From Spitzer to Herschel Extragalactic Surveys Evolution of the Infrared Luminosity Function and of the Cosmic Star Formation Rate Density

HERMES

SKA AFRICA
SQUARE KILOMETRE ARRAY

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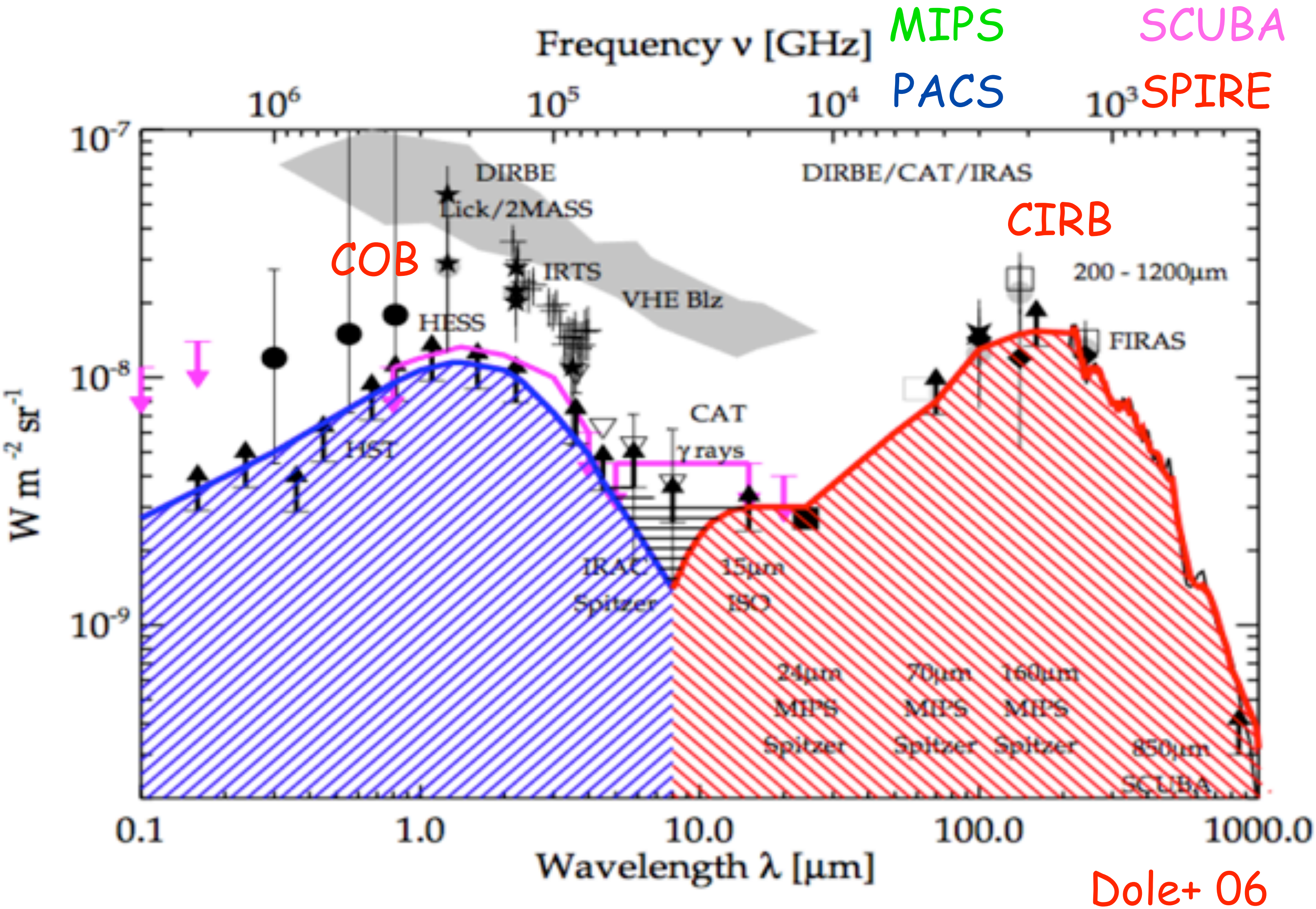
and the HerMES Consortium (Coordinated by Jamie Bock & Seb Oliver)

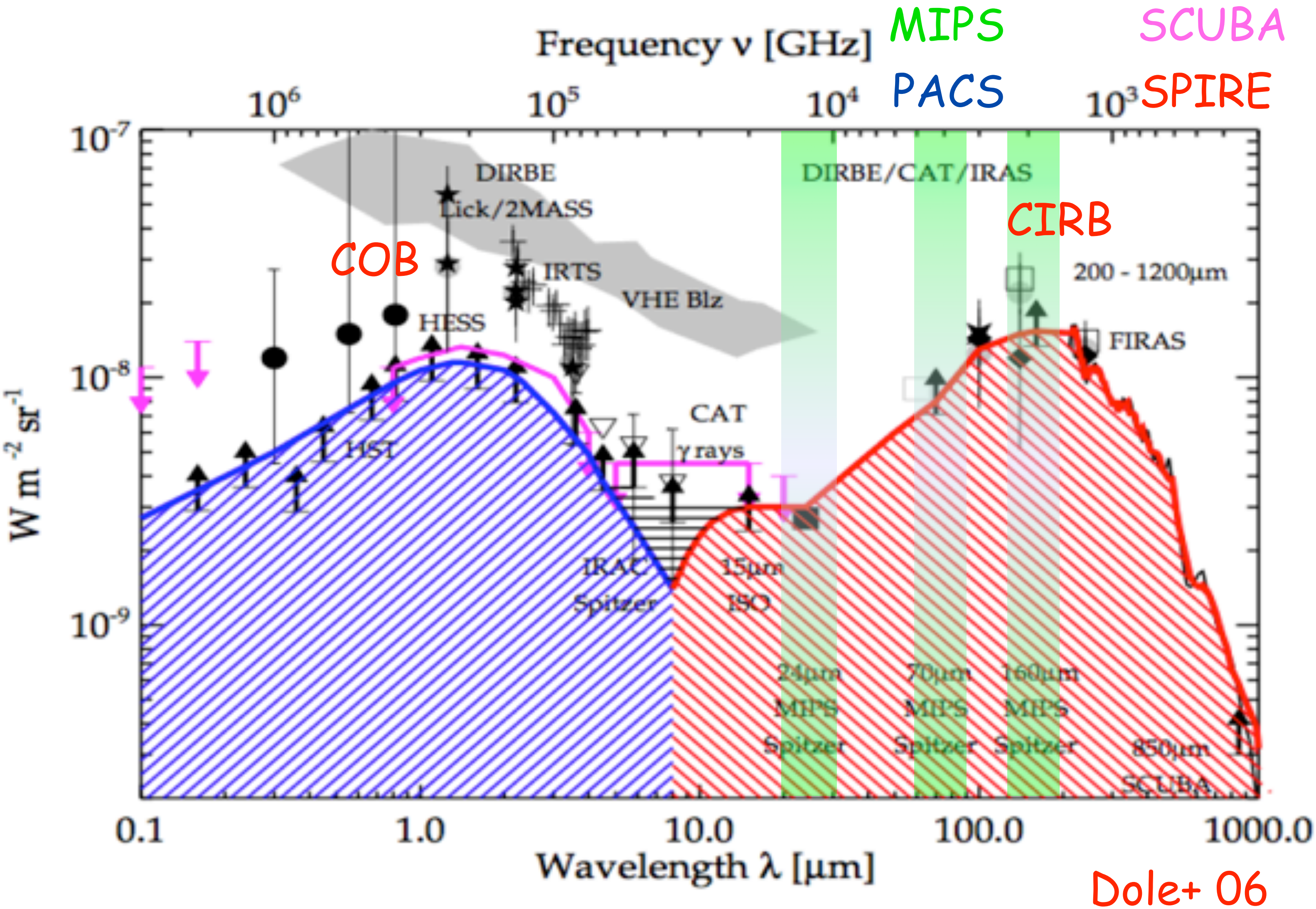
"Planck & Others", Bologna, 16 February 2012

Breaking down the CIRB



A full understanding of galaxy formation and evolution requires resolving the CIRB into its constituent sources and studying their properties at 'all' wavelengths

Breaking down the CIRB



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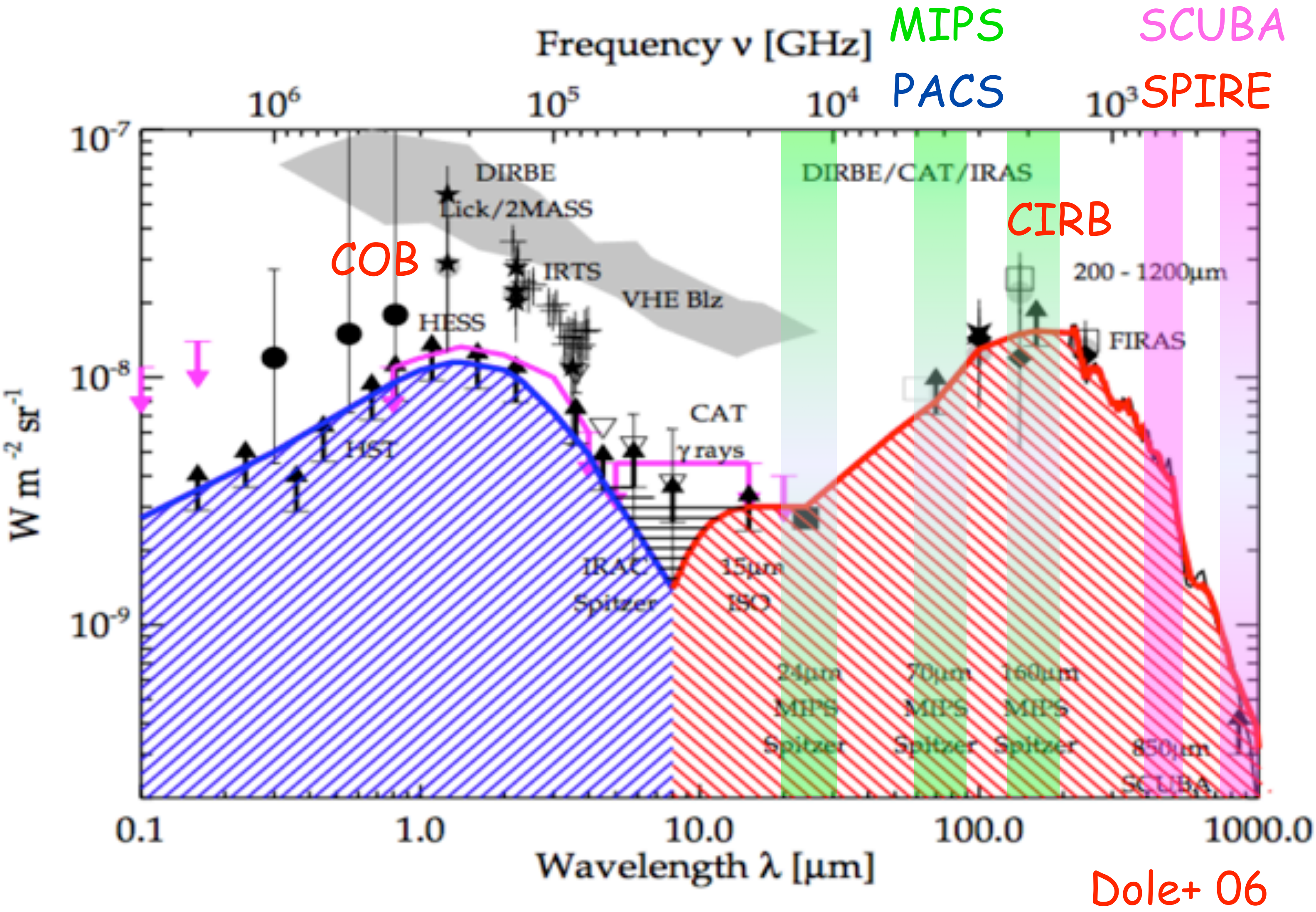

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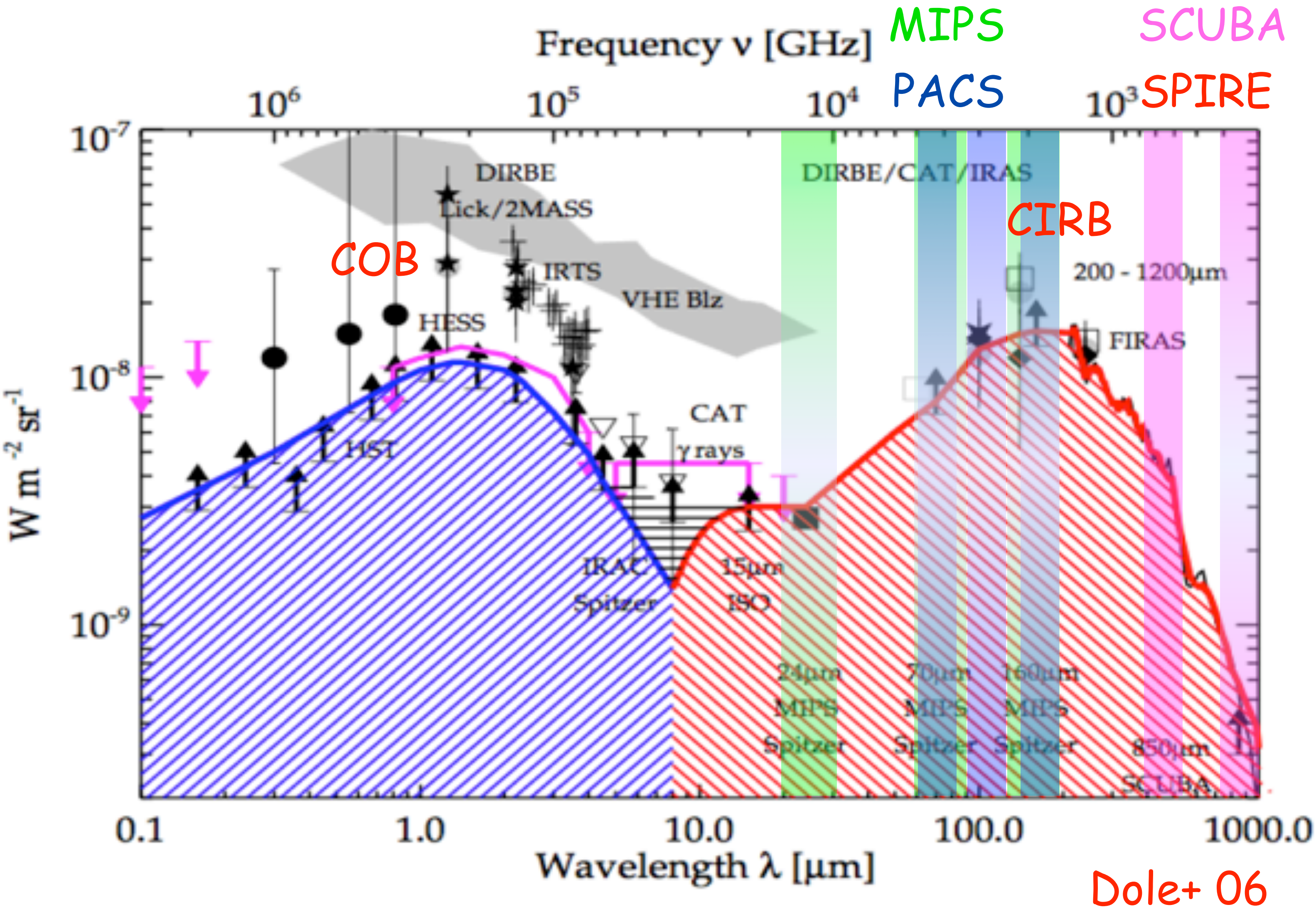

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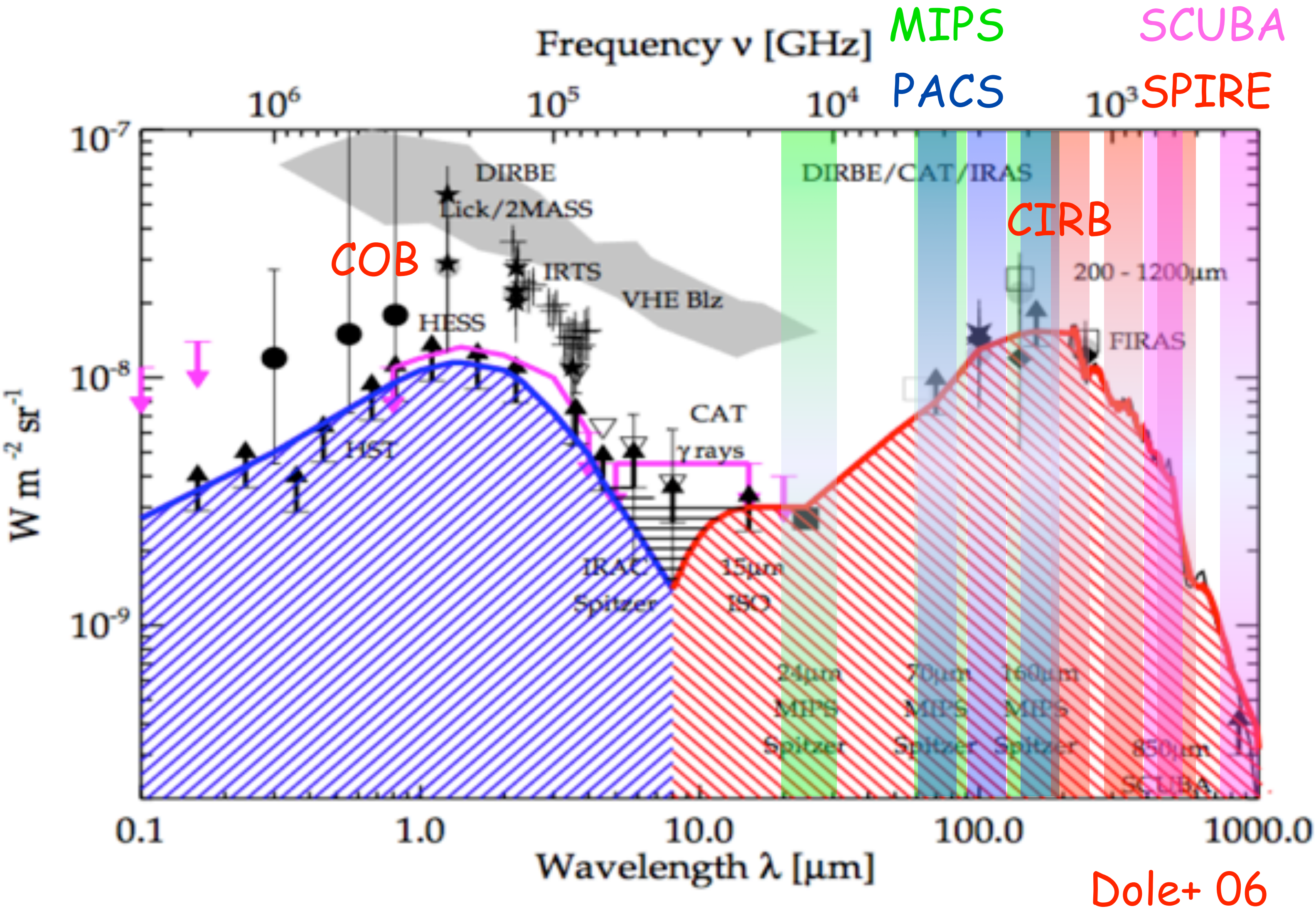
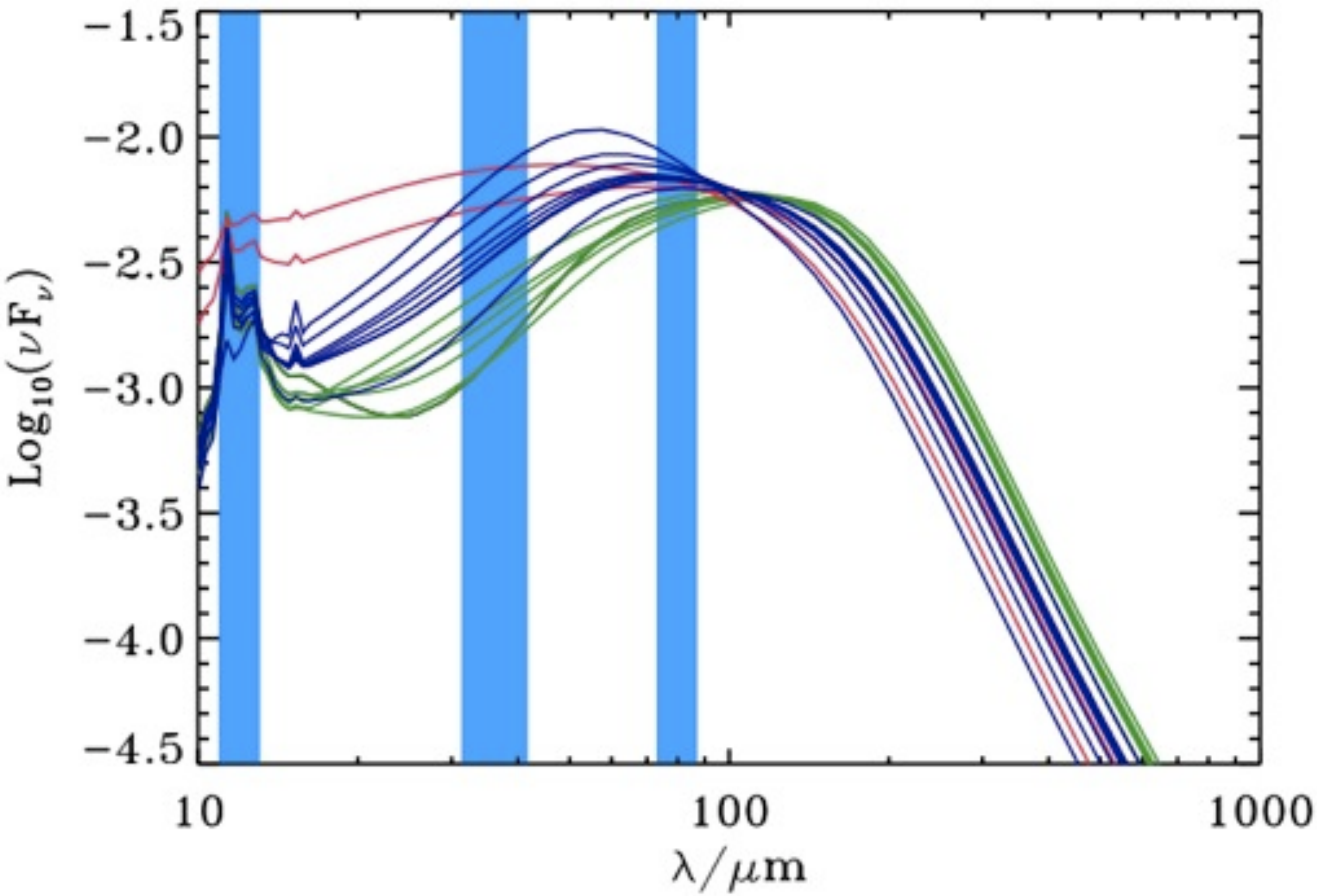


A full understanding of galaxy formation and evolution requires resolving the CIRB into its constituent sources and studying their properties at 'all' wavelengths

Constraining Bolometric Luminosity With Spitzer

MIPS 24/70/160 micron Bands @ z~1.0



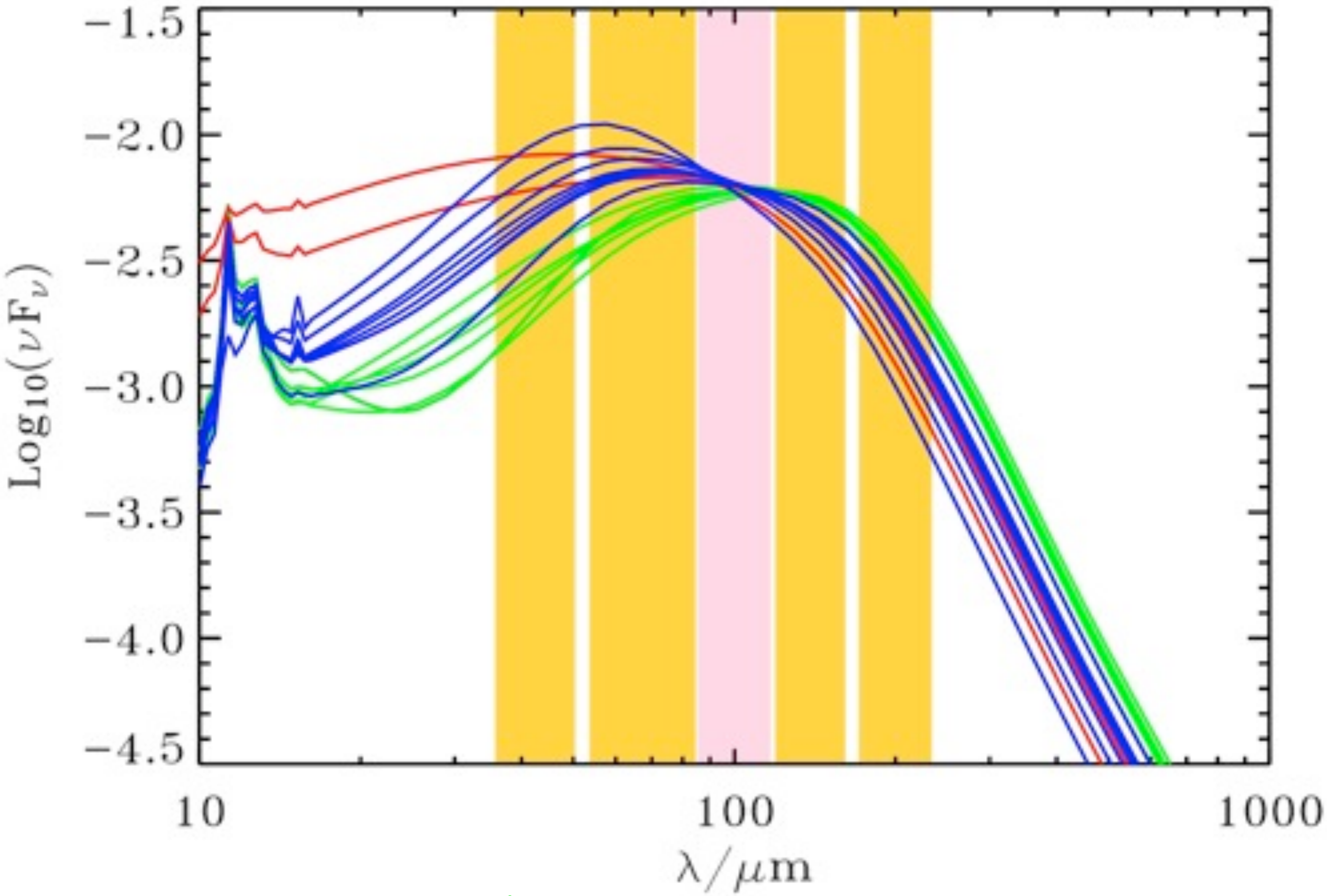
Spirals Starbursts AGNs

Xu's model spectra normalized so as to have same LIR

Spitzer-based estimates are biased (and increasingly so with redshift)

Constraining Bolometric Luminosity With Herschel

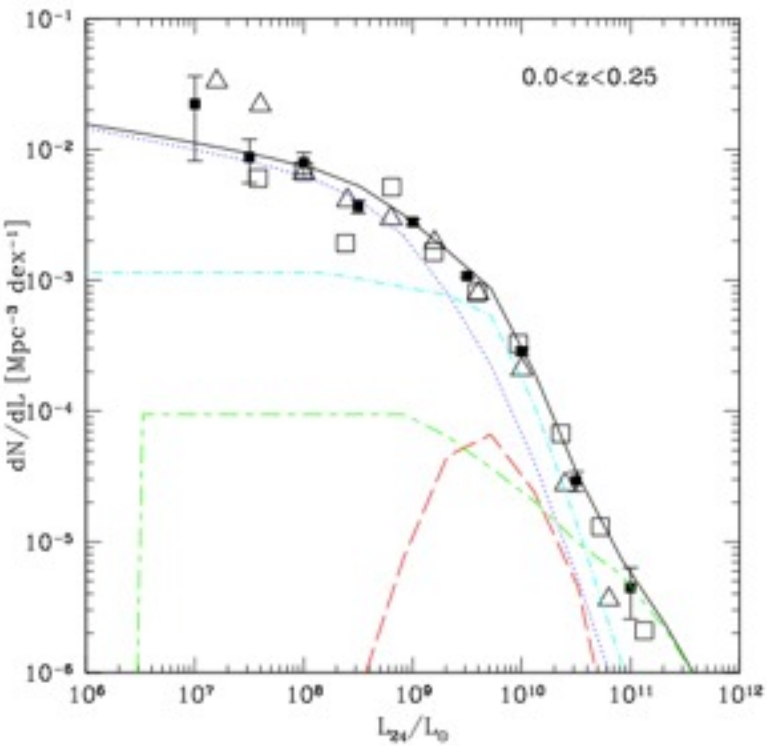
5 PACS+SPIRE (100 to 500 micron) Bands @ z~1.5

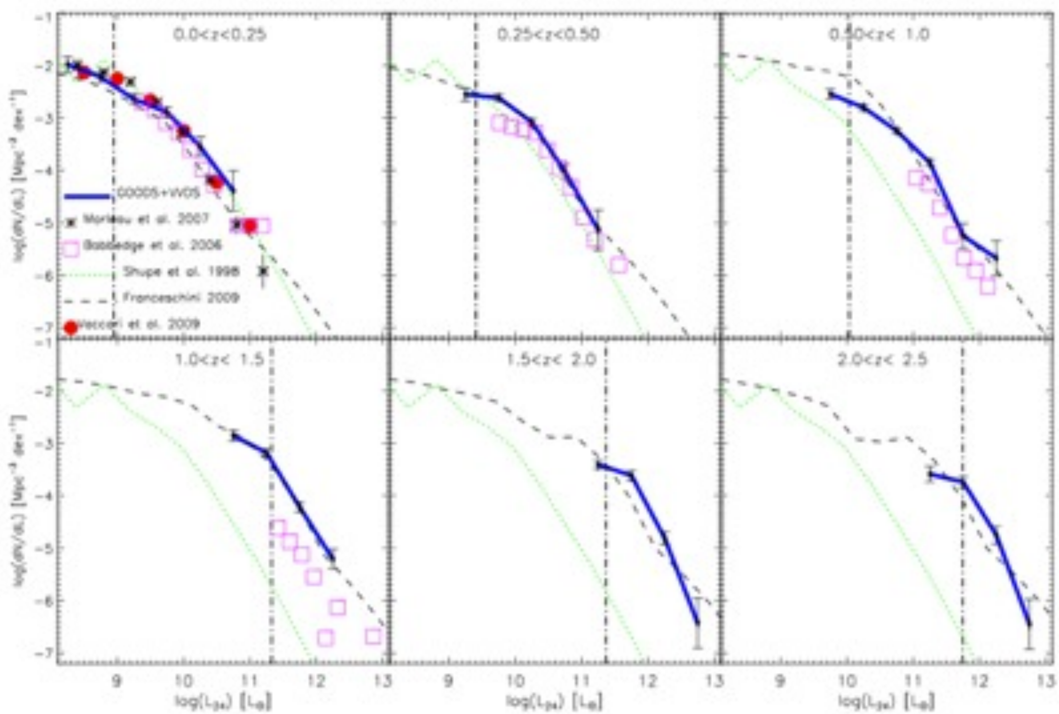


Spirals Starbursts AGNs

Xu's model spectra normalized so as to have same LIR
Herschel bands are crucial in constraining the bolometric luminosity of galaxies
This helps untangling the contribution of AGN and SF and thus constrain SFH

Taking stock of Spitzer MIPS-24 Surveys
Deep & Wide MIR Luminosity Functions



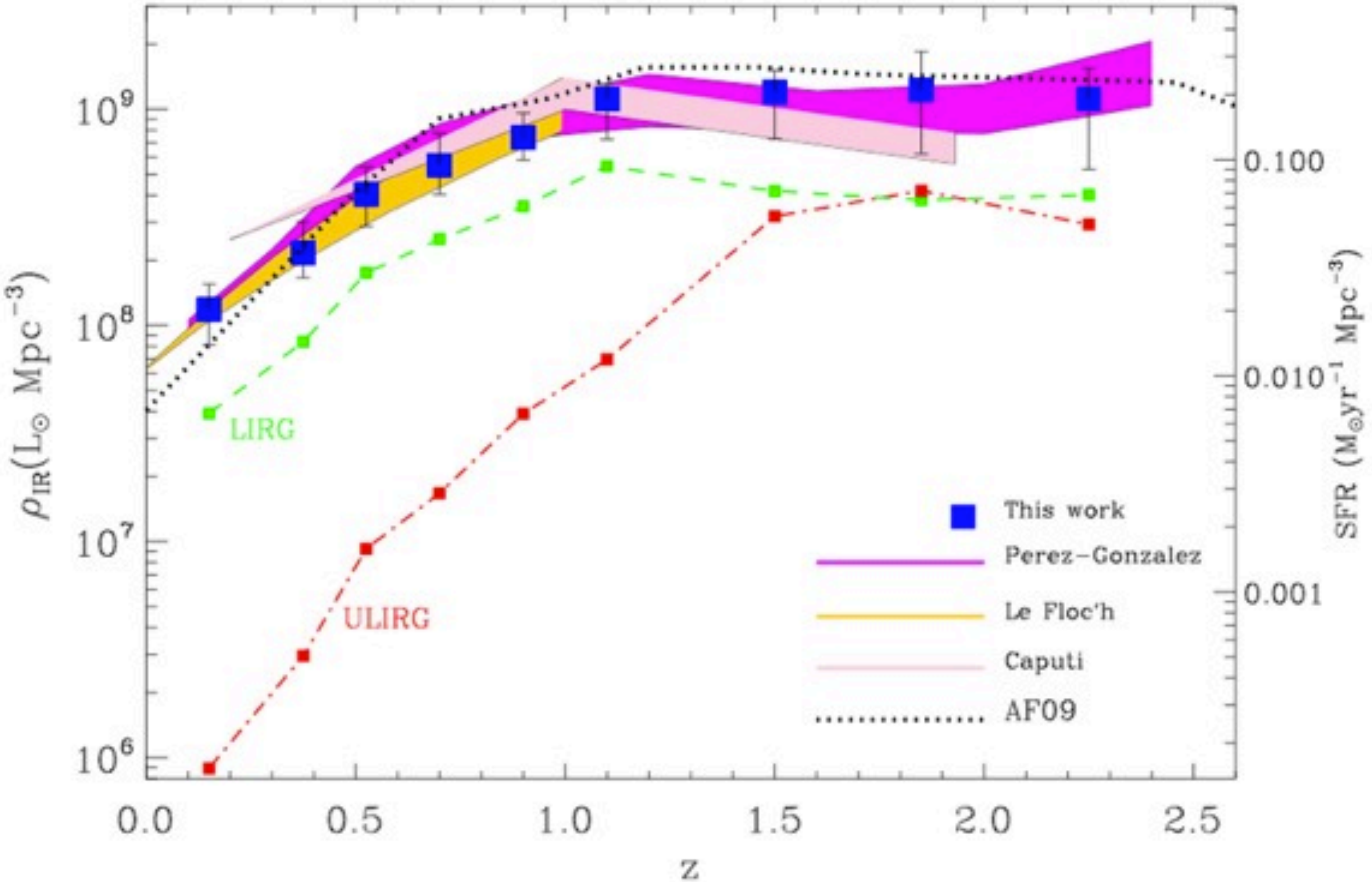


SWIRE-SDSS 24 micron low-z LF
Vaccari et al. 09

GOODS-VVDS 24 micron high-z LF
Rodighiero et al. 10

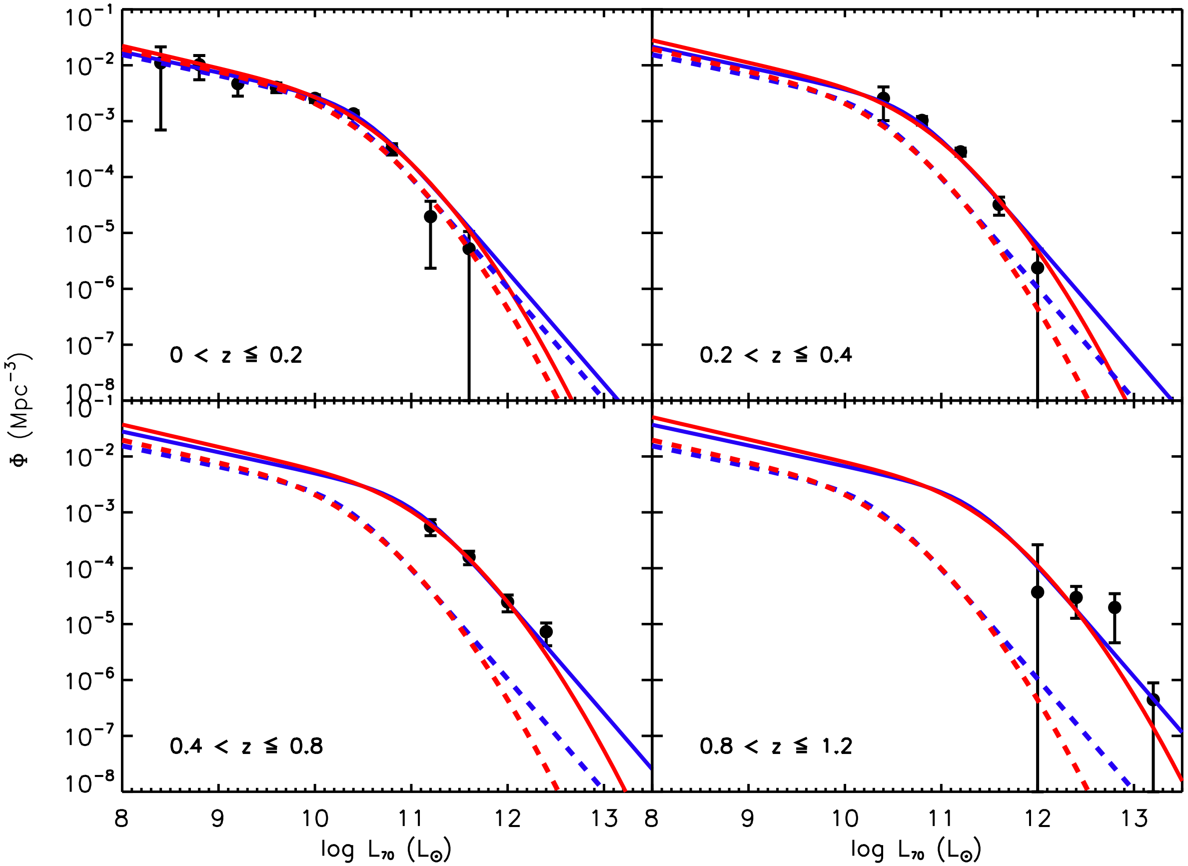
Multi-Wavelength Ancillary “Data Fusion” in Deep & Wide “Cosmic Windows”

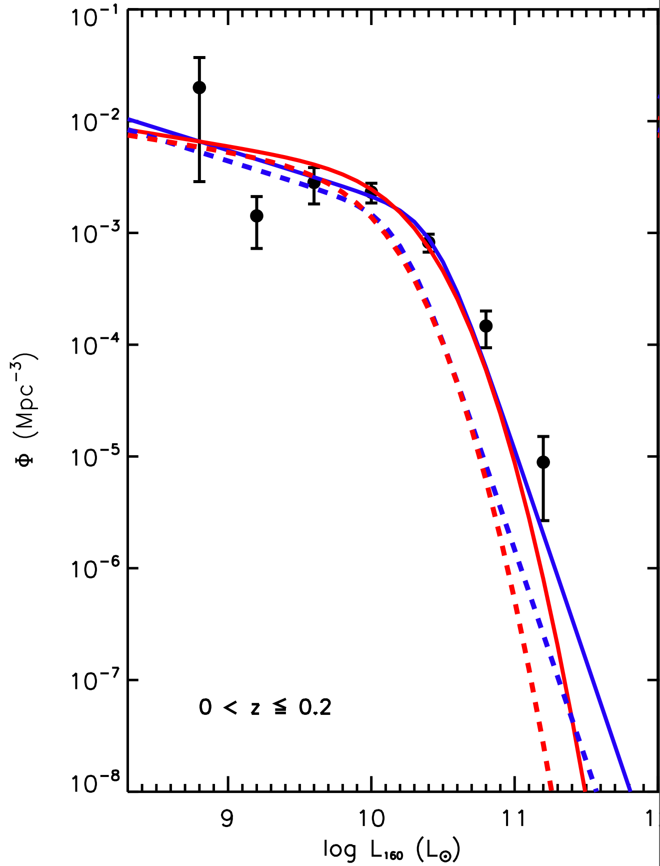
Taking stock of Spitzer MIPS-24 Surveys
The Cosmic Star Formation Rate Density



GOODS-VVDS SFR Density of 24 micron Sources- Rodighiero et al. 10
(Based on IR Bolometric 8-1000 micron Luminosity)

Taking stock of Spitzer MIPS-Ge Surveys
Wide FIR Luminosity Functions





SWIRE MIPS-Ge 70 and 160 micron low-z LF
Bayesian Parametric Maximum Likelihood Estimator
Patel et al. in prep

Taking stock of Spitzer MIPS-Ge Surveys
The Cosmic Star Formation Rate Density

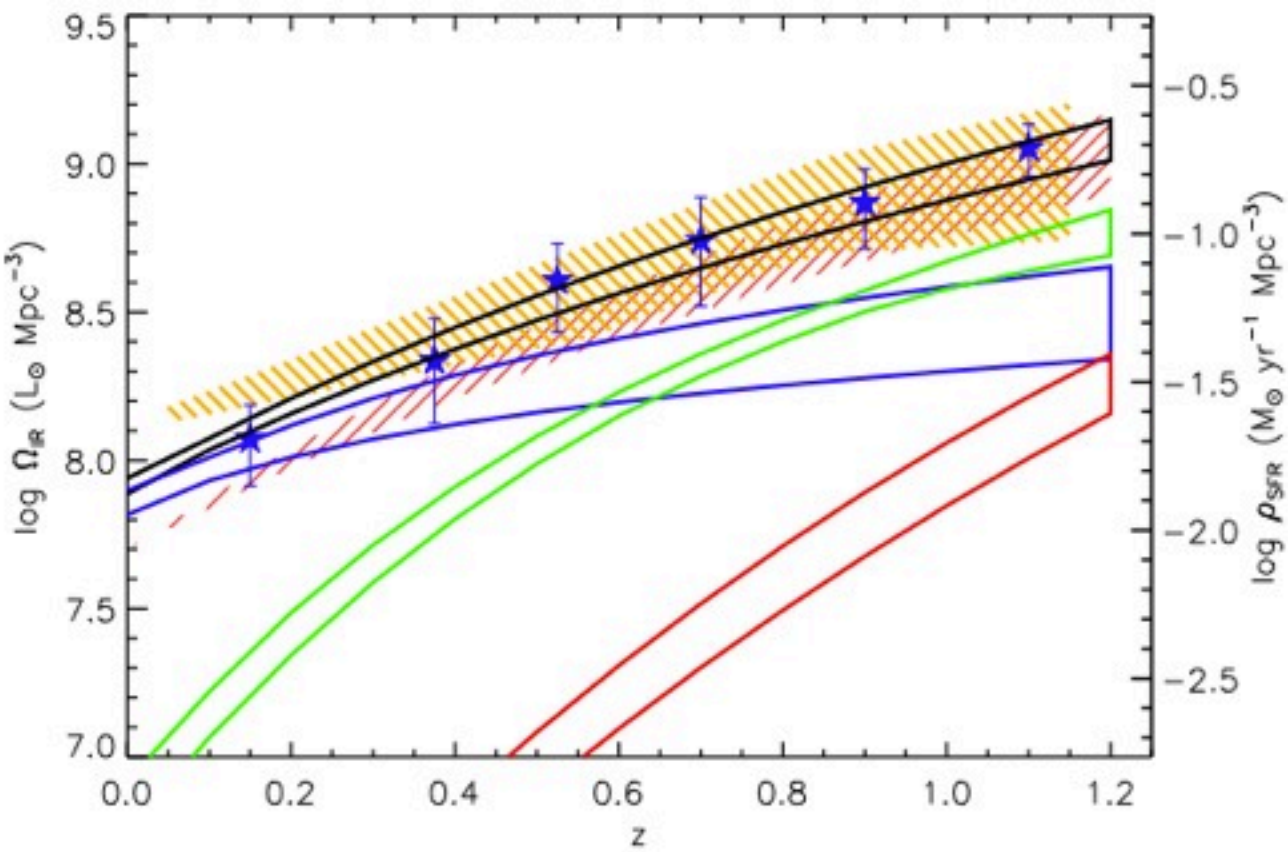


Figure 17. Evolution of the comoving infrared luminosity density up to $z = 1.2$ (solid black line region) and the contribution by normal galaxies ($L_{IR} < 10^{11}$ $L_\odot$; solid blue line region), LIRGs ($L_{IR} = 10^{11} - 10^{12}$ $L_\odot$; solid green line region) and ULIRGs ($L_{IR} = 10^{12} - 10^{13}$ $L_\odot$; solid red line region). The black solid region is obtained by using the 1 σ errors of α_L and α_D. The filled red line region is taken from Le Floc'h et al. (2005), filled orange line region is from Magnelli et al. (2009) and filled blue stars are taken from Rodighiero et al. (2010).

SWIRE SFR Density of 70 micron Sources - Patel et al. in prep
(Based on IR Bolometric 8-1000 micron Luminosity)

The HerMES Consortium

Bruno Altieri, Alex Amblard, Vinod Arumugam, Robbie Auld, Herve Aussel, Tom Babbedge, Alexandre Beelen, Matthieu Bethermin, Andrew Blain, Jamie Bock, Alessandro Boselli, Carrie Bridge, Drew Brisbin, Veronique Buat, Denis Burgarella, Nieves Castro-Rodriguez, Antonio Cava, Pierre Chanial, Ed Chapin, Scott Chapman, Michele Cirasuolo, Dave Clements, Alex Conley, Luca Conversi, Asantha Cooray, Darren Dowell, Naomi Dubois, Eli Dwek, Simon Dye, Steve Eales, David Elbaz, Duncan Farrah, Patrizia Ferrero, Matt Fox, Alberto Franceschini, Walter Gear, Elodie Giovannoli, Jason Glenn, Eduardo Gonzalez-Solares, Matt Griffin, Mark Halpern, Martin Harwit, Evanthia Hatziminaoglou, Sebastian Heinis, Peter Hurley, HoSeong Hwang, Edo Ibar, Olivier Ilbert, Kate Isaak, Rob Ivison, Guilaine Lagache, Louis Levenson, Nanyao Lu, Suzanne Madden, Bruno Maffei, Georgios Magdis, Gabriele Mainetti, Lucia Marchetti, Gaelen Marsden, Jason Marshall, Angela Mortier, Hien Nguyen, Brian O'Halloran, Seb Oliver, Alain Omont, Francois Orieux, Mathew Page, Pasquale Panuzzo, Andreas Papageorgiou, Harsit Patel, Chris Pearson, Ismael Perez-Fournon, Michael Pohlen, Jason Rawlings, Gwen Raymond, Dimitra Rigopoulou, Laurie Riguccini, Davide Rizzo, Giulia Rodighiero, Isaac Roseboom, Michael Rowan-Robinson, Miguel Sanchez-Portal, Bernhard Schulz, Douglas Scott, Nick Seymour, David Shupe, Anthony Smith, Jason Stevens,, Myrto Symeonidis, Markos Trichas, Katherine Tugwell, Mattia Vaccari, Elisabetta Valiante, Ivan Valtchanov, Joaquin Vieira, Laurent Vigroux, Lingyu Wang, Rupert Ward, Don Wiebe, Gillian Wright, Kevin Xu, Mike Zemcov, + *Consultants and Working Members*

Faculty and Researchers, Postdocs, Students

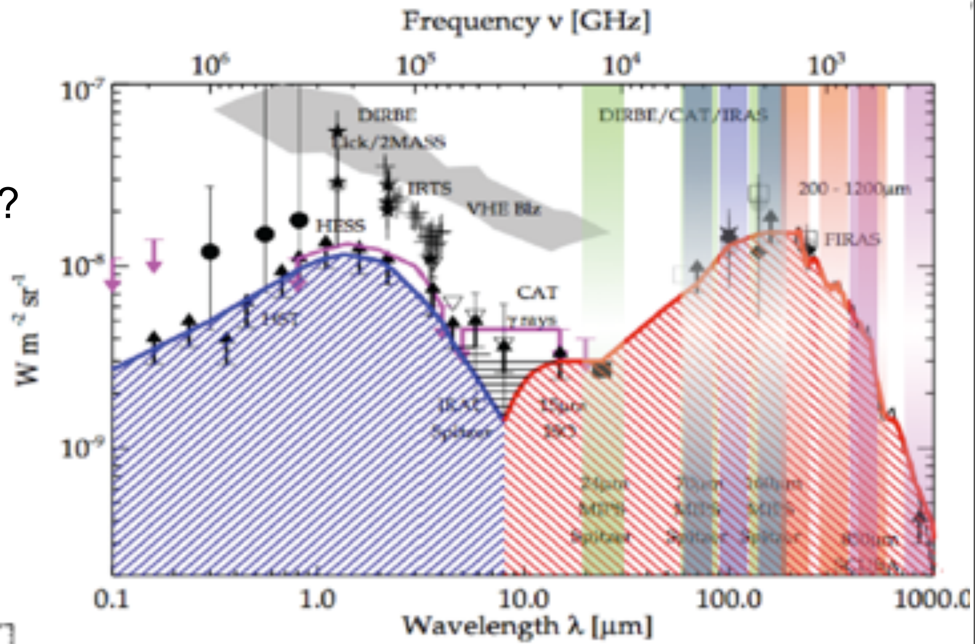
Project : http:///hermes.sussex.ac.uk

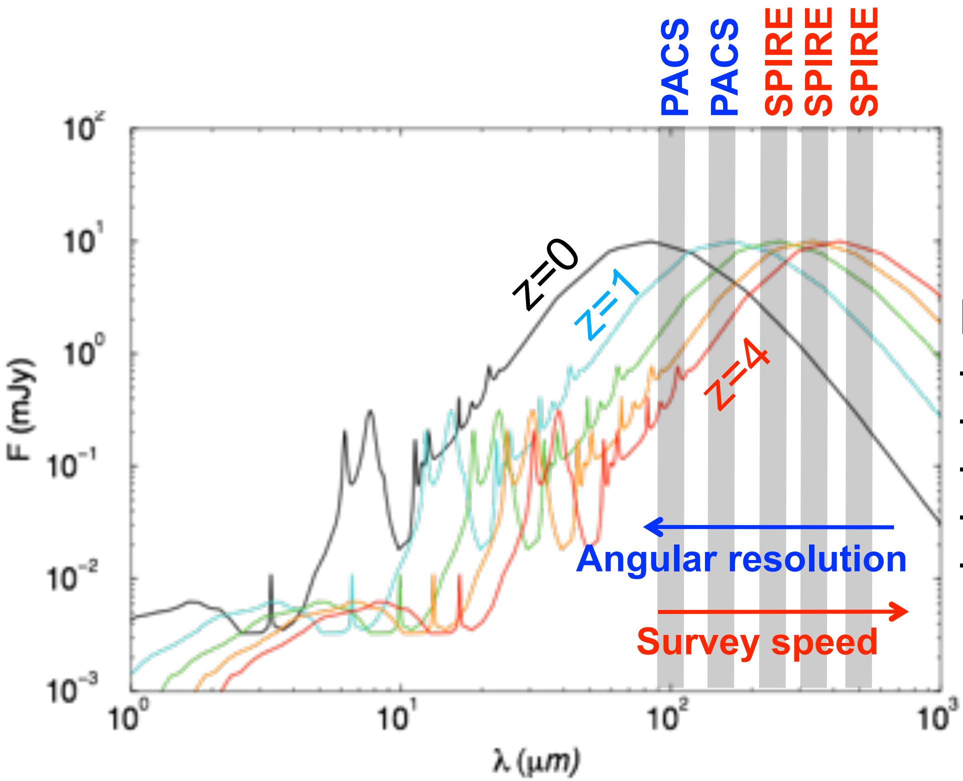
Data : http://hedam.oamp.fr/HerMES

HerMES Science Motivation

What is the history of Far-IR galaxies?

- How do they assemble and evolve over time?
- Where have luminous FIR systems gone today?
- How do FIR galaxies relate to dark matter?
- What is the role of dust in star formation?
- What is the connection between dusty star formation and AGNs?

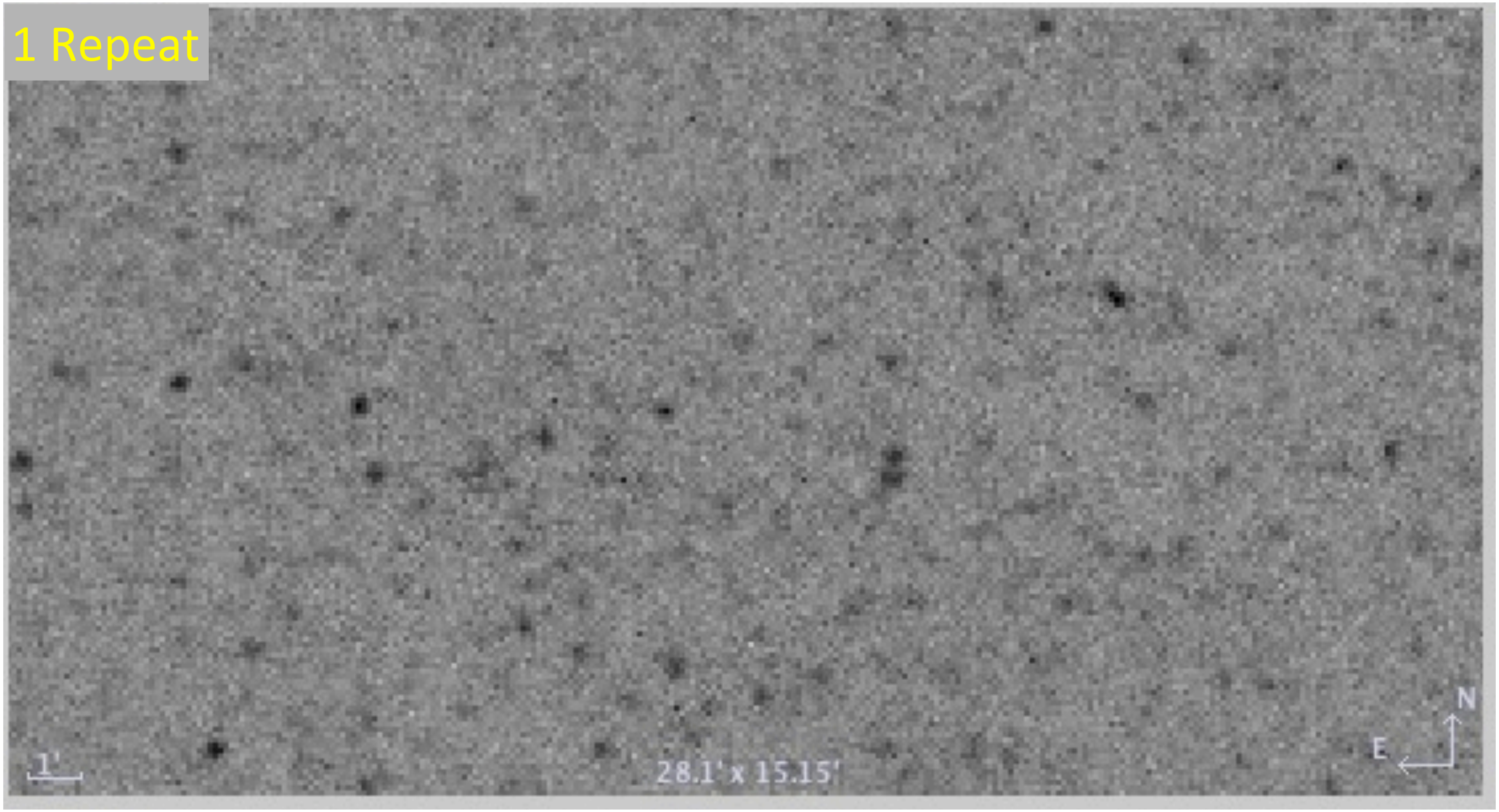




Herschel Extragalactic Imaging Surveys

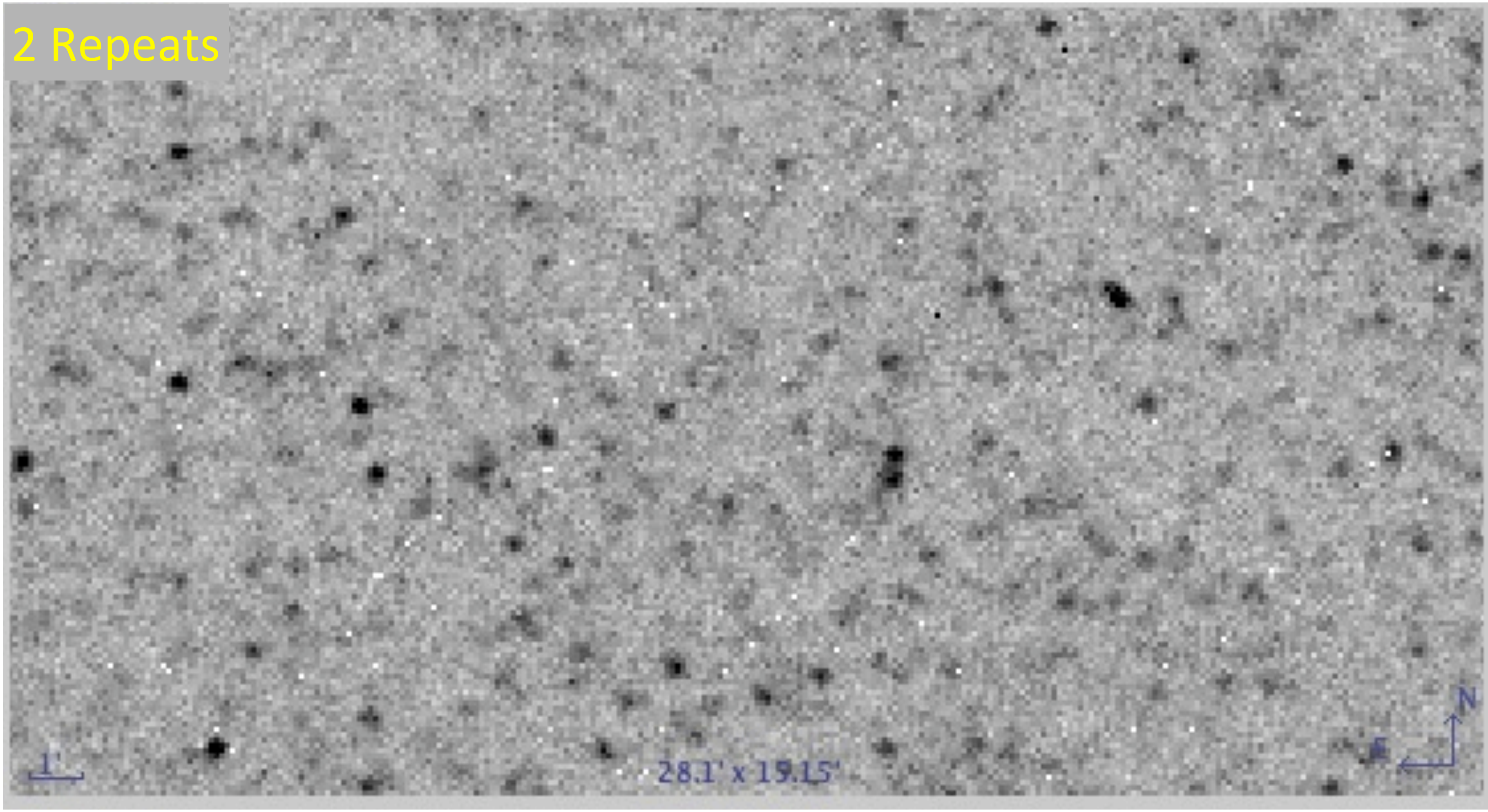
- High-sensitivity (albeit with moderate resolution)
- Use PACS & SPIRE at 100-500 um
- Observe the SED peak of IR galaxies at 1<z<4
- Derive IR 'Bolometric' (8-1000 um) Luminosities
- Detect Large and Uniform Samples of (U)LIRGs

Mapping to the Confusion Limit



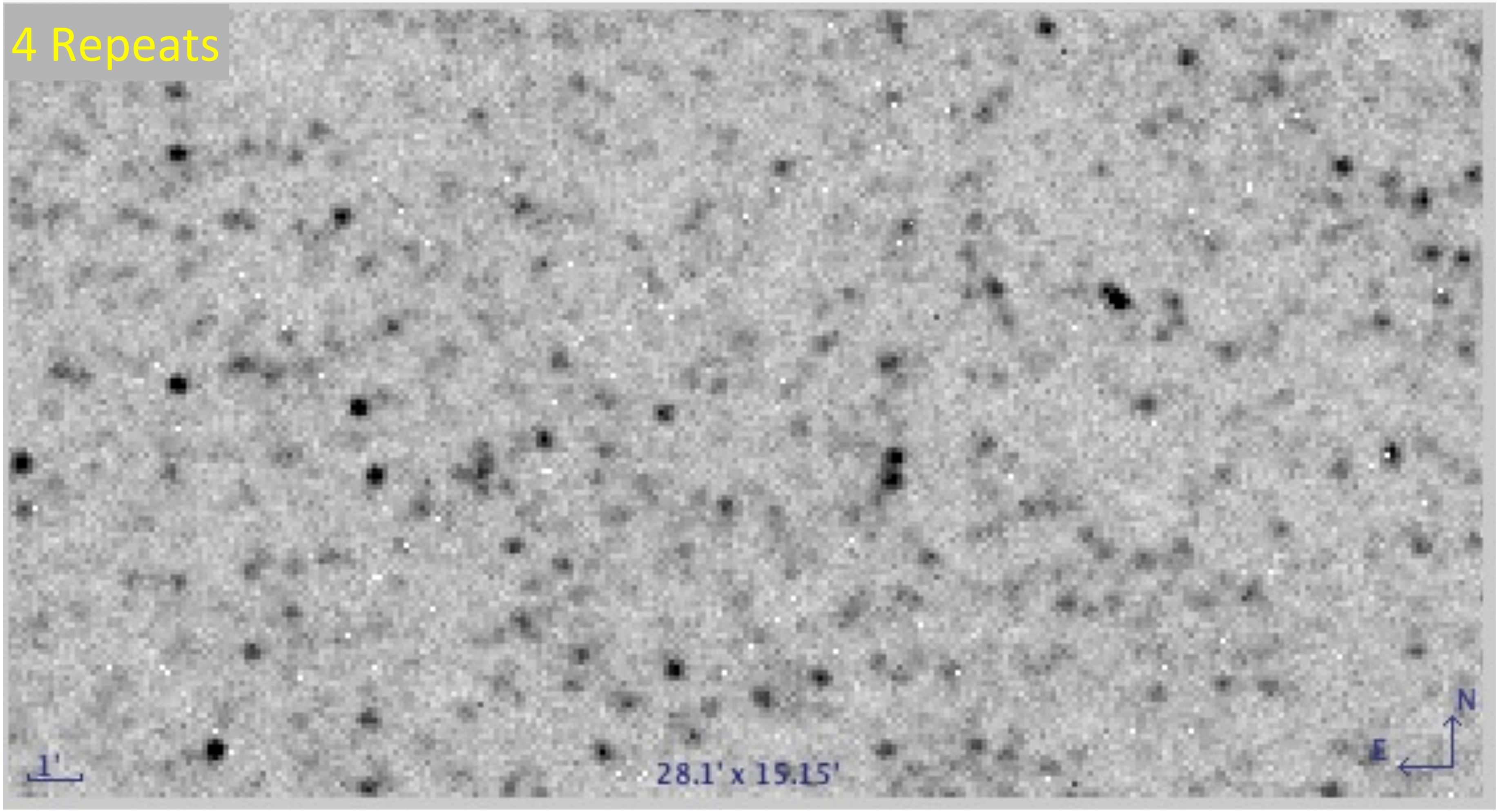
0.7 h for 1 sq. deg

Mapping to the Confusion Limit



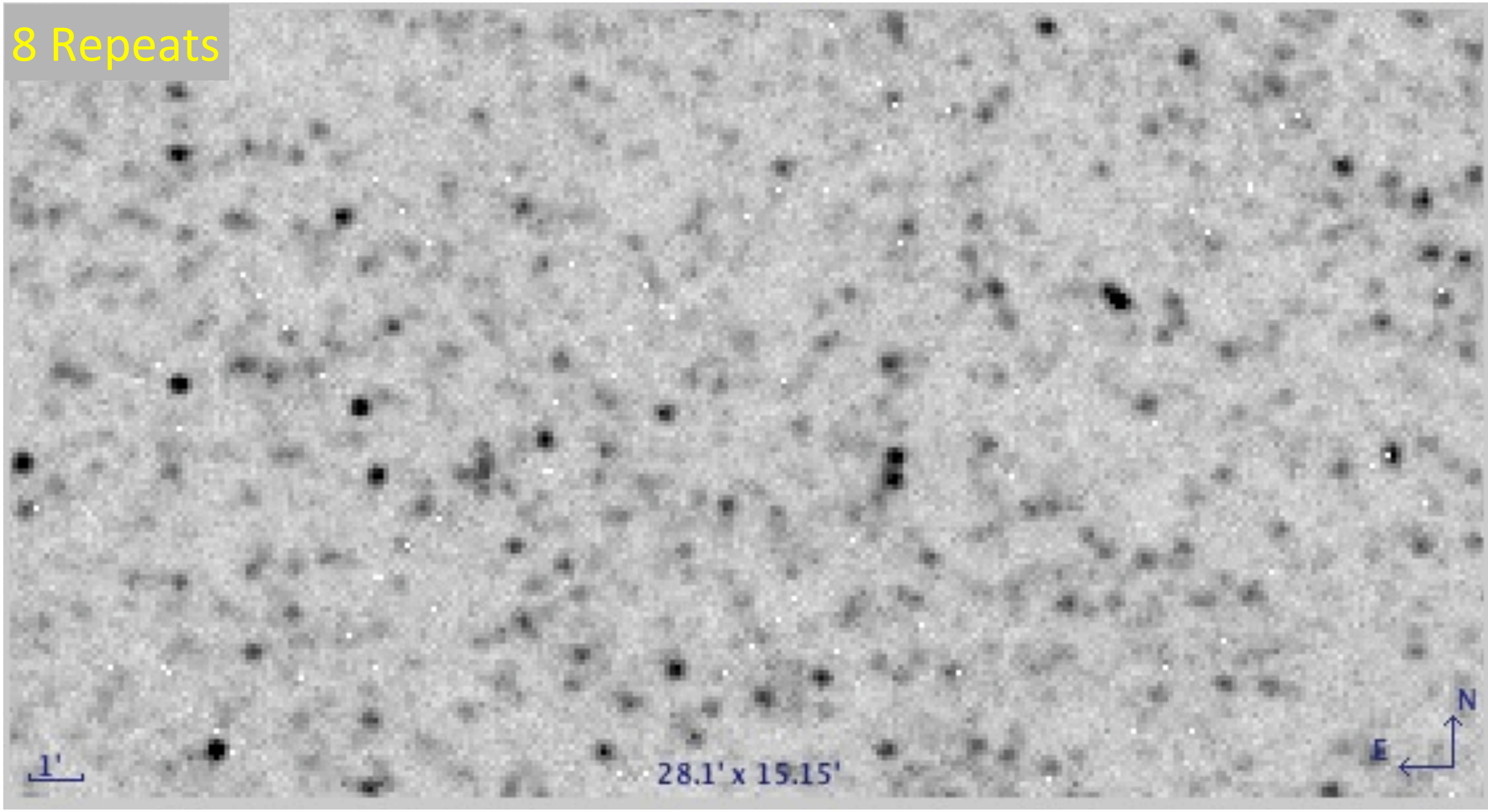
1.5 h for 1 sq. deg

Mapping to the Confusion Limit



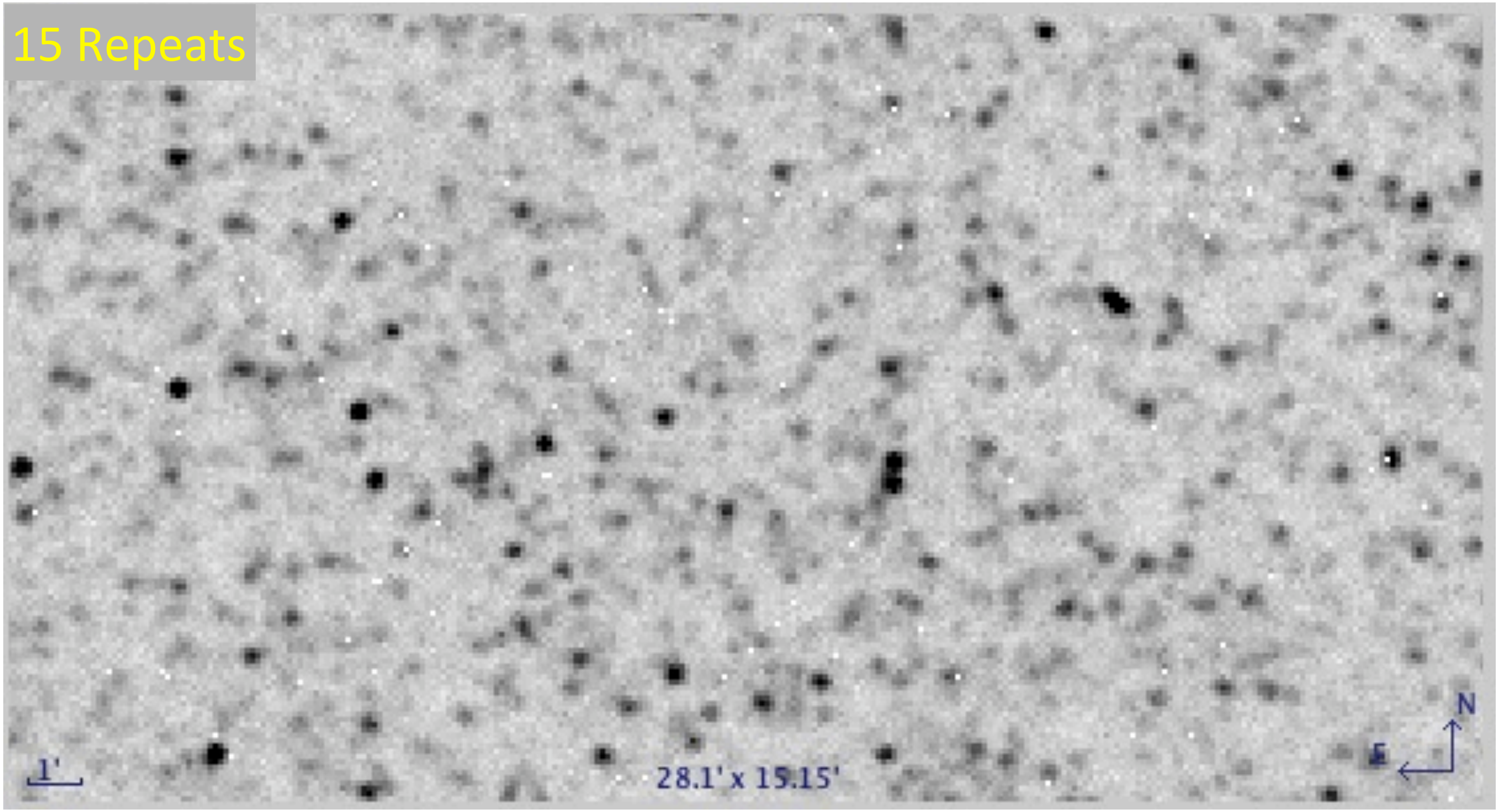
3 h for 1 sq. deg

Mapping to the Confusion Limit



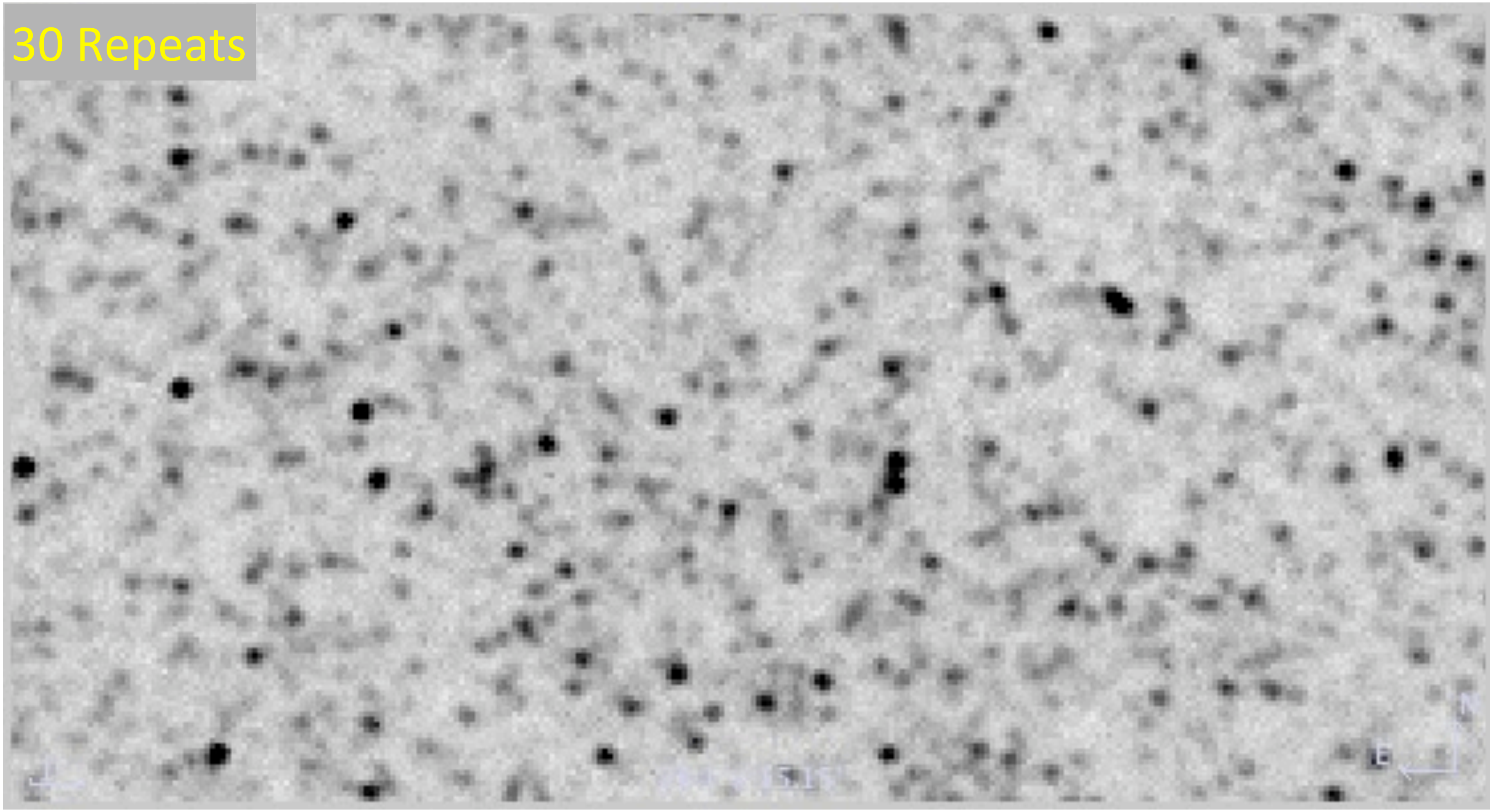
6 h for 1 sq. deg

Mapping to the Confusion Limit



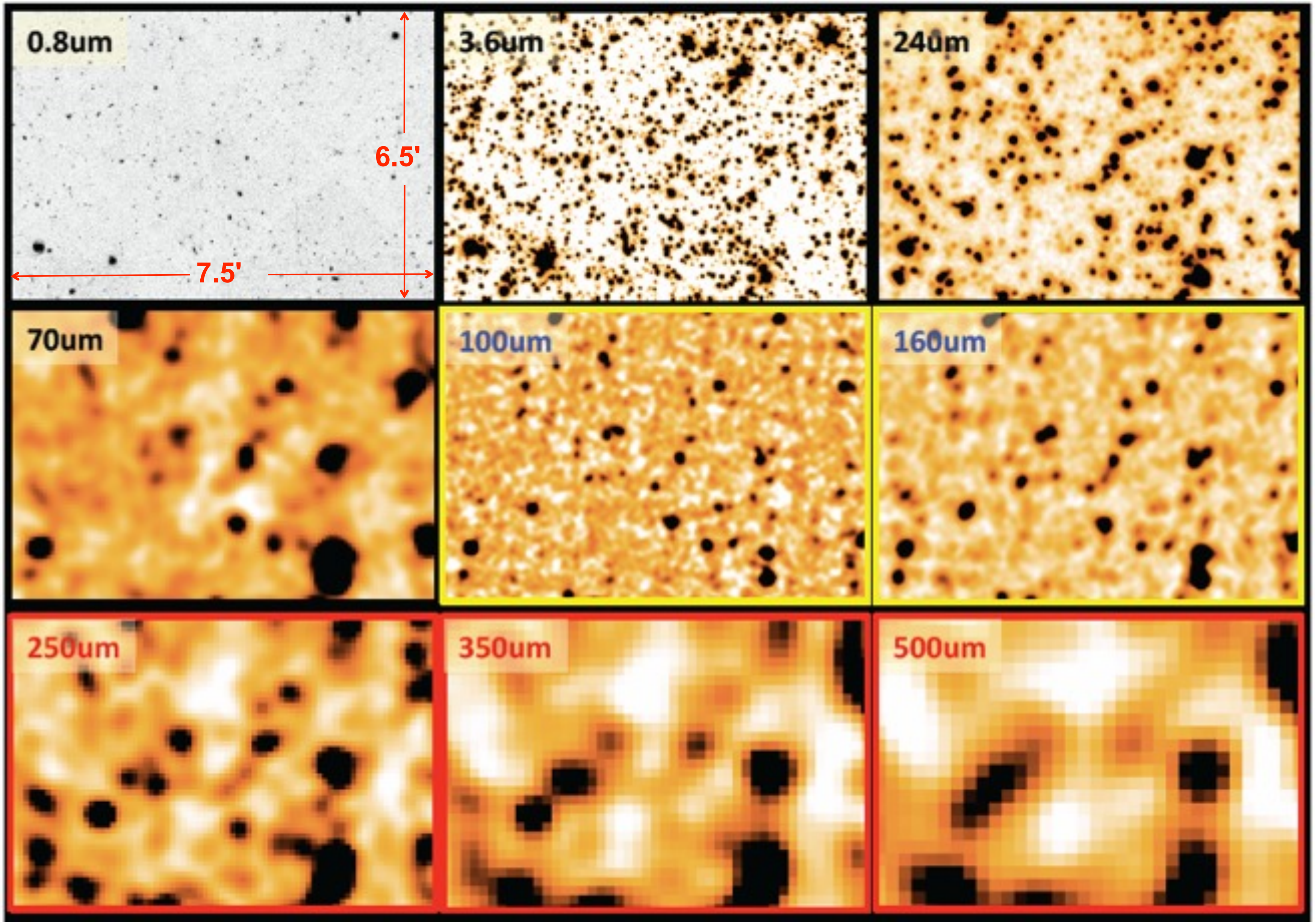
11 h for 1 sq. deg

Mapping to the Confusion Limit



22 h for 1 sq. deg

The Confusion Challenge



D. Elbaz

Three Ways to Deal with Confusion

“Blind” Source Extraction

- Need to be careful about bias and source blending
- Blind follow-up in large beam is laborious (~SCUBA)
- However these are the most interesting source populations

“Prior” Source Extraction

- Estimate Herschel flux of ‘known’ sources
- Reliable to within confusion noise
- Follows bias inherent in ‘input’ catalog

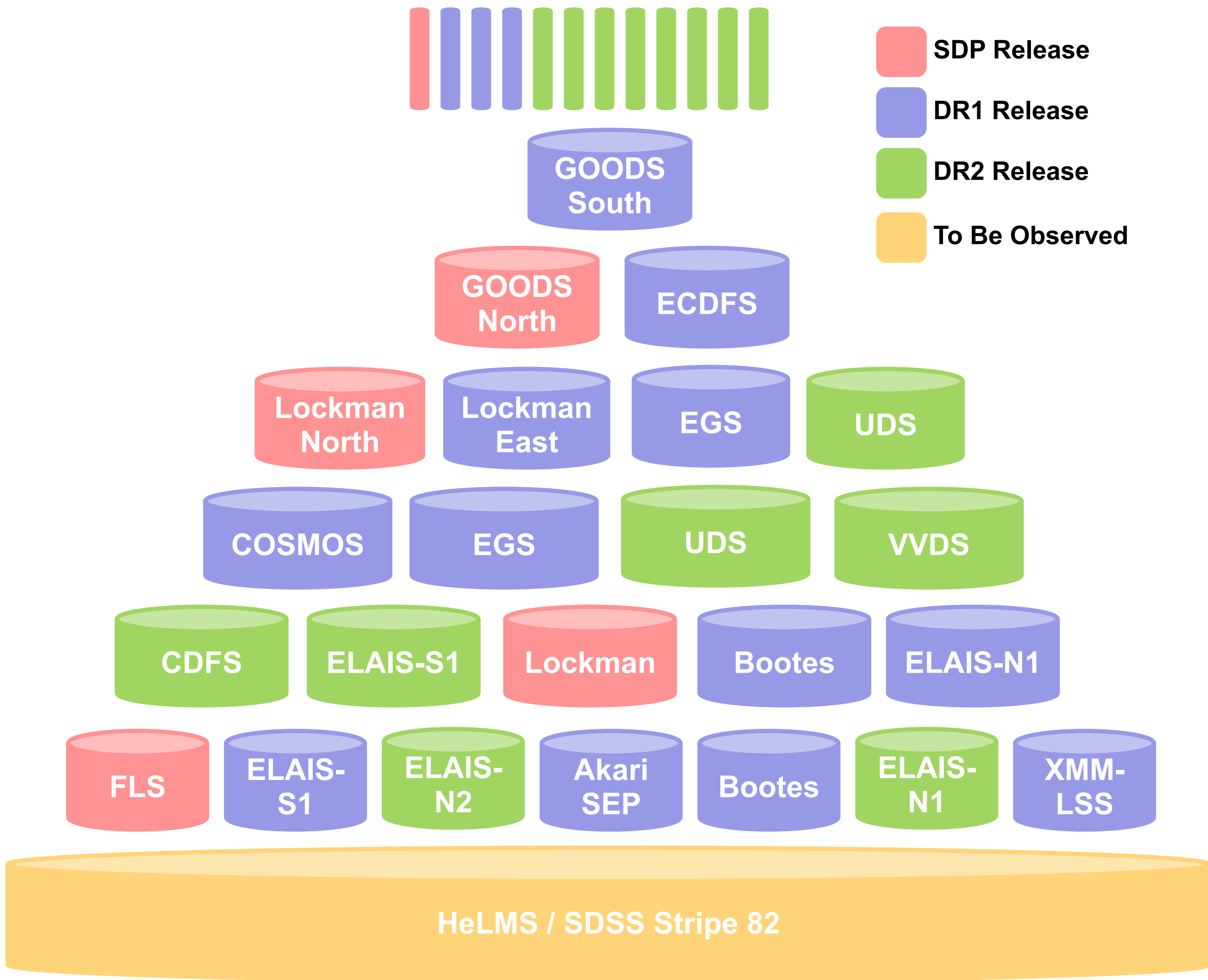
Map-Based Analysis

- Much more information in maps than in reliable sources
- Tends to be ensemble information : P(D), fluctuations, etc
- Maps have high statistical fidelity!

HerMES : Wedding Cake Survey

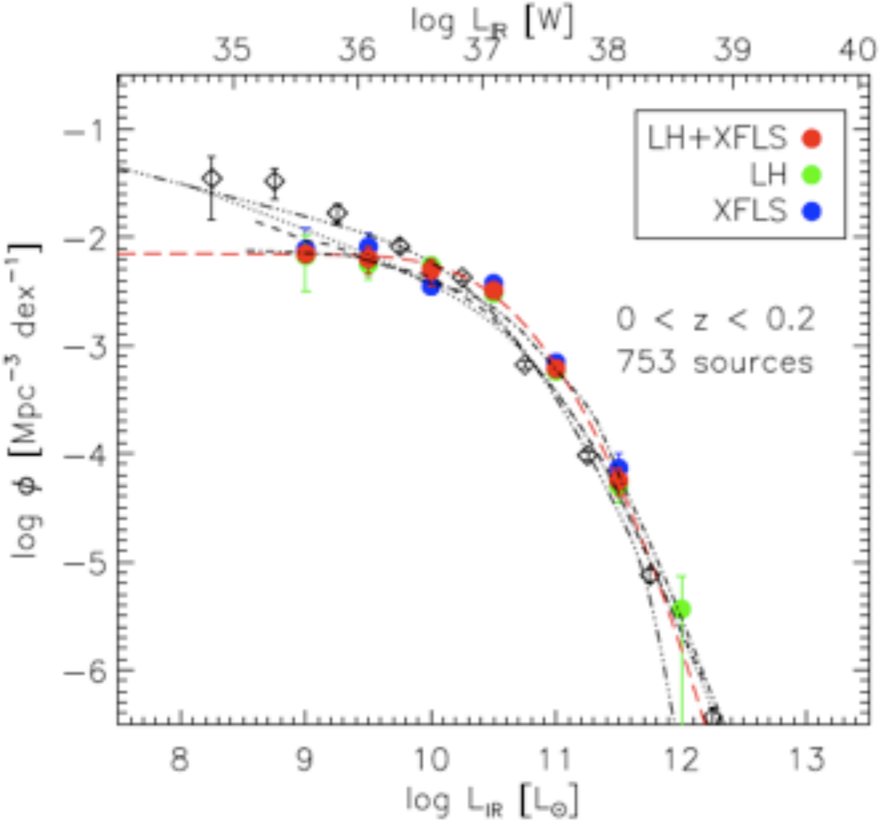
Clusters

L1	**0.11 □°**
L2	**0.36 □°**
L3	**1.25 □°**
L4	**4 □°**
L5	**30 □°**
L6	**40 □°**
L7	**270 □°**



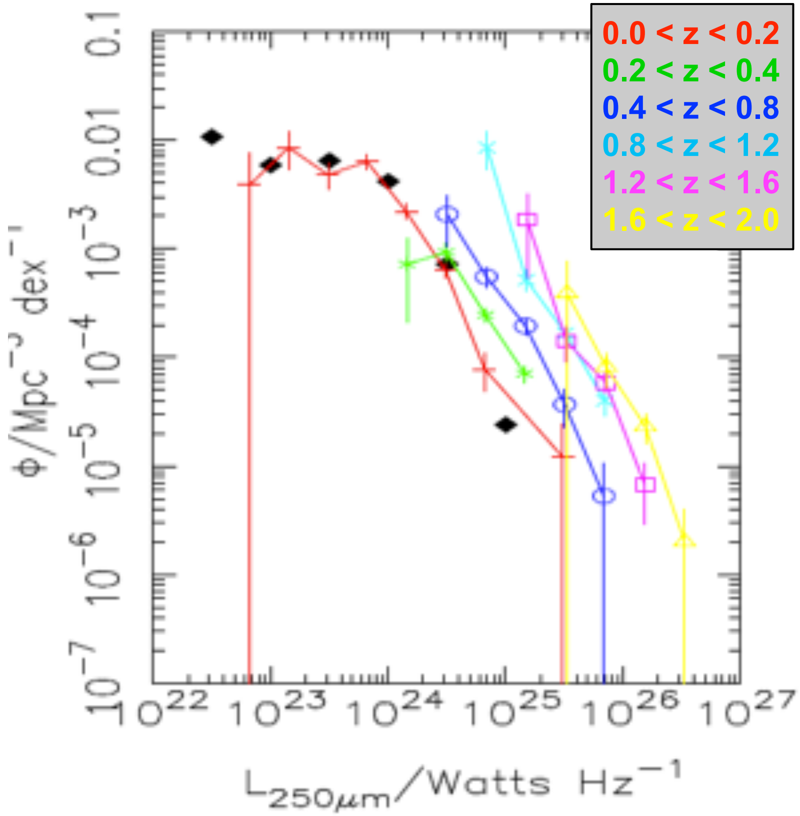
SDP : Strong Luminosity Evolution

HerMES IR Bolometric Local Luminosity Function



Vaccari et al. 2010

HerMES Rest-Frame 250 μm LF



Eales et al. 2010

- Local sub-mm galaxy LF slightly above models
- Luminosity function evolves out to z ~ 2
- Is it flattening out at z > 1?
- Next : better statistics, SED models, LF estimators & selection functions

The Evolution of the SMM Luminosity Function (Vaccari et al. in prep)

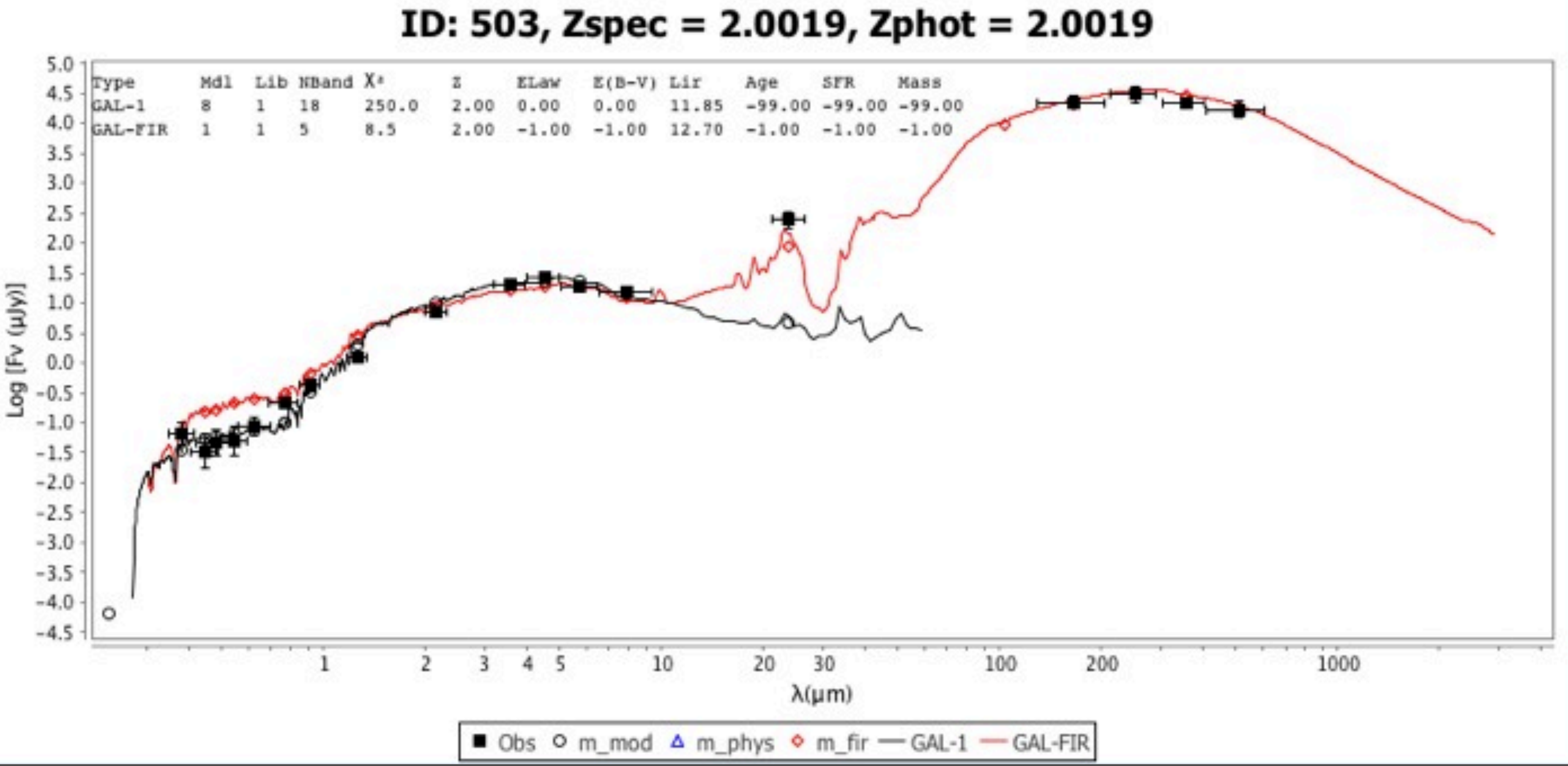
- **Extending previous work to most deep and wide fields**
- **Combining PACS/PEP and SPIRE/HerMES Data**
- **Making use of extensive ancillary photometry/spectroscopy**

Field	Area	S_{250}^{lim}	PACS	SPIRE	Phot-Z
GOODS-S	0.05	10	PEP	HerMES	Santini+ 09
GOODS-N	0.05	10	PEP	HerMES	Berta+ 11
ECDFS	0.25	12	PEP	HerMES	Cardamone+ 10
LHN	0.4	12	HerMES	HerMES	Strazzullo+ 10
LHE	0.4	12	PEP	HerMES	Fotopoulou+ 12
EGS	0.4	12	PEP	HerMES	Barro+ 11
UDS	0.6	10	HerMES	HerMES	Cirasuolo+ 10
COSMOS	1.7	10	PEP	HerMES	Ilbert+ 09

- **More Careful Data Reduction : Berta+ 10 / Roseboom+ 10**
- **Improved Selection Function : Opt-Z, MIPS-24, SPIRE-250**
- **Comparing Different Luminosity Function Estimators**

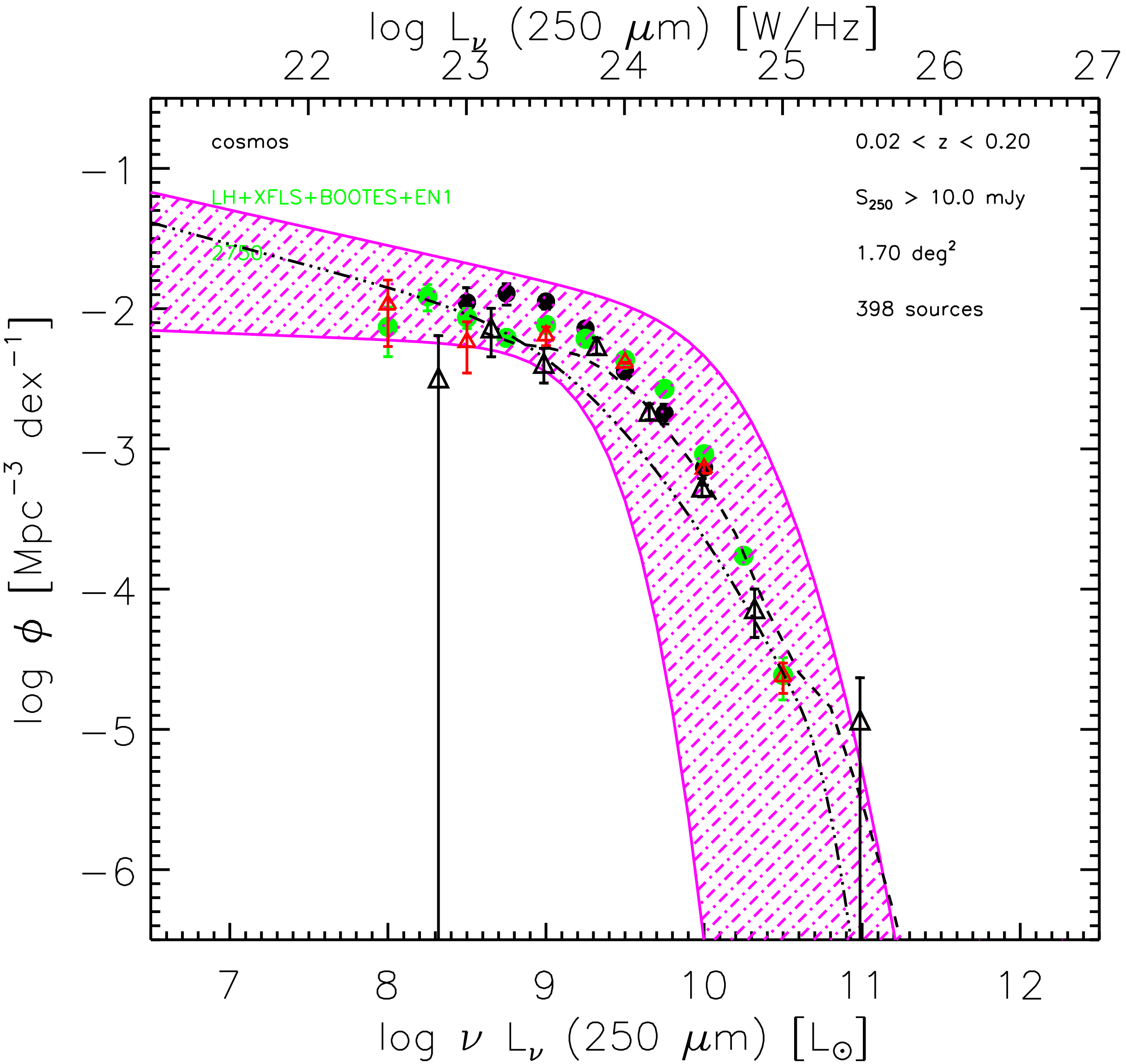
SPIRE-Selected Samples & Ancillary Data
Monochromatic & Bolometric Luminosity Functions

- **SPIRE-250-micron samples based on MIPS-24-micron priors**
- **Photometric/Spectroscopic Redshifts for >95% of sources**
- **LePhare SED Fitting using extended Polletta library**
- **“1/Vmax” assessed based on SPIRE/MIPS/Optical Cuts**



Preliminary Results

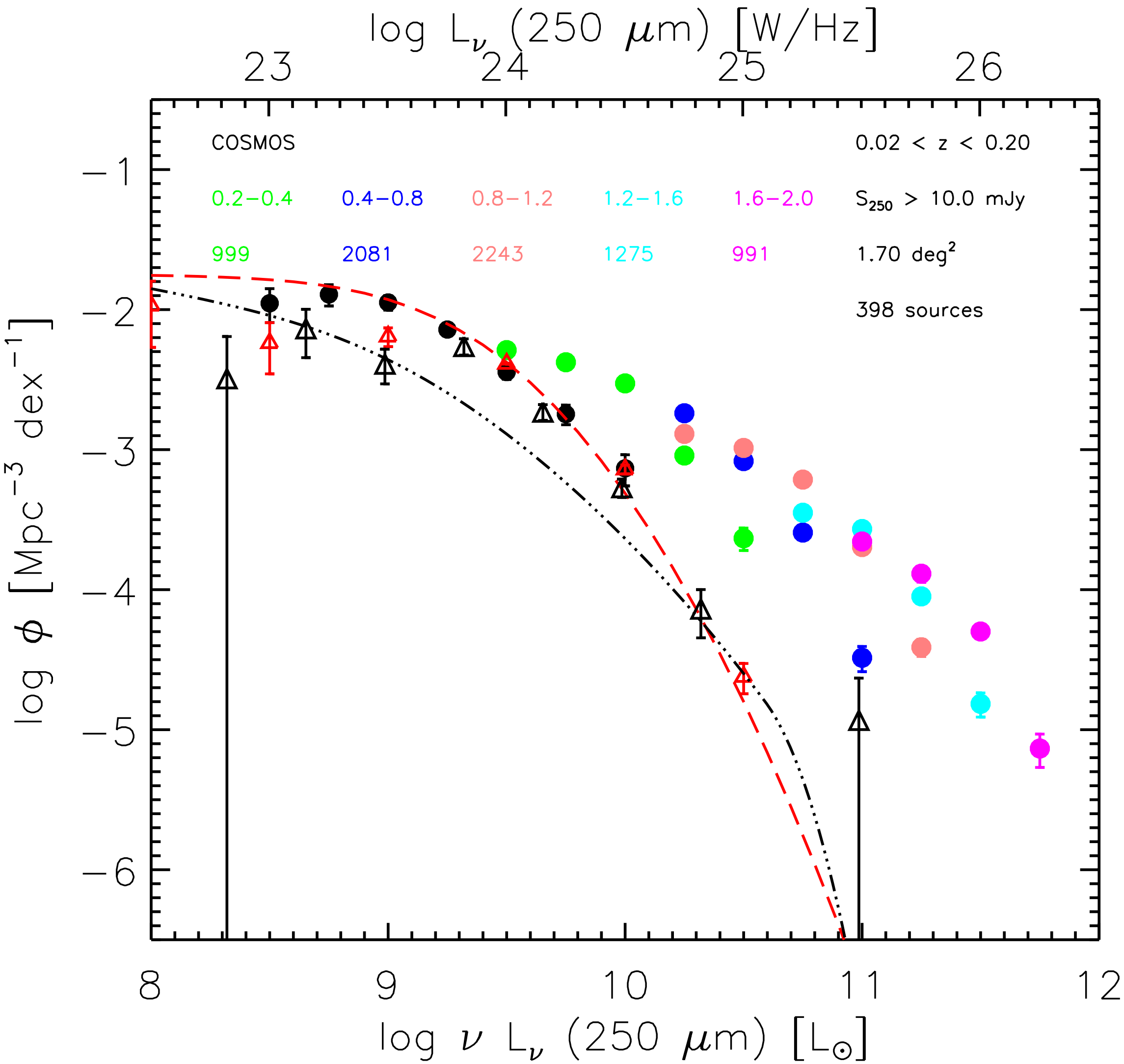
- **250 micron LLF in COSMOS and HerMES-SDSS**



Circles : COSMOS
Circles : HerMES-SDSS
Triangles : Eales+ 10
Triangles : Vaccari+ 10
MCMC : COSMOS LLF

Preliminary Results

- **250 micron LF(z) in COSMOS (0<z<2)**



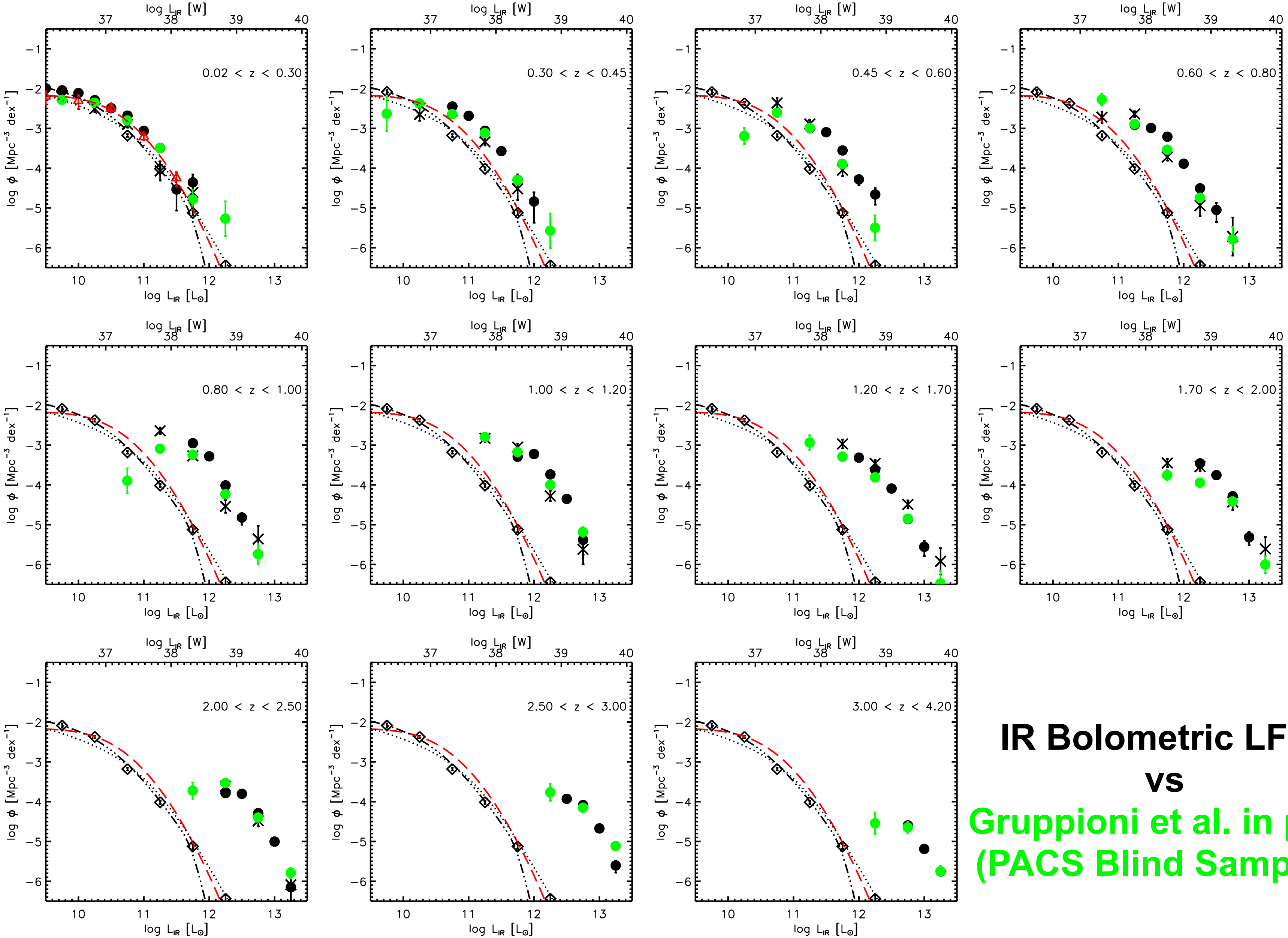
Circles : COSMOS LLF
Circles : HerMES-SDSS
Triangles : Eales+ 10 LLF
Triangles : Vaccari+ 10 LLF
MCMC : COSMOS LLF

~ consistent with SDP

higher-z estimates more dependent on adopted SED types

(See e.g. Lapi+ 2011)

Preliminary Results



IR Bolometric LF(z)

vs

Gruppioni et al. in prep
(PACS Blind Samples)

What's Next?

- Optimize SED Libraries
- Double Check Selection Function
- Compare LF Estimators
- Compute 100/160/250/BOL Estimates
- Estimate LF(z) Evolution

The Evolution of the Infrared Luminosity Function

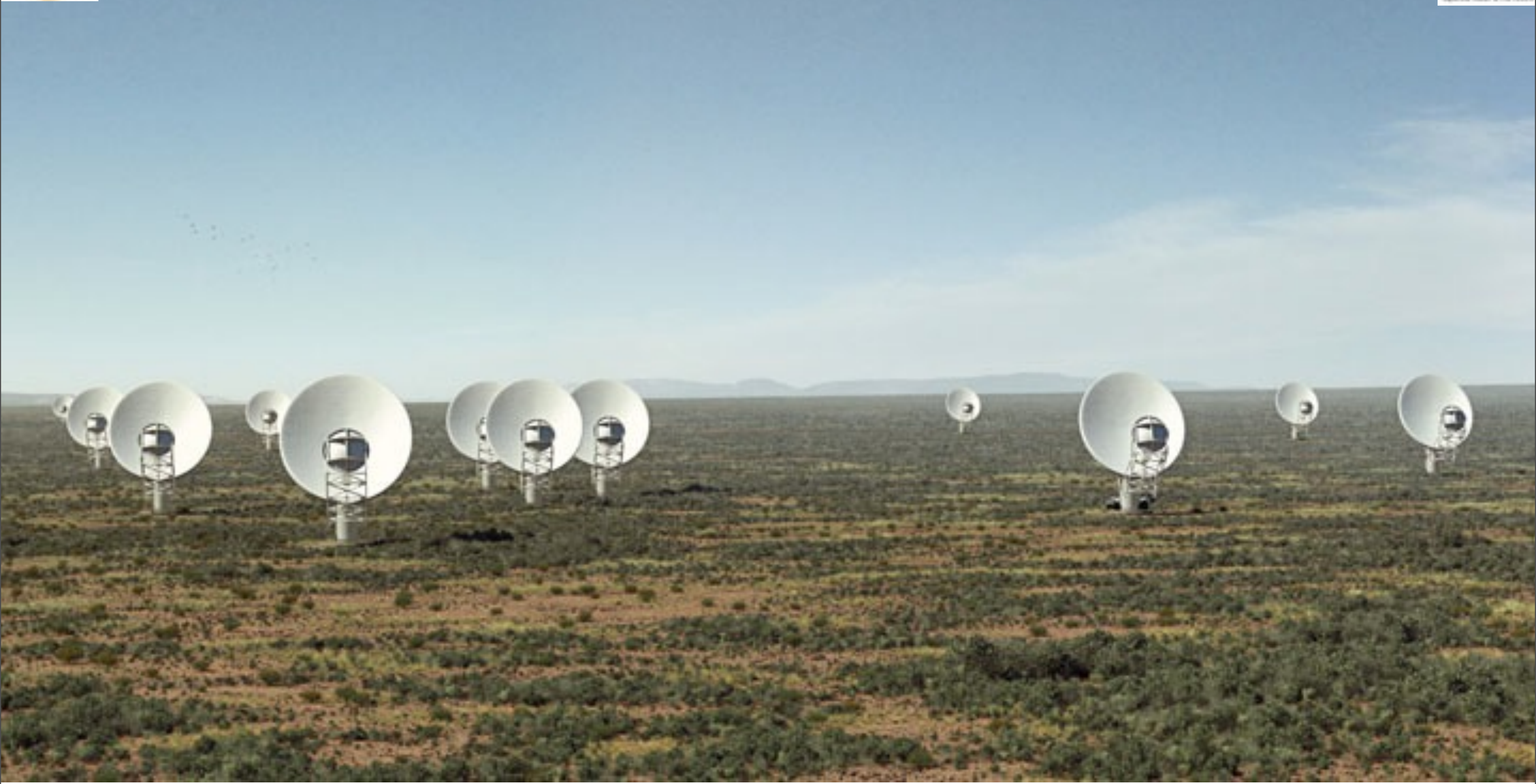
Spitzer Post-Cold-Mission Science Work

- Orders of magnitude increase in sensitivity
- Limited depth (and z-range) at λ>24 micron

Herschel (PEP-)HerMES DR1 Science Work

- Fully FIR/SMM spectral range up to z~4
- Observations now almost complete
- DR1 release and publications in preparation
- PACS-SPIRE joint estimates of IR LF(0<z<4)

What's (Also) Next? http://www.ska.ac.za/



- MeerKAT will provide radio resolution & sensitivity well-matched with IR
- MIGHTEE survey will sample the radio luminosity function deep & wide
- FIR/radio correlation probed up to high-z as a function of 'any' parameter
- WSRT-APERTIF-WODAN & ASKAP-EMU will probe larger & shallower areas

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