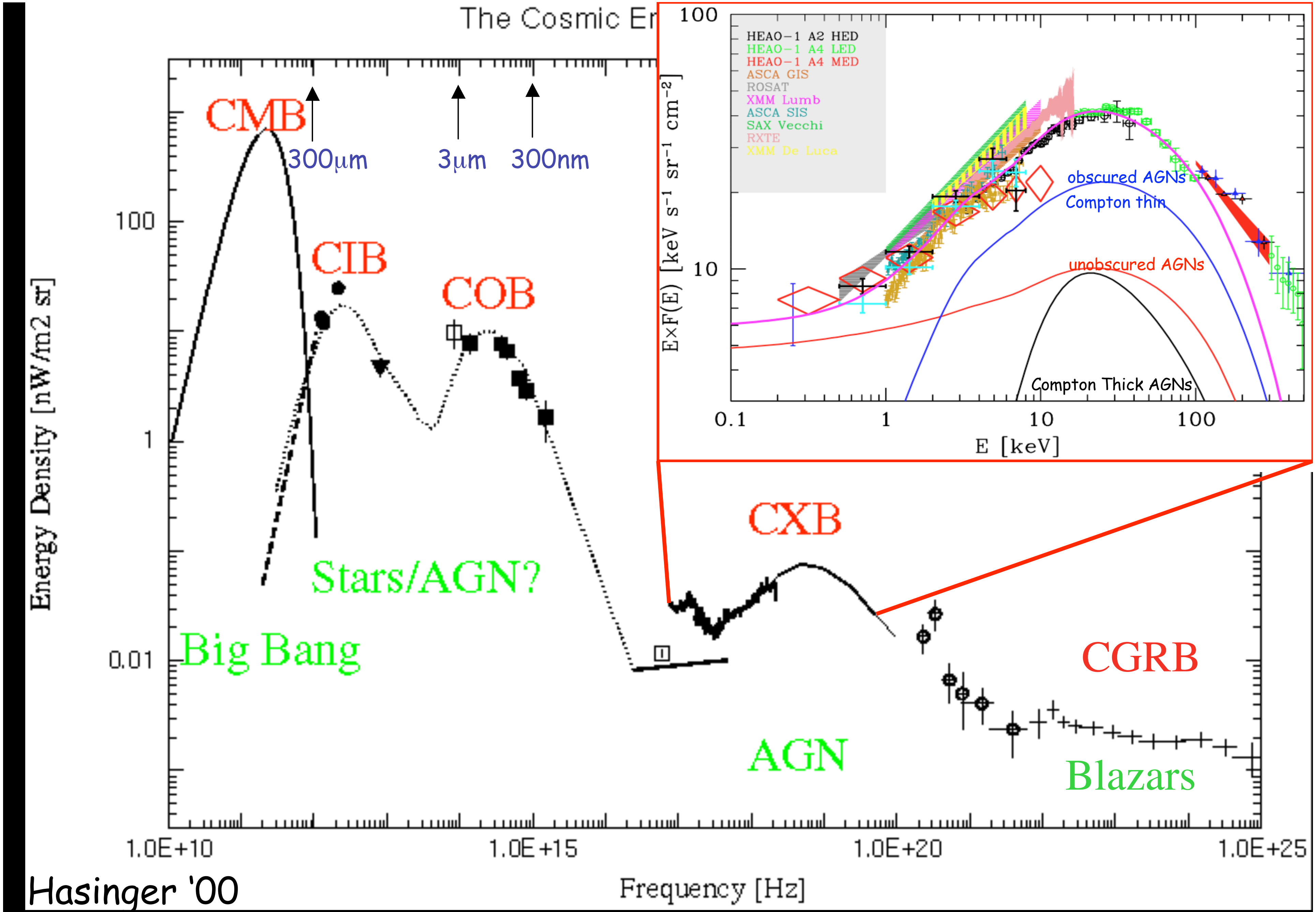
However, it is as important to start with follow-up of Spitzer/Herschel targets to understand the origin of star formation inside distant galaxies and :

- measure the molecular gas content of distant galaxies to understand the origin of the long duty cycle of distant LIRGs (and AGNs) & derive their SFE:

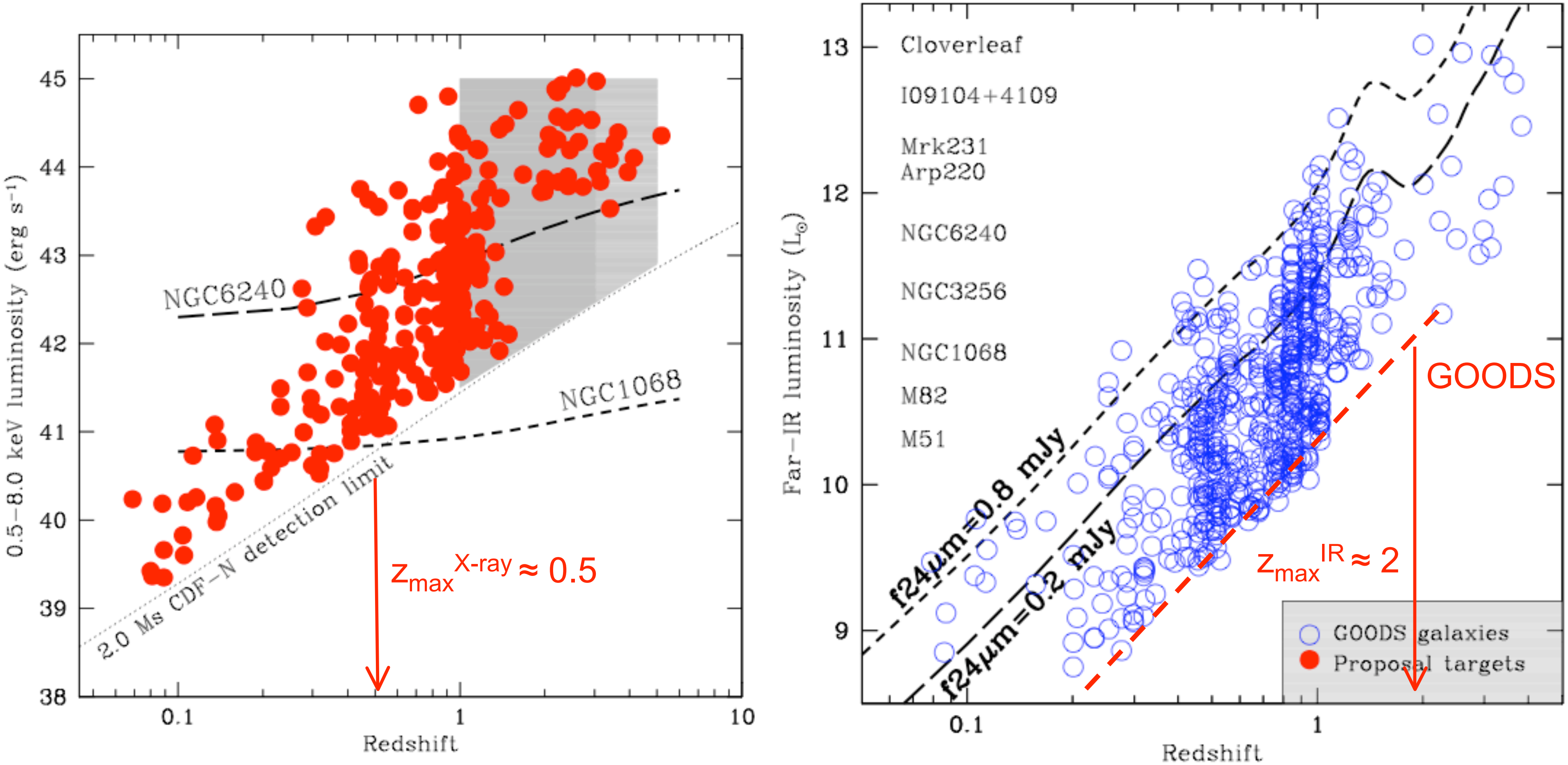
  SSFR=SFR/M* was x6 at z~1, what about the SFE=SFR/M_{gas} ?
- resolve the regions of star formation inside distant galaxies: nuclear or extended ? Starbursts or "quiescent"-mode (using also CII vs CO maps) ?

These follow-ups must span the parameter space: SFR (L_{IR}), M_* (-> SSFR), Σ (local galaxy density), morphologies (isolated, mergers, pairs, compact)

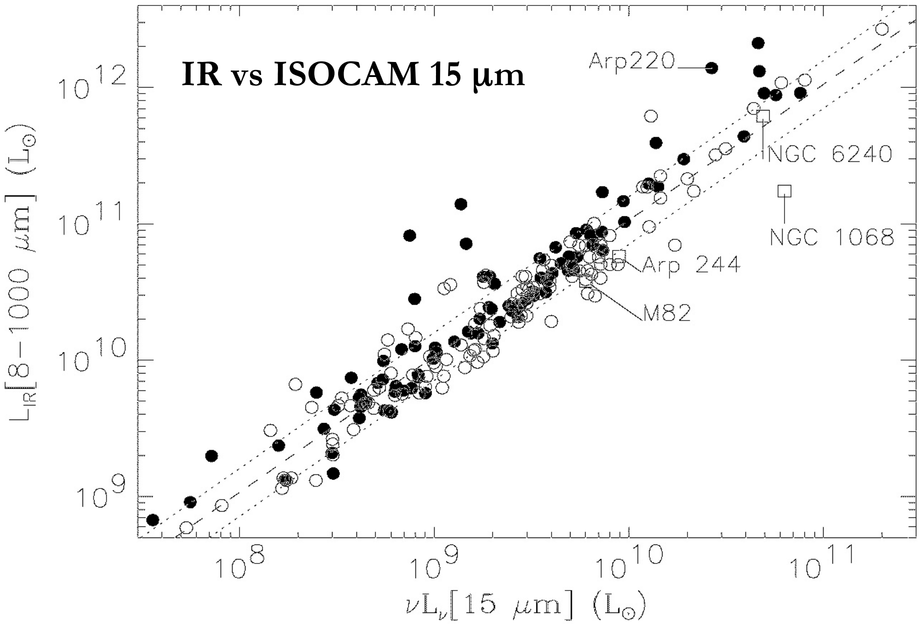
THANKYOU…

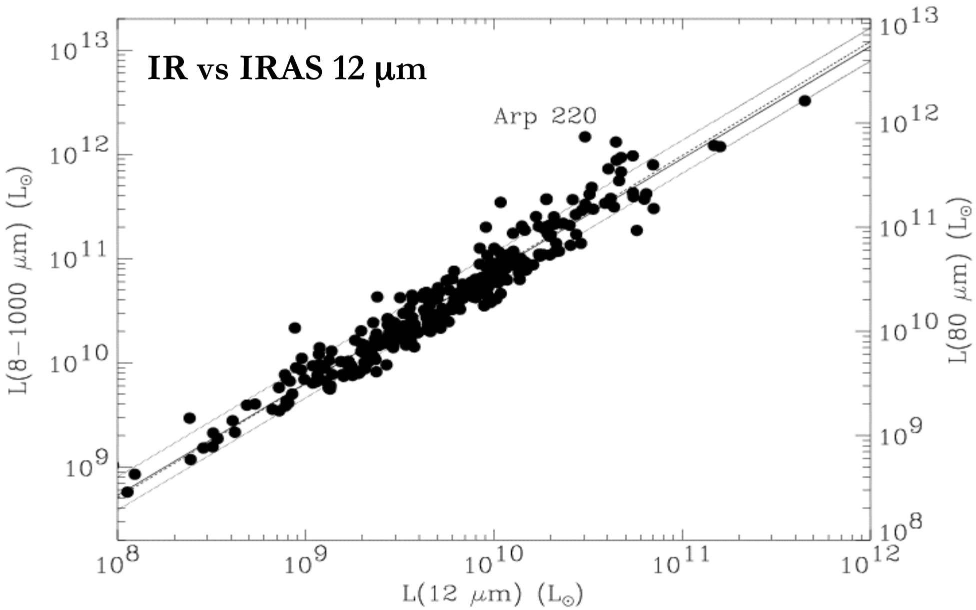

The Cosmic En
CMB
CIB
COB
300μm
3μm
300nm
Stars/AGN?
Big Bang
CXB
CGRB
AGN
Blazars
Energy Density [nW/m2 sr]
Frequency [Hz]
1.0E+10
1.0E+15
1.0E+20
1.0E+25
100
1
0.01
HEAO−1 A2 HED
HEAO−1 A4 LED
HEAO−1 A4 MED
ASCA GIS
ROSAT
XMM Lumb
ASCA SIS
SAX Vecchi
RXTE
XMM De Luca
obscured AGNs
Compton thin
unobscured AGNs
Compton Thick AGNs
E×F(E) [keV s−1 sr−1 cm−2]
E [keV]
0.1
1
10
100
Hasinger '00

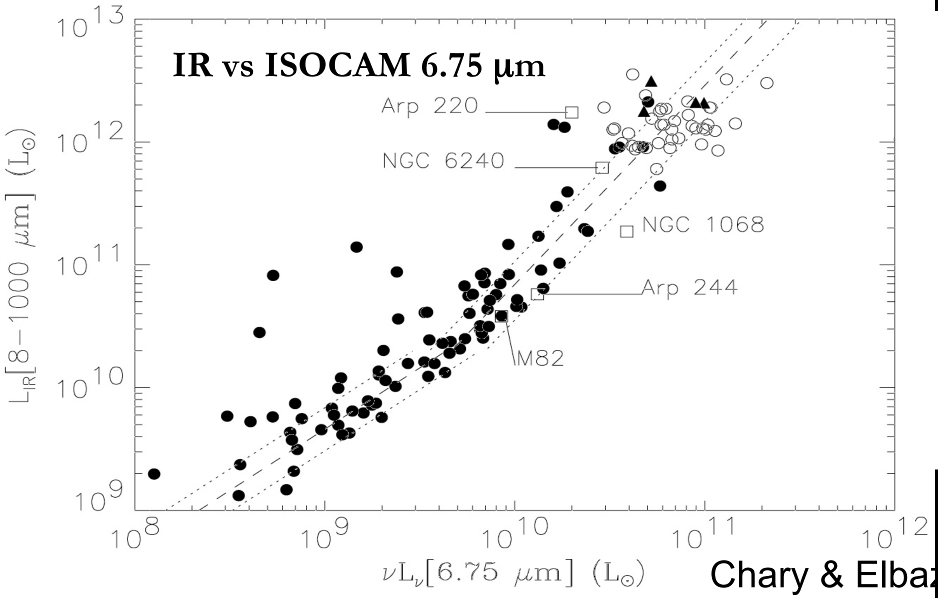
GOODS ultra-deep mid IR survey can detect NGC 1068-like CT AGNs to z~2 Chandra only to z~0.5 even with 2 mega-seconds !



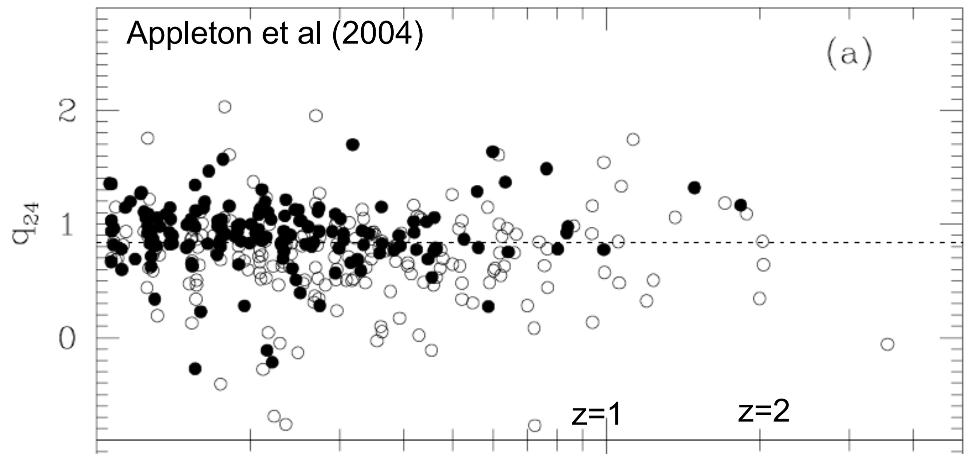
MIR-FIR & MIR-radio correlation -> SFR can be derived from MIR at z~1







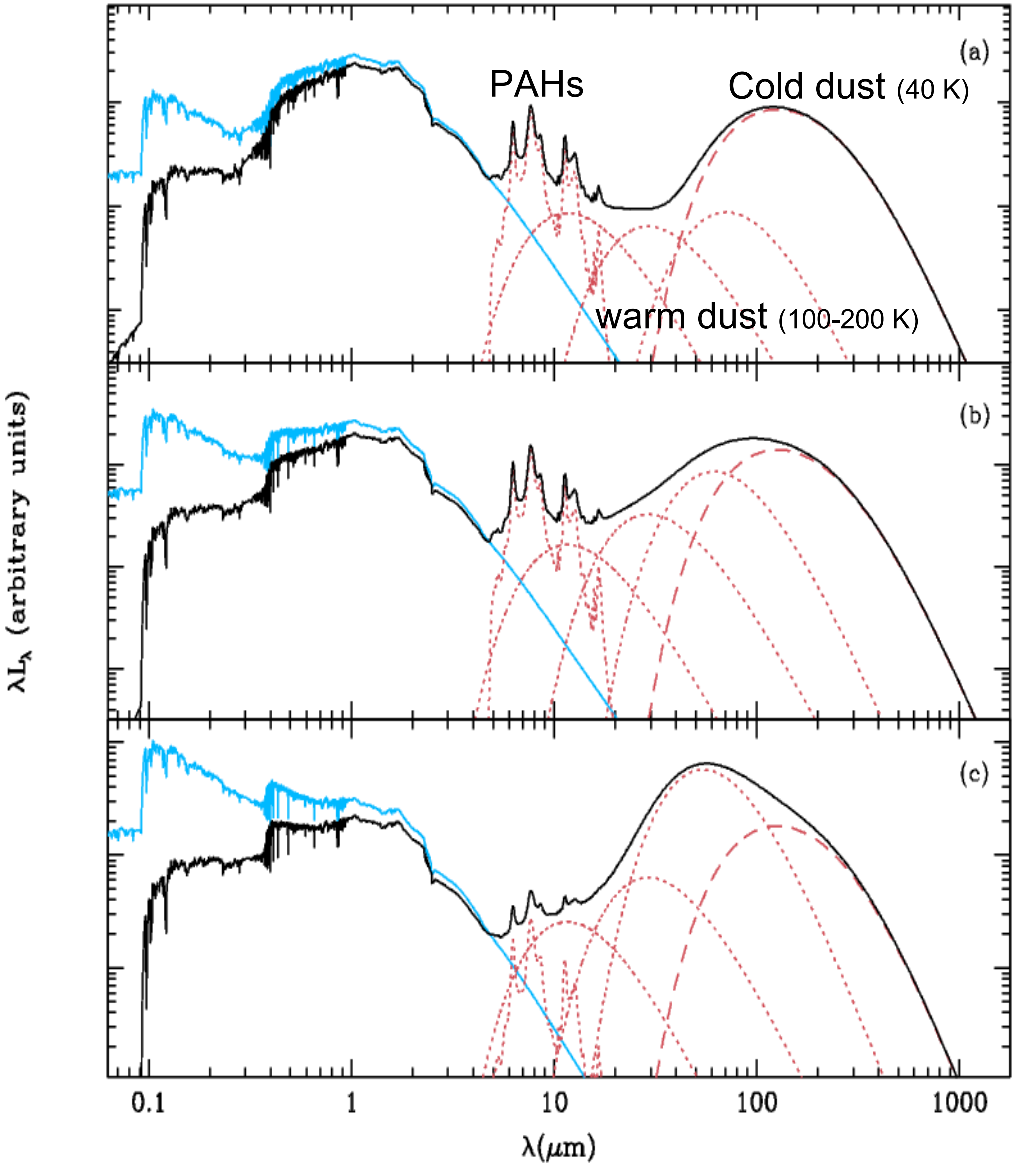
Chary & Elba

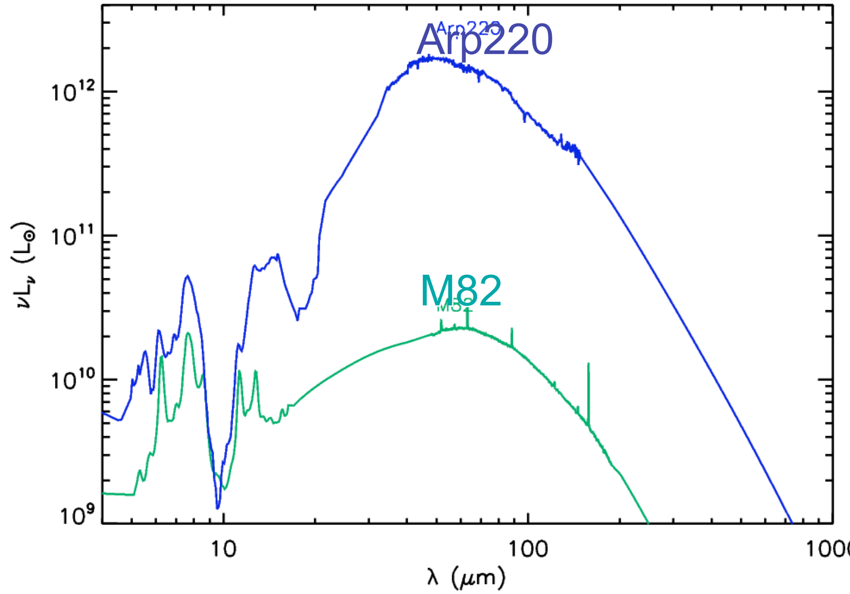


(Condon et al. 1991):

$$q = log_{10}\left(\frac{L_{\rm FIR}({\rm W})}{3.75\times10^{12}({\rm Hz})}\times\frac{1}{L_{\rm 1.4GHz}({\rm W\ Hz^{-1}})}\right)$$

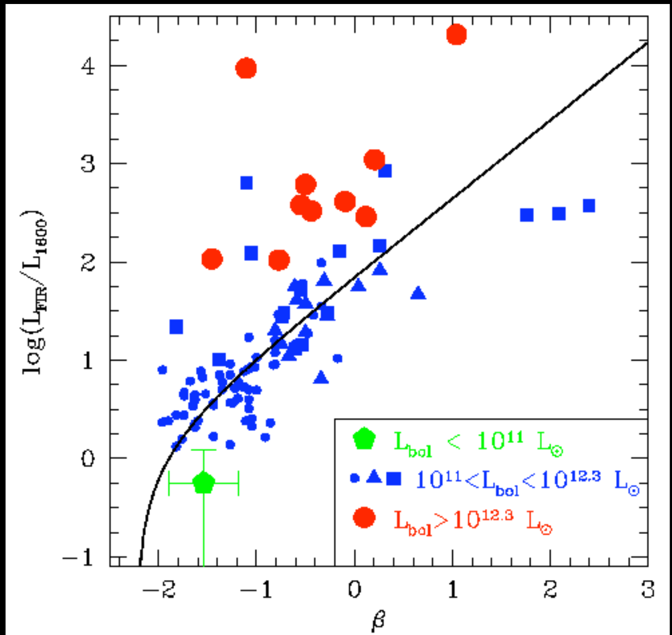
Spectral energy distributions of SF galaxies from UV to sub-mm



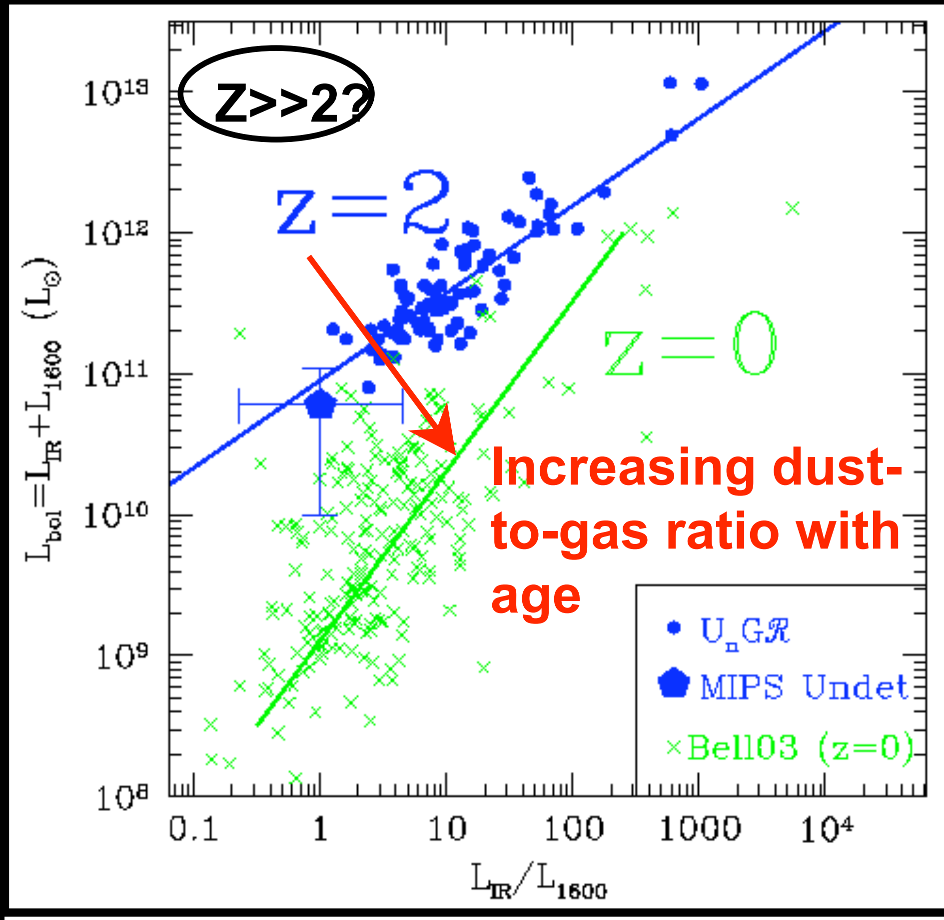


Da Cunha, Charlot & Elbaz (2007, in prep)

UV-IR connection



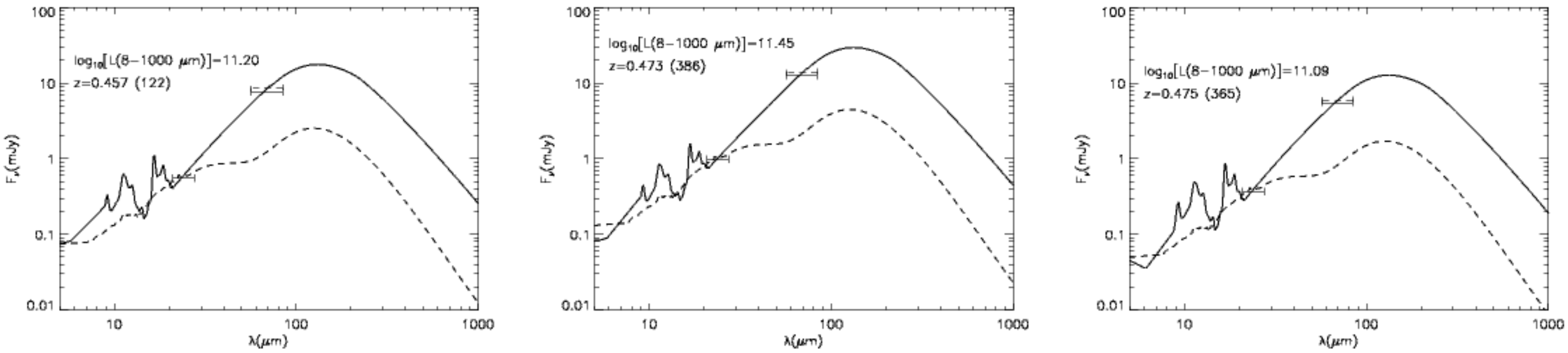
- L* galaxies follow local relation between β and attenuation



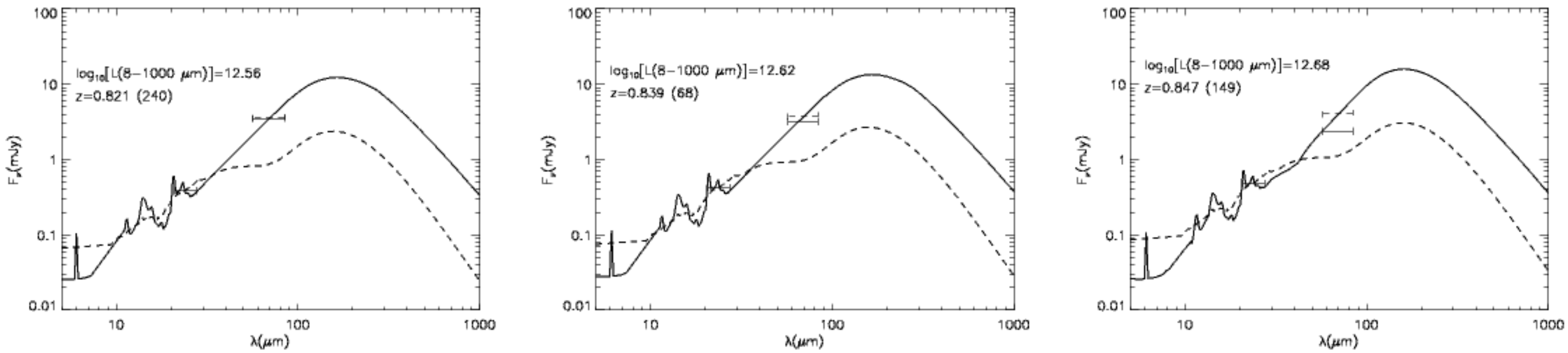
(Reddy et al. 2006)

Observed versus predicted 70 µm / Chary & Elbaz (2001) SEDs

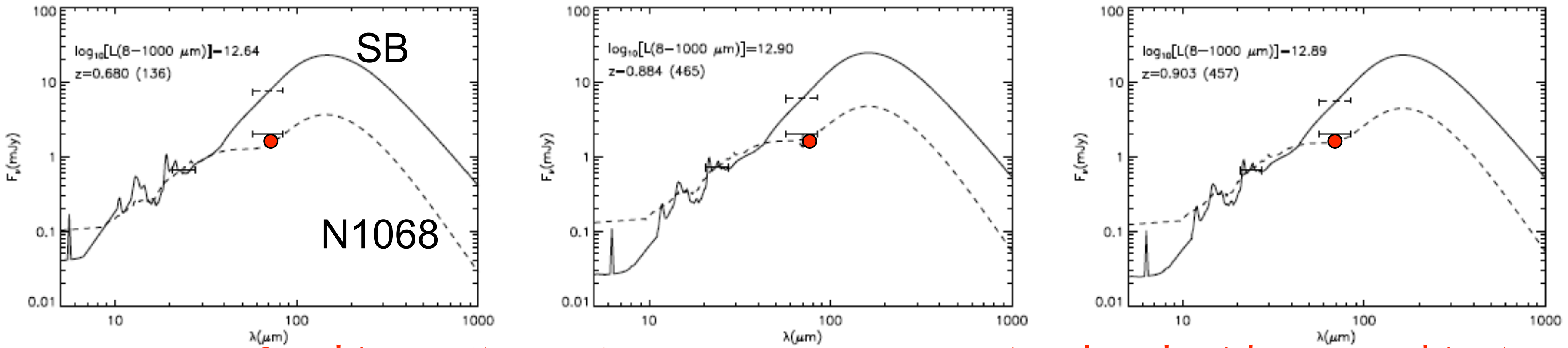
LIRGs @ z~0.5



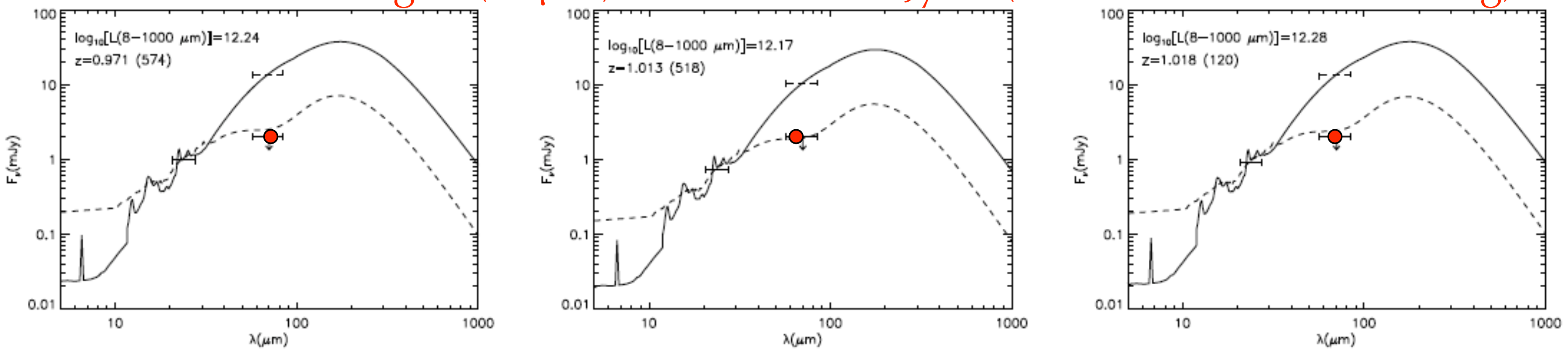
ULIRGs @ z~0.8



Spitzer 24 μm sources at z~1 anomalously faint at 70 μm



Stacking : F(70μm)= 1.50±0.18 mJy (2σ level without stacking)



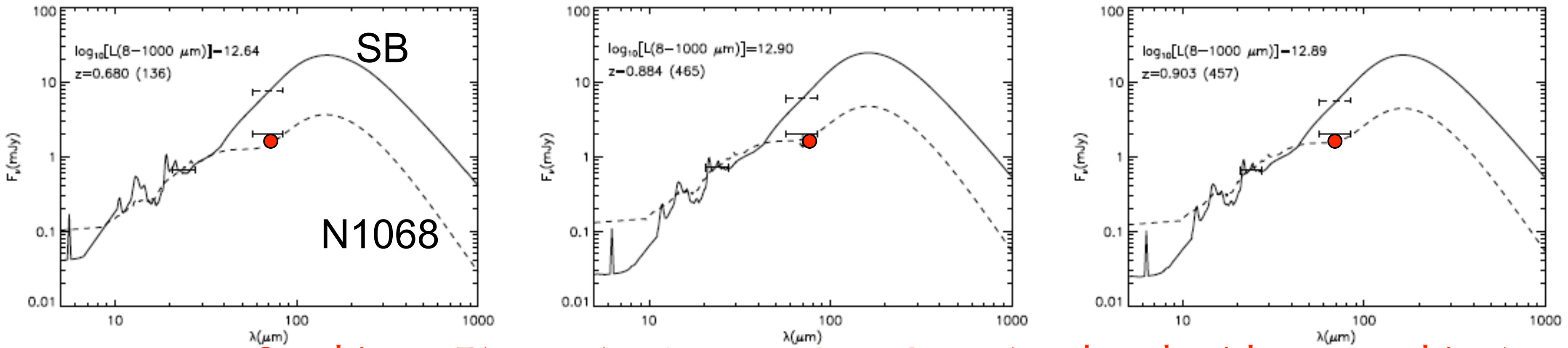
NGC 1068 (Le Floc'h et al. 01: ~70% MIR from AGN)

X-ray Stacking: hard src ~ 20 Compton Thick AGNs ! (X-ray unselected as AGNs)

-> 720/sq.deg. <-> 2800/sq.deg. required to produce the X-ray bkg (Worsley et al. 05)

≠ radio excess X-ray undetected AGNs (Donley, Rieke et al. 06)…

Spitzer 24 μm sources at z~1 anomalously faint at 70 μm



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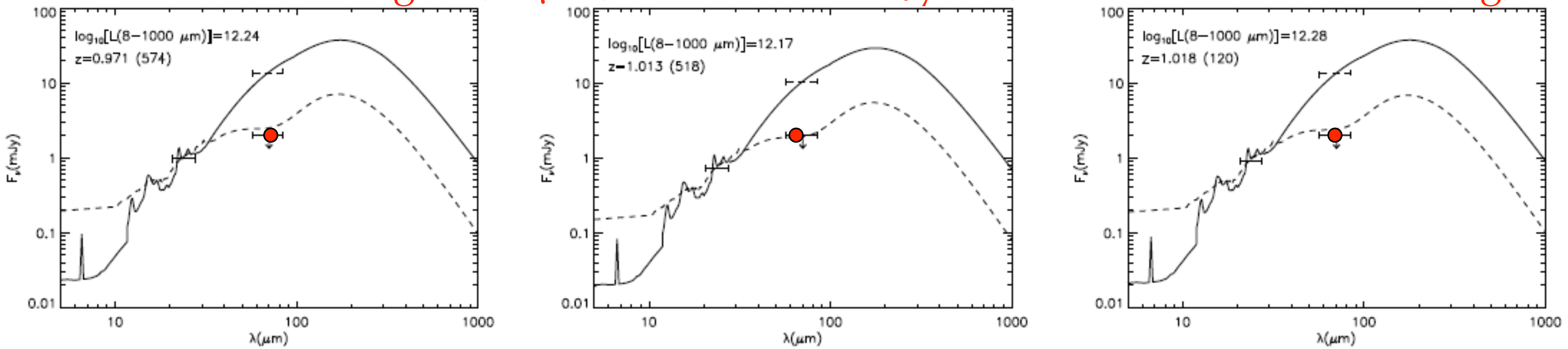

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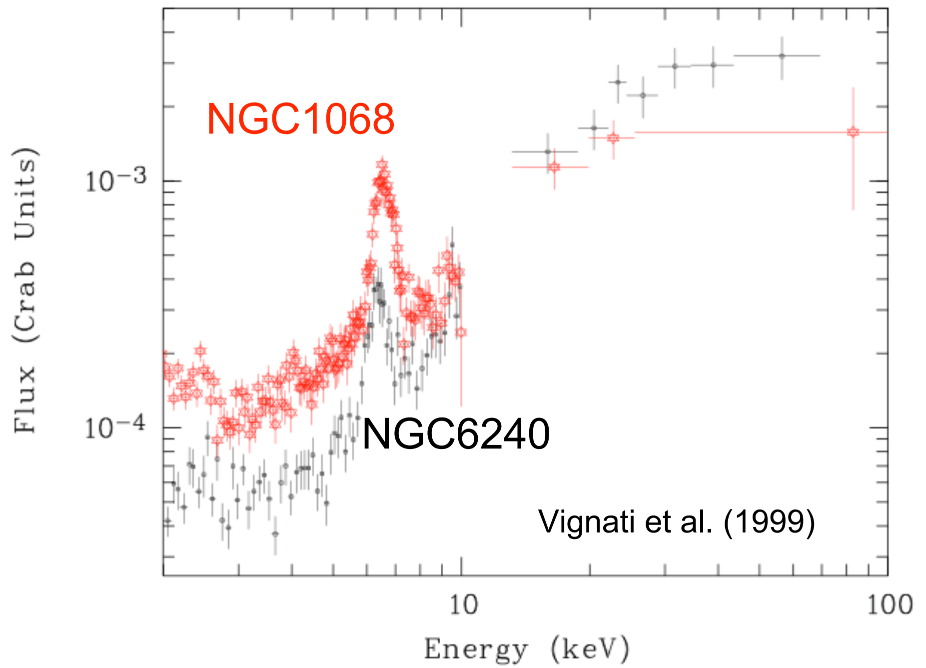
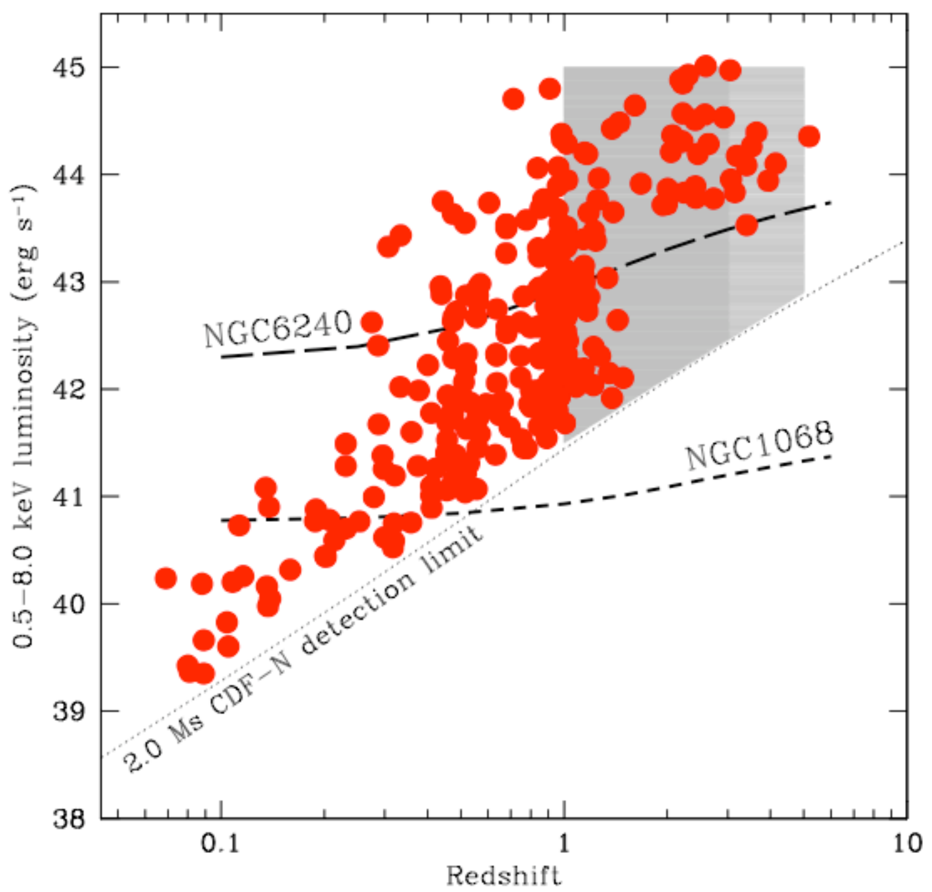
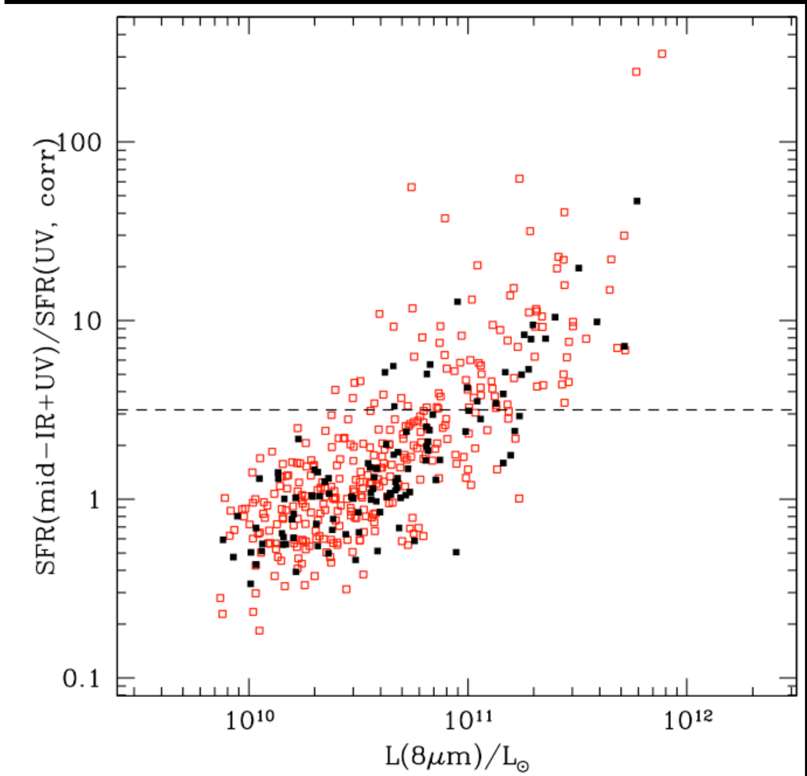
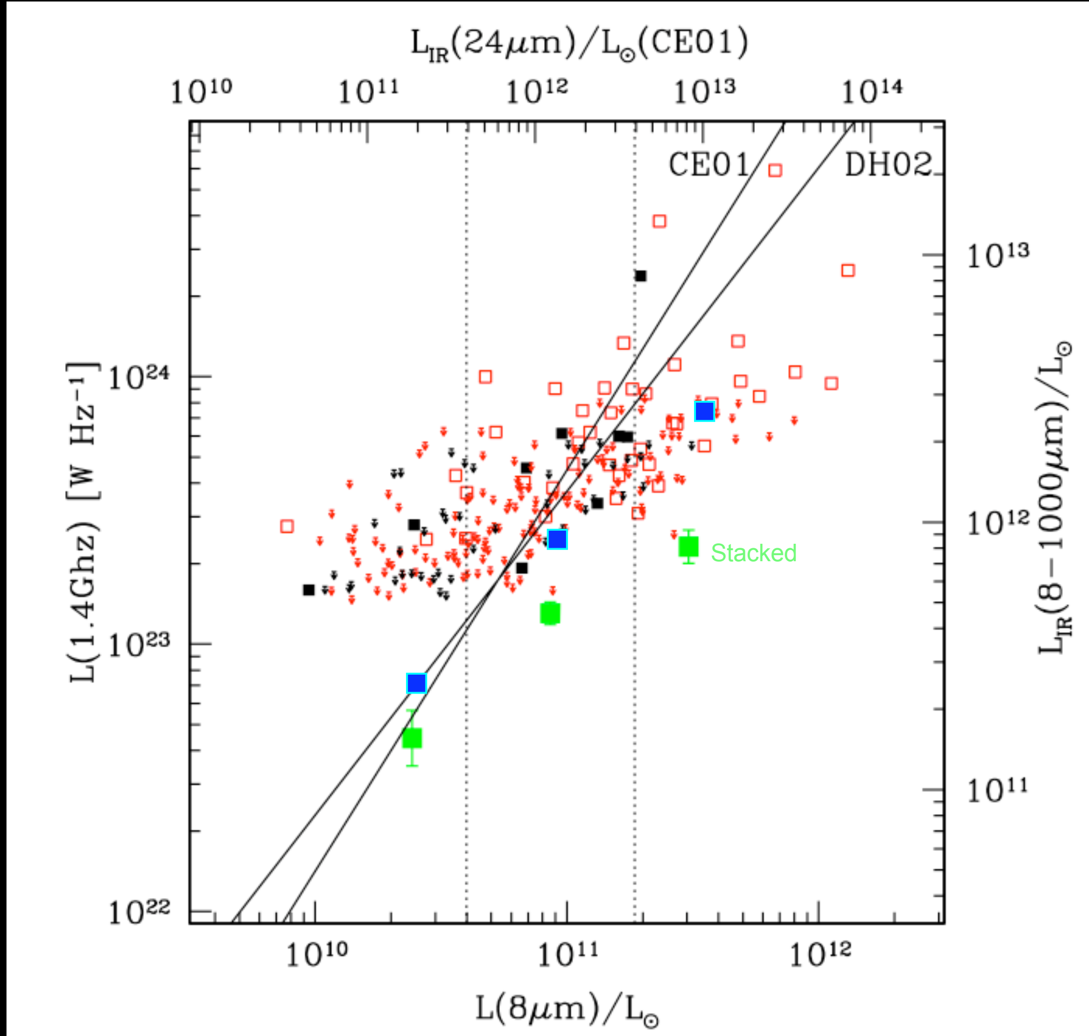
~50% of cosmic X-ray background remains to be resolved… Compton Thick AGNs such as NGC 1068 are missed at z>0.5 by the deepest X-ray surveys (even 2 Msec Chandra CDFN)





Luminous objects at 8 μm, z~2 present a mid infrared excess inconsistent with a star formation origin…

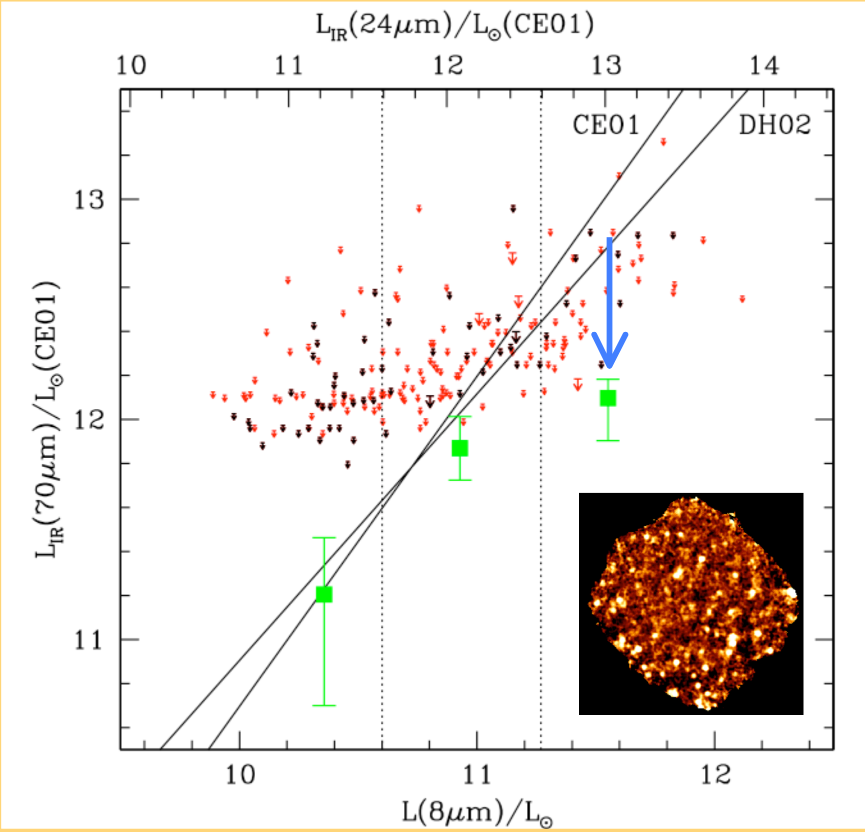




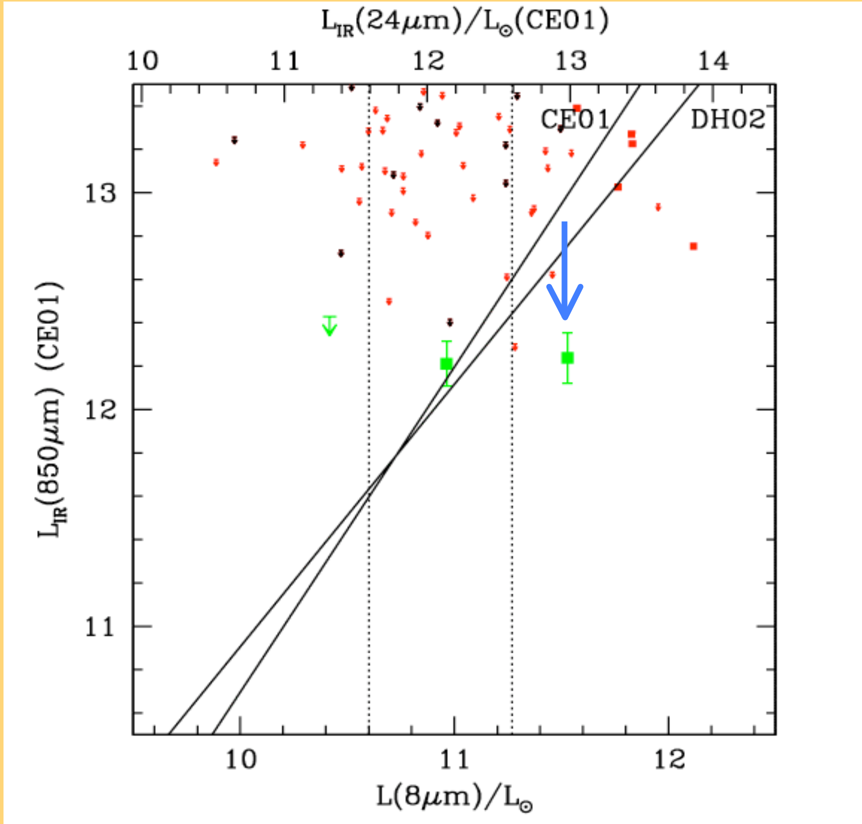
Daddi et al. 07

Luminous objects at 8 μm, z~2 present a mid infrared excess inconsistent with a star formation origin…

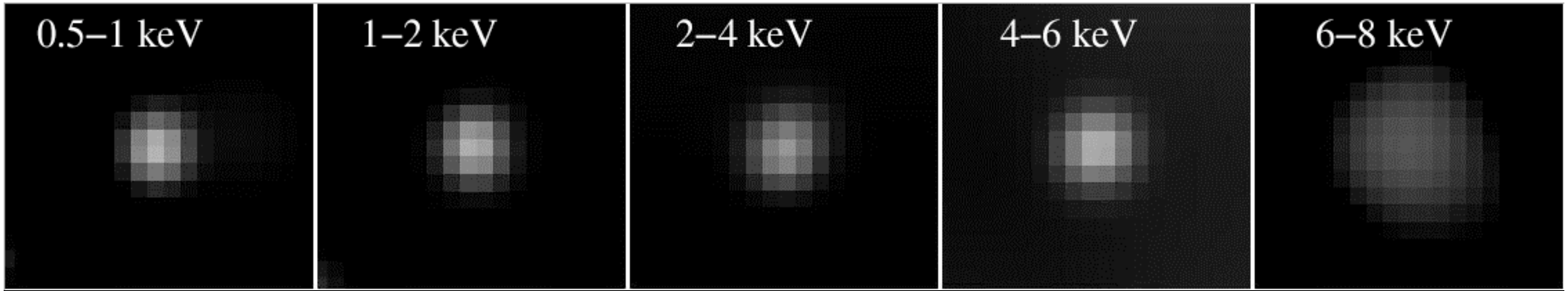
Spitzer 70 μm



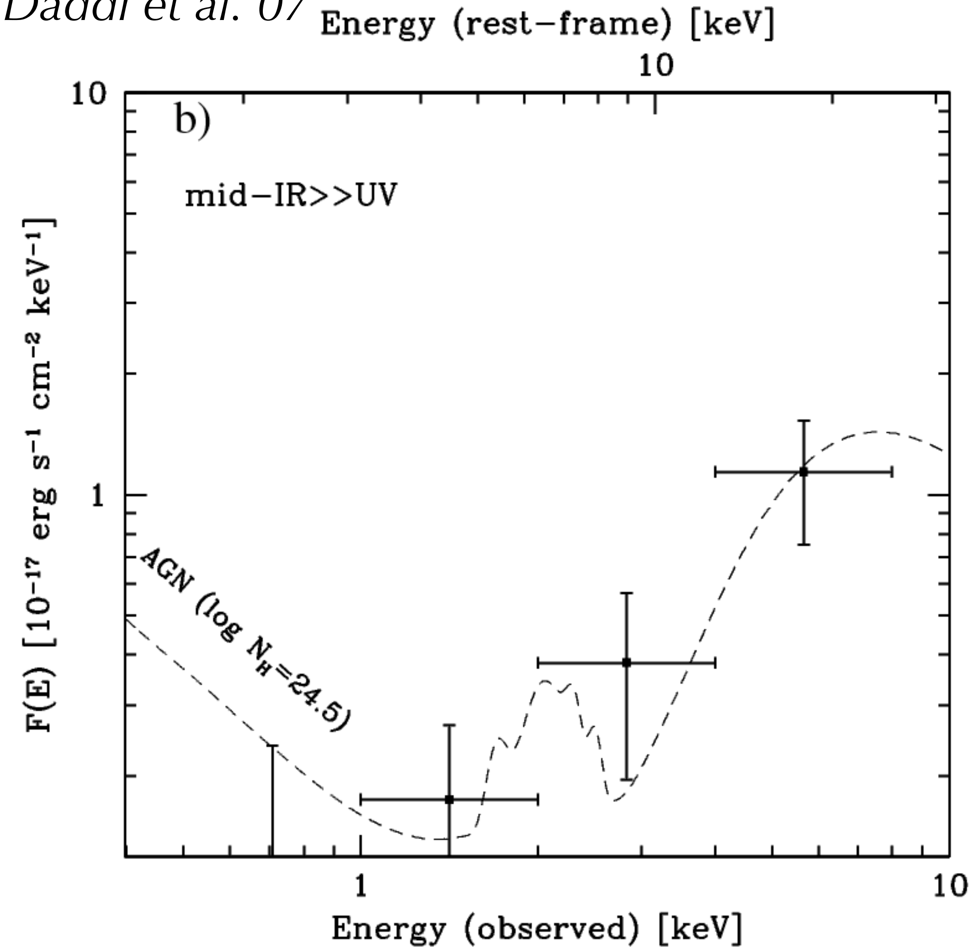
SCUBA 850 μm



Daddi et al. 07



Daddi et al. 07



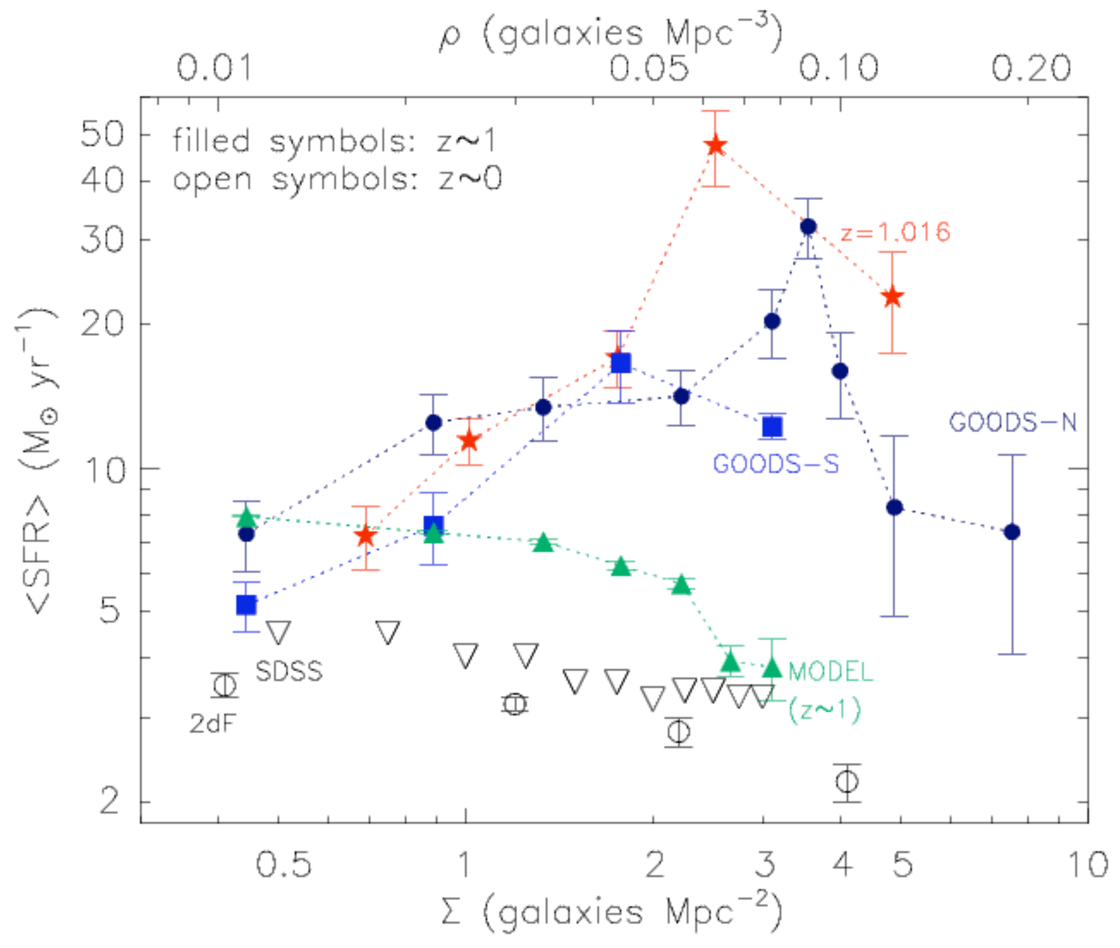
Sub-band stacking with Chandra
=> Compton Thick AGNs

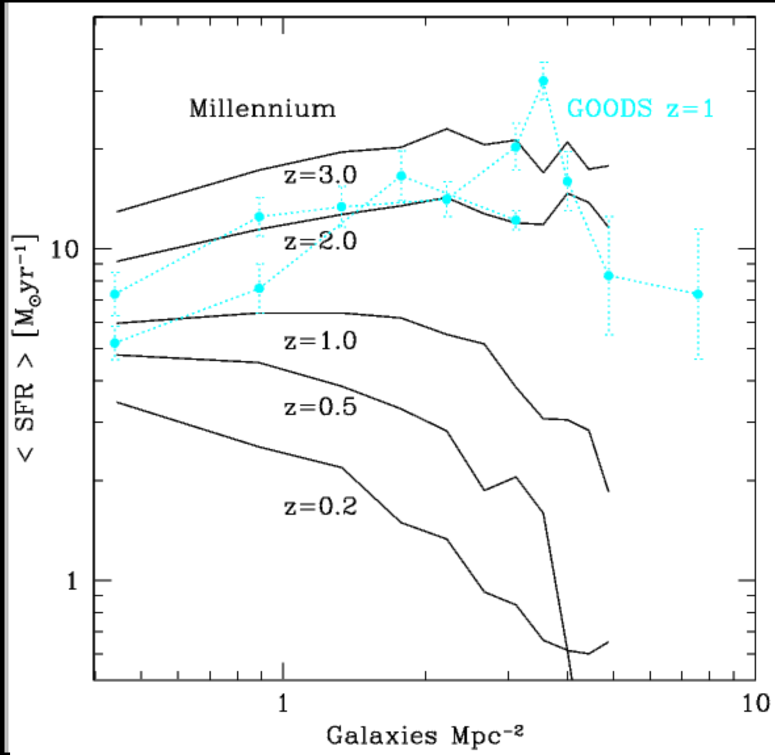
Subtracting power-law from SF
--> remarkably similar to AGN template with $N_H = 3 \times 10^{24}$ cm^{-2}

dashed line: AGN SED from Gilli et al 07 including 6.7 keV Fe line and for the z distribution of the sample.

20-30 % of massive galaxies @z=2 are candidate CT AGNs, this fraction increases with mass up to 50-60% for $M^* > 4 \times 10^{10} M_\odot$ hence this phase is not exceptional !

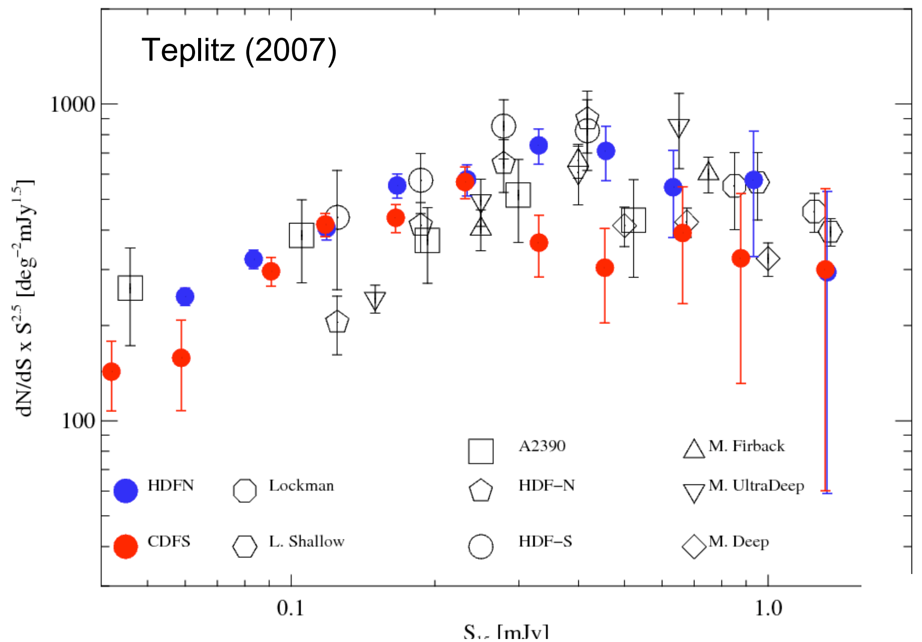
The star formation - galaxy density relation is reversed at z~1
(Elbaz et al. 2007)





from simulated lightcones generated by Kitzbichler & White (2006) Semi-analytical model of Croton et al. (2006) applied to the Millennium Run simulation (Springel et al. 2005)

Latest Spitzer differential counts



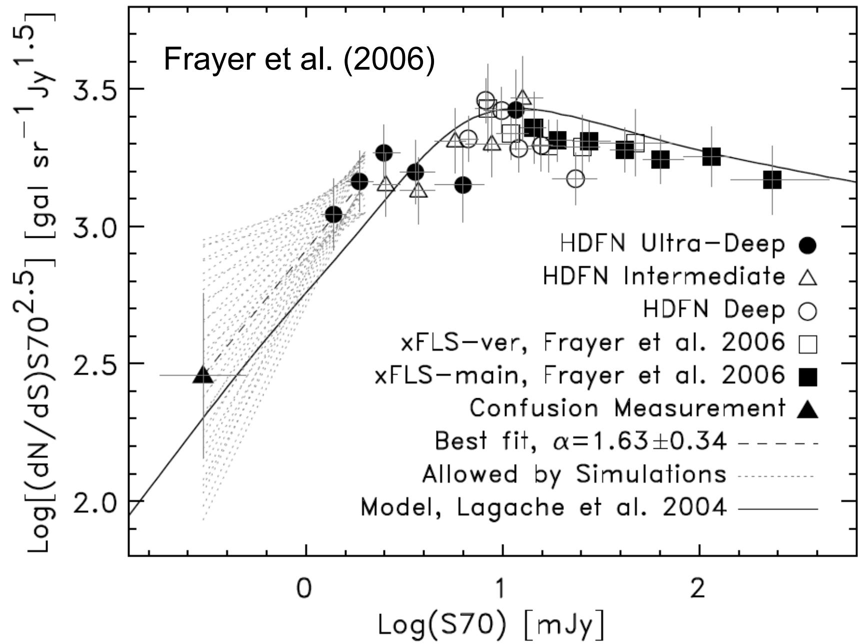
Latest Spitzer

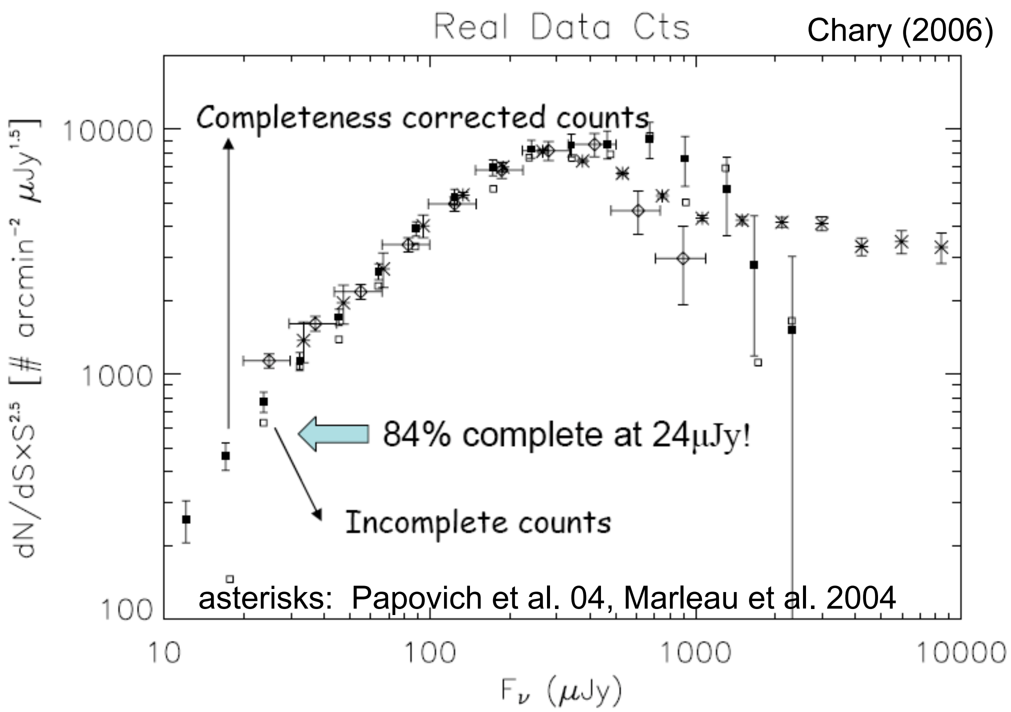
S(16μm,5σ)= 40 μJy

S(24μm,5σ)= 25 μJy

(84% complete at 24 μJy)

S(70μm,5σ)= 2 mJy





Great Observatories Origins Deep Survey (GOODS)

1- "Complete" in spec z *-> 3D local environment at 1 Mpc scale*	Intense spectroscopic follow-up from Keck + VLT
2- SFR : connection to UV	Spitzer-MIPS 20μJy@24μm ->3 $M_{\odot} yr^{-1}$@z~1: SFR=SFR(IR)+SFR(UV)
3- ultra-deep X-ray imaging *+stacking*	Deepest Chandra surveys (2 Msec North, 1 Msec South)--> X-ray AGNs
4- High resolution optical imaging	HST-ACS --> galaxy morphology (AB=28 in 4 ACS bands BViz)
5- Optical-NIR-IRAC	~1μJy IRAC (AB=24.5) + Subaru,VLT… -> stellar masses (using PEGASE)

The specific SFR (SSFR=SFR/M*) of local starbursts, LIRGs, ULIRGs

SFR/M* ~ 0.06 Gyr^{-1} (MW) --> $\tau \approx 20$ Gyr (time to x2 M*)

x 10 = 0.5 Gyr^{-1} (M82)--> $\tau \approx 2$ Gyr

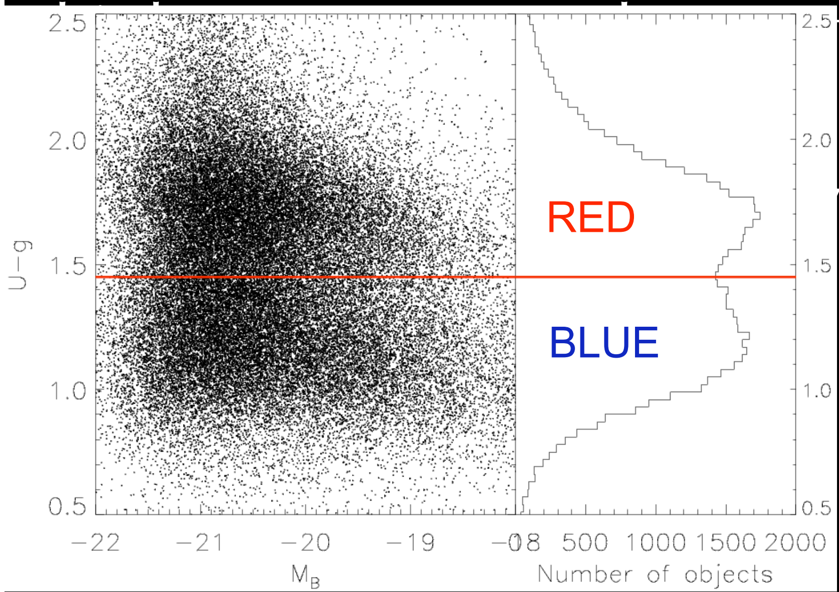
x 20 = 10 Gyr^{-1} (Arp 220) --> $\tau \approx 0.1$ Gyr

SSFR=SFR/M*=SFR /(<SFR> x age x mass loss fraction)

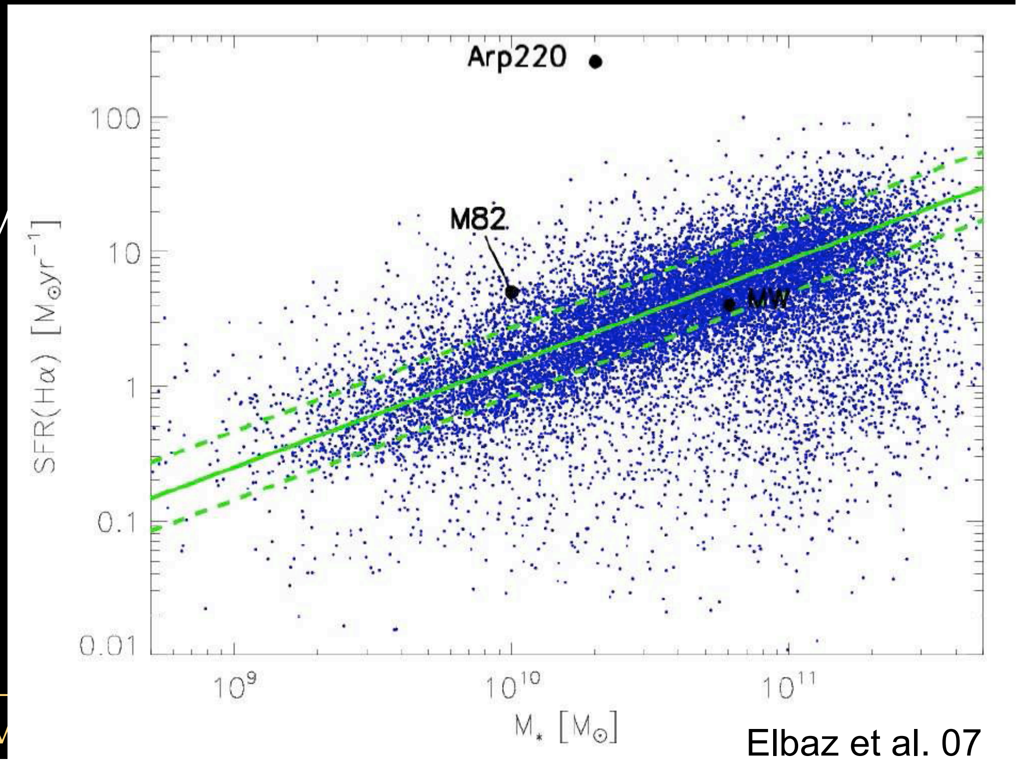
age~10 Gyr, mass loss fraction~0.5 => SSFR --> b=SFR/<SFR>

for

cy



SDSS data from Brinchmann et al. (2004)

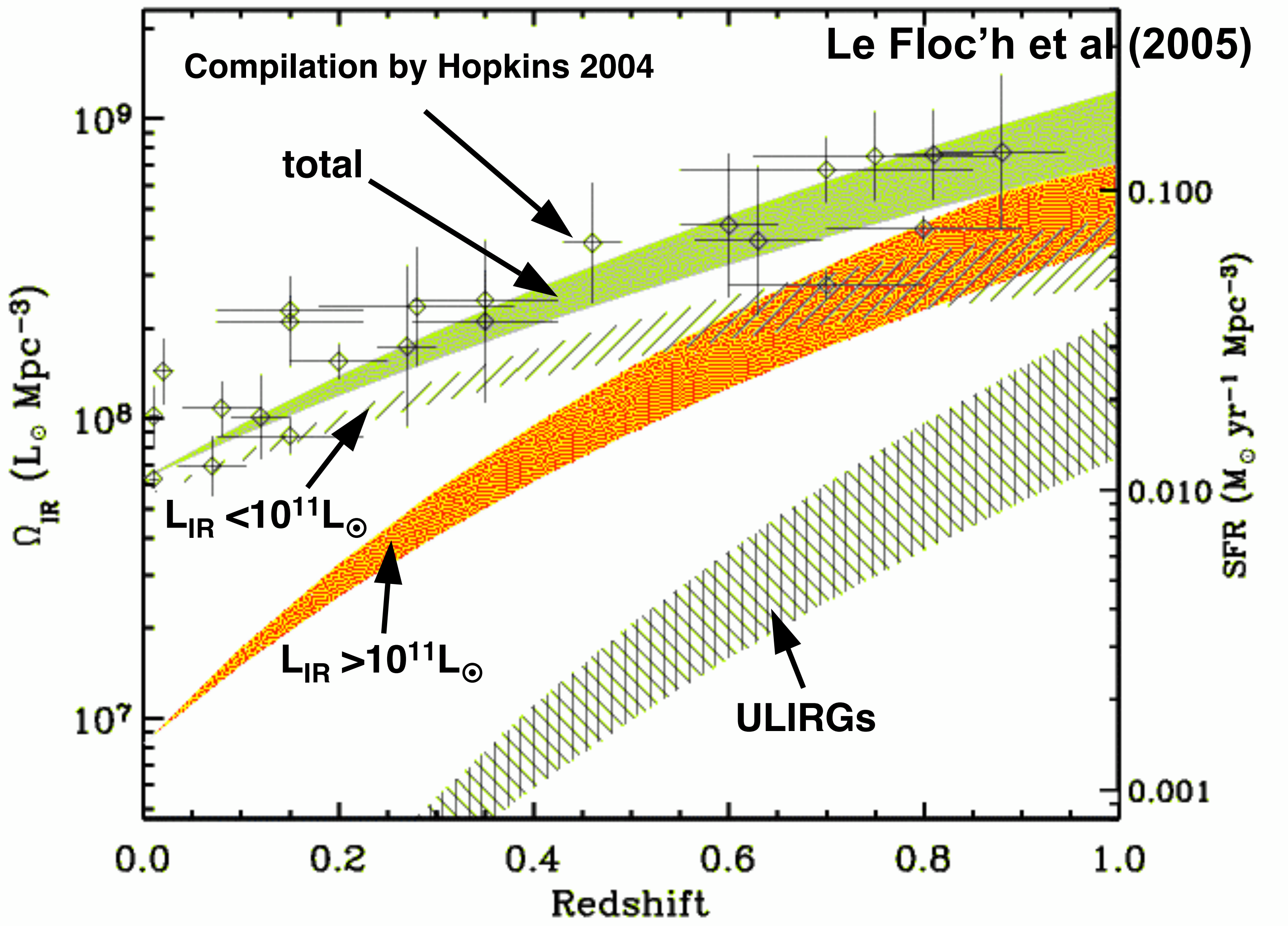


LIRGs and ULIRGs dominate the cosmic SFR @ 0.6 < z < 3

Comoving IR luminosity density LIRGs/ULIRGs times ~70 @ z~1

$\mathcal{L}_{IR}(z=0)$~7.8x10^6 L$_\odot$Mpc^{-3} --> $\mathcal{L}_{IR}(z=1)$~ 500x10^6 L$_\odot$Mpc^{-3} LIRGs & ULIRGs

Chary & Elbaz (2001) , Le Floc'h et al (2005)



LIRG:
10^{12} L$_\odot$≥L$_{IR}$≥10^{11} L$_\odot$
ULIRG:
10^{13} L$_\odot$≥L$_{IR}$≥10^{12} L$_\odot$
HLIRG:
L$_{IR}$≥10^{13} L$_\odot$

LIRGs dominate the CSFR at z > 0.6

At z=1: 70 % CSFR
LIRGs = 60 %
ULIRGs = 10 %

Limitation of Herschel's depth

- Herschel is confusion limited at all wavelengths except 70 μm
- It would take 3.4 years to cover one GOODS field (10'x15') at the confusion limit at 70 μm of 0.1 mJy !
- And this would only allow Herschel to measure the FIR light of the same galaxies as Spitzer at $z<3$ and better above $z\sim3$.