First Results from Extragalactic Surveys with Herschel and Cosmological Studies with Herschel-SPIRE Legacy Survey (HSLS)

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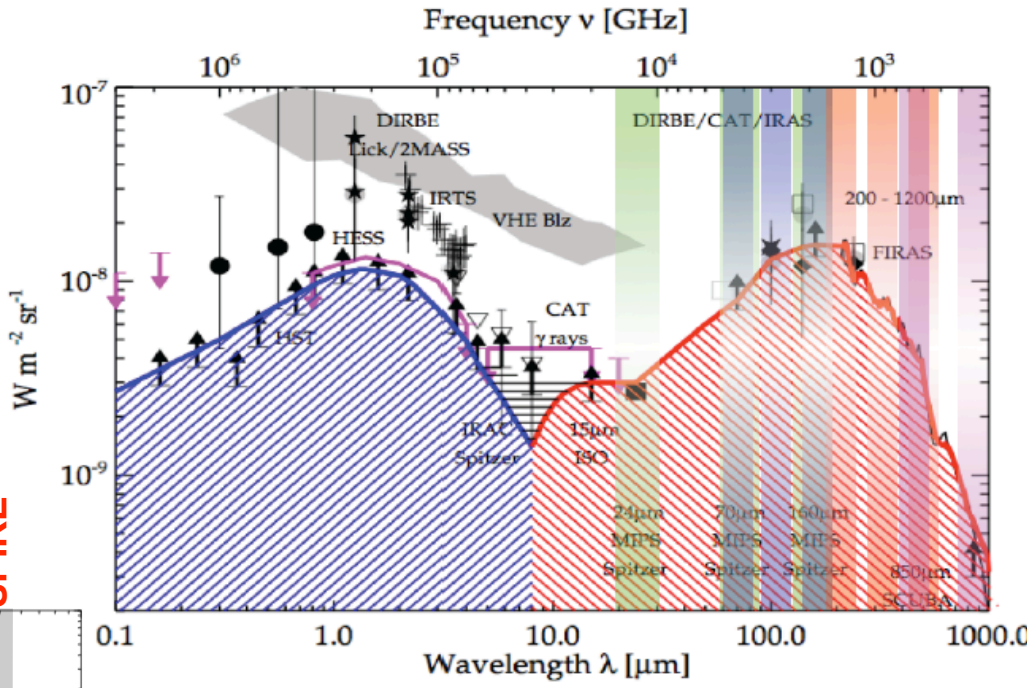
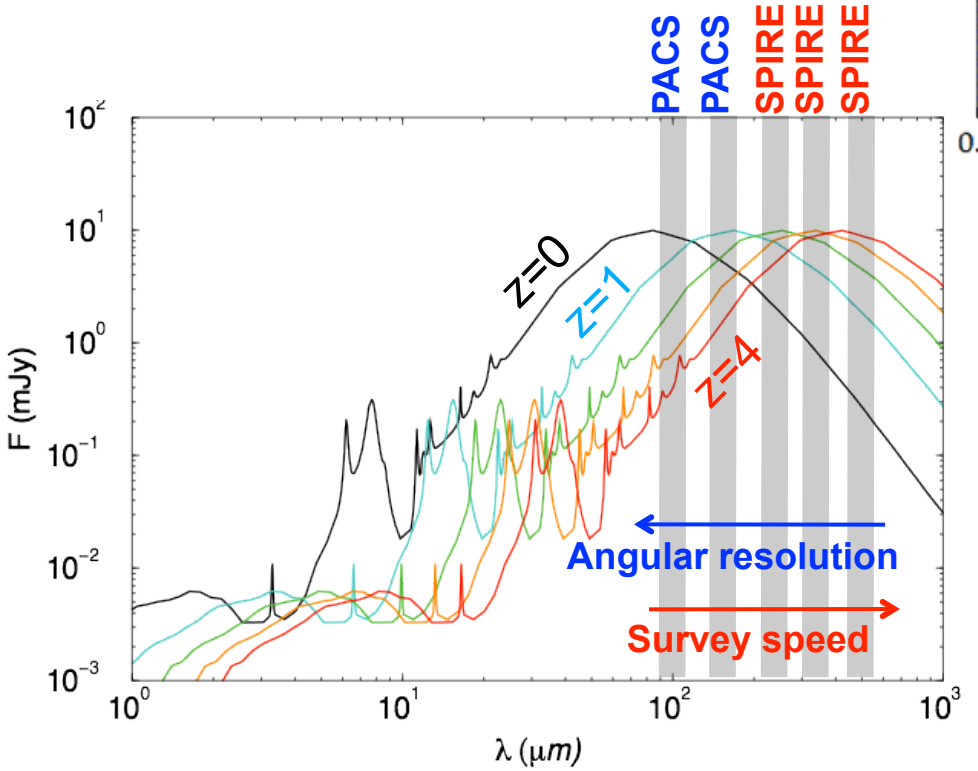
Extragalactic Surveys with Herschel

Far-Infrared Galaxy Formation
- History and evolution
- Populations
- Energetics
- Large scale structure





Herschel Extragalactic Surveys
- Observe at SED peak
- Bolometric far-IR luminosities
- Large and uniform samples

Herschel High-z Key Projects

HerMES: *Herschel* Multi-tiered Extragalactic Survey

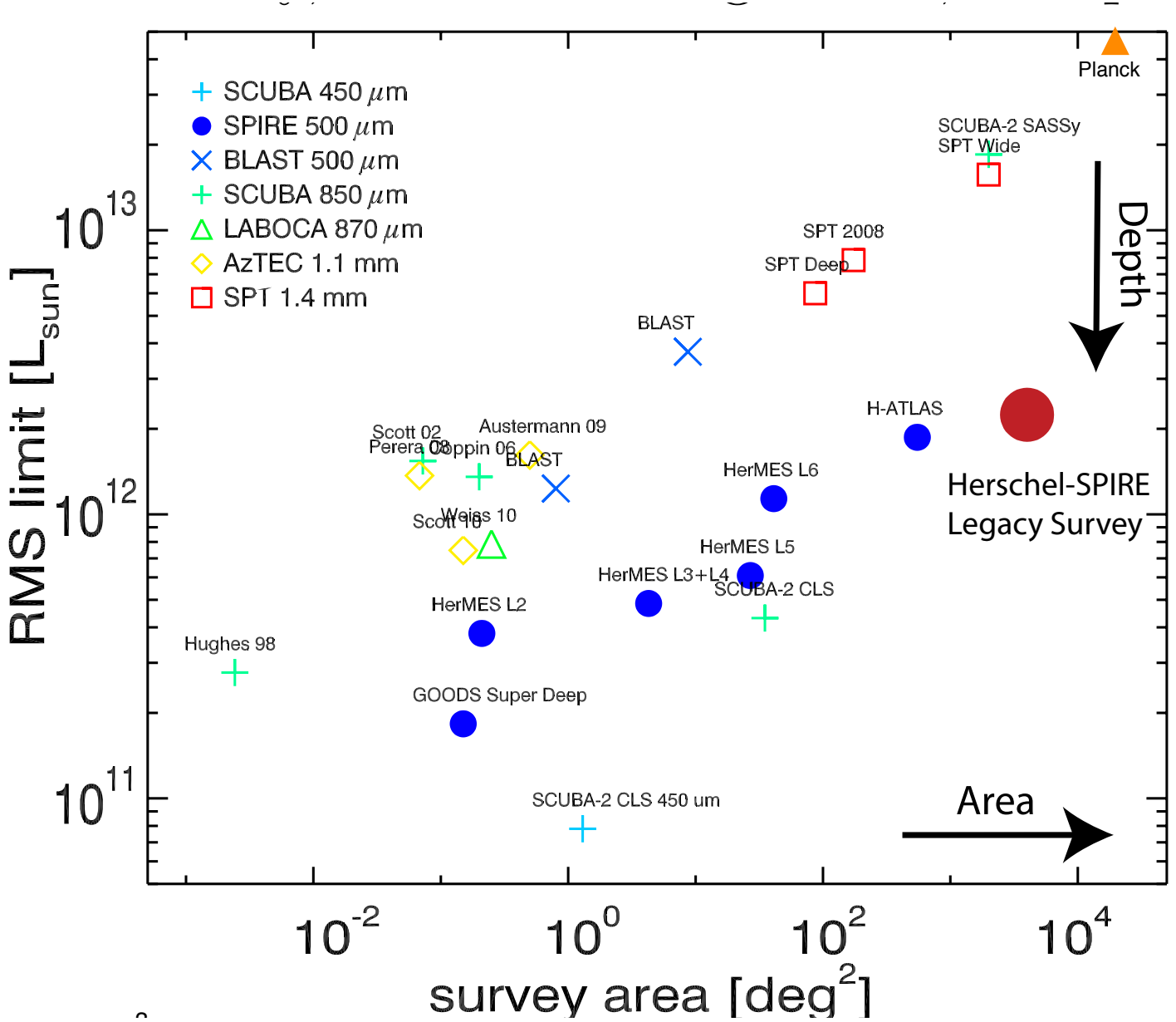
- PACS + SPIRE
- 70 sq deg from 20′×20′ to 3.6°×3.6° (850 hours) + 12 clusters
- Bolometric luminosities of galaxies, cosmic SFH
- Wedding cake to probe range of luminosities and environments

H-ATLAS: *Herschel*-Astrophysical Terahertz Large Area Survey

- PACS + SPIRE
- 550 sq deg (600 hours)
- Low-z sciences, lensed sources, AGN
- Expect ~500,000 detections to z~3, majority at 250 & 350 um

HSLS: *Herschel*-SPIRE Legacy Survey ***(Just proposed for Open Time)***

- 4000 sq deg (780 hours), includes 1000 sq. deg in Stripe-82
- 2.5 to 3.0 million source detections; 10,000 at z >4 and 2000 at z > 5; 1200 strongly lensed bright sources; 200 “proto-clusters” at z~2
- Cosmology driven: e.g., joint Planck+HSLS studies, ISW, SZ, CMB lens


SCUBA 450 μm
SPIRE 500 μm
BLAST 500 μm
SCUBA 850 μm
LABOCA 870 μm
AzTEC 1.1 mm
SPT 1.4 mm
Planck
SCUBA-2 SASSy
SPT Wide
SPT 2008
SPT Deep
BLAST
H-ATLAS
Depth
Herschel-SPIRE
Legacy Survey
Scott 02
Perera 08
Austermann 09
Coppin 06
BLAST
HerMES L6
Scott 10
Weiss 10
HerMES L5
HerMES L3+L4
SCUBA-2 CLS
HerMES L2
Hughes 98
GOODS Super Deep
SCUBA-2 CLS 450 um
Area
RMS limit [L_sun]
survey area [deg^2]
10^13
10^12
10^11
10^-2
10^0
10^2
10^4

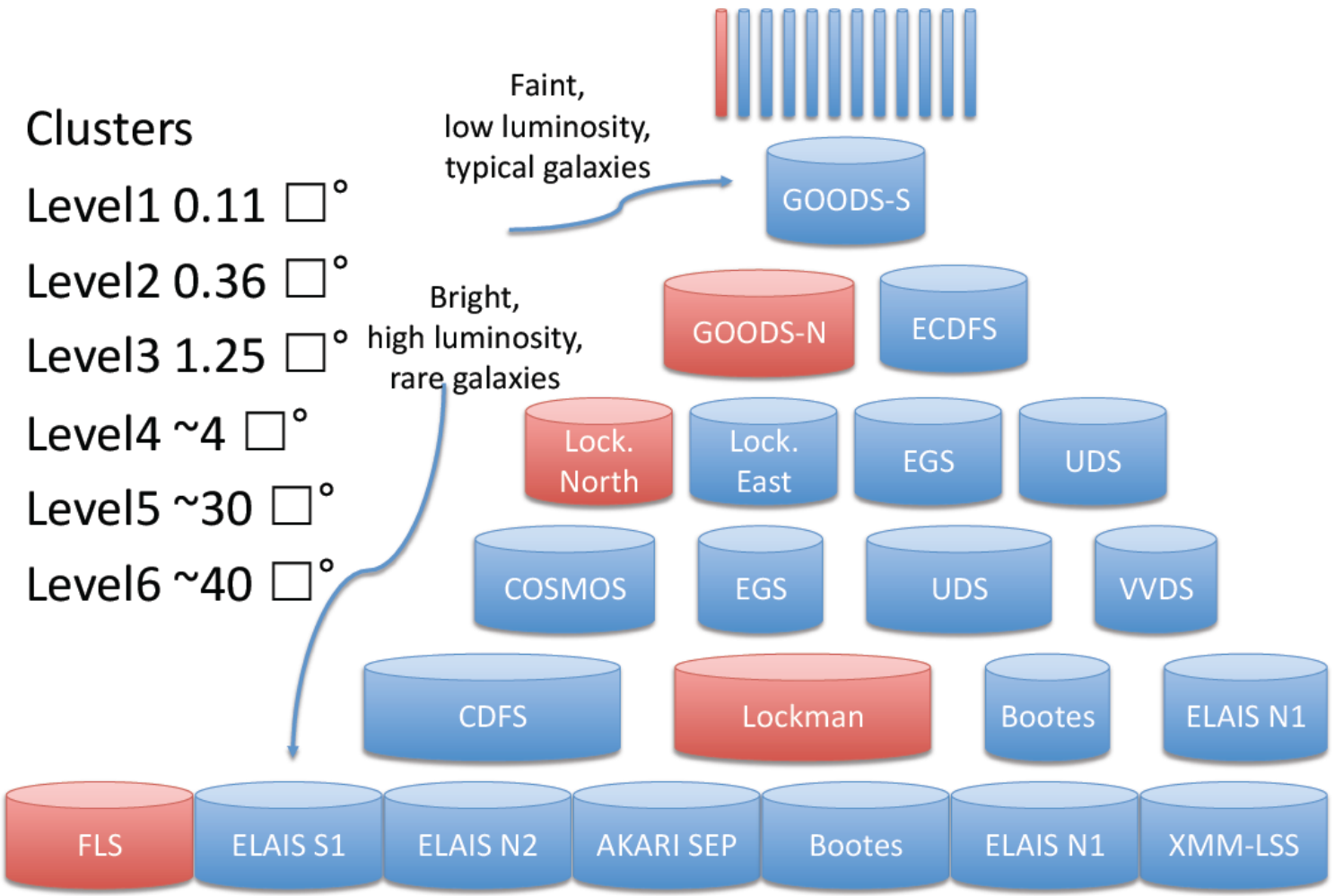
SPIRE GT Program

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, Veroniquw Buat, Denis Burgarella, Nieves Castro-Rodriguez, Antonio Cava, Pierre Chanial, Ed Chapin, Scott Chapman, Michele Cirasuolo, Dave Celments, Alex Conley, Luca Conversi, **Asantha Cooray,** Gianfranco DeZotti, **Darren Dowell,** Naomi Dubois, Jim Dunlop, Eli Dwek, Simon Dye, Steve Eales, David Elbaz, Erica Ellingson, Tim Ellsworth-Bowers, Duncan Farrah, Patrizia Ferrero, Matt Fox, Alberto Franceschini, Ken Ganga, Walter Gear, Elodie Giovannoli, **Jason Glenn,** Eduardo Gonzalez-Solares, Matt Griffin, Mark Halpern, Martin Harwit, Evanthia Hatziminaoglou, Sebastian Heinis, **George Helou,** Jiasheng Huang, Peter Hurley, HoSeong Hwang, Edo Ibar, Olivier Ilbert, Kate Isaak, Rob Ivison, Ali Ahmed Khostovan, Martin Kunz, Guilaine Lagache, Louis Levenson, Carol Lonsdale, **Nanyao Lu**, Suzanne Madden, Bruno Maffei, Georgios Magdis, Gabriele Mainetti, Lucia Marchetti, Elizabeth Marsden, Gaelen Marsden, **Jason Marshall,** Ketron Mitchell-Wynne, Glenn Morrison, Angela Mortier, **Hien Nguyen,** Brian O'Halloran, Seb Oliver, Alain Omont, Frazer Owen, Mathew Page, Maurillo Pannella, Pasquale Panuzzo, Andreas Papageorgiou, Harsit Patel, Chris Pearson, Ismael Perez-Fournon, Michael Pohlen, Naseem Rangwala, Jason Rawlings, Gwen Raymond, Dimitra Rigopoulou, Laurie Riguccini, Davide Rizzo, Giulia Rodighiero, Isaac Roseboom, Michael Rowan-Robinson, Miguel Sanchez-Portal, Rich Savage, **Bernhard Schulz,** Douglas Scott, Paolo Serra, Nick Seymour, **David Shupe,** Anthony Smith, Jason Stevens, Veronica Strazzullo, Myrto Symeonidis, Markos Trichas, Katherine Tugwell, Mattia Vaccari, Elisabetta Valiante, Ivan Valtchanov, **Joaquin Vieira, Marco Viero,** Laurent Vigrouz, Lingyu Wang, Rupert Ward, Don Wiebe, Gillian Wright, **Kevin Xu, Mike Zemcov**

Faculty and Researchers, Postdocs, Students, **(US participants)**

SPIRE

HERMES

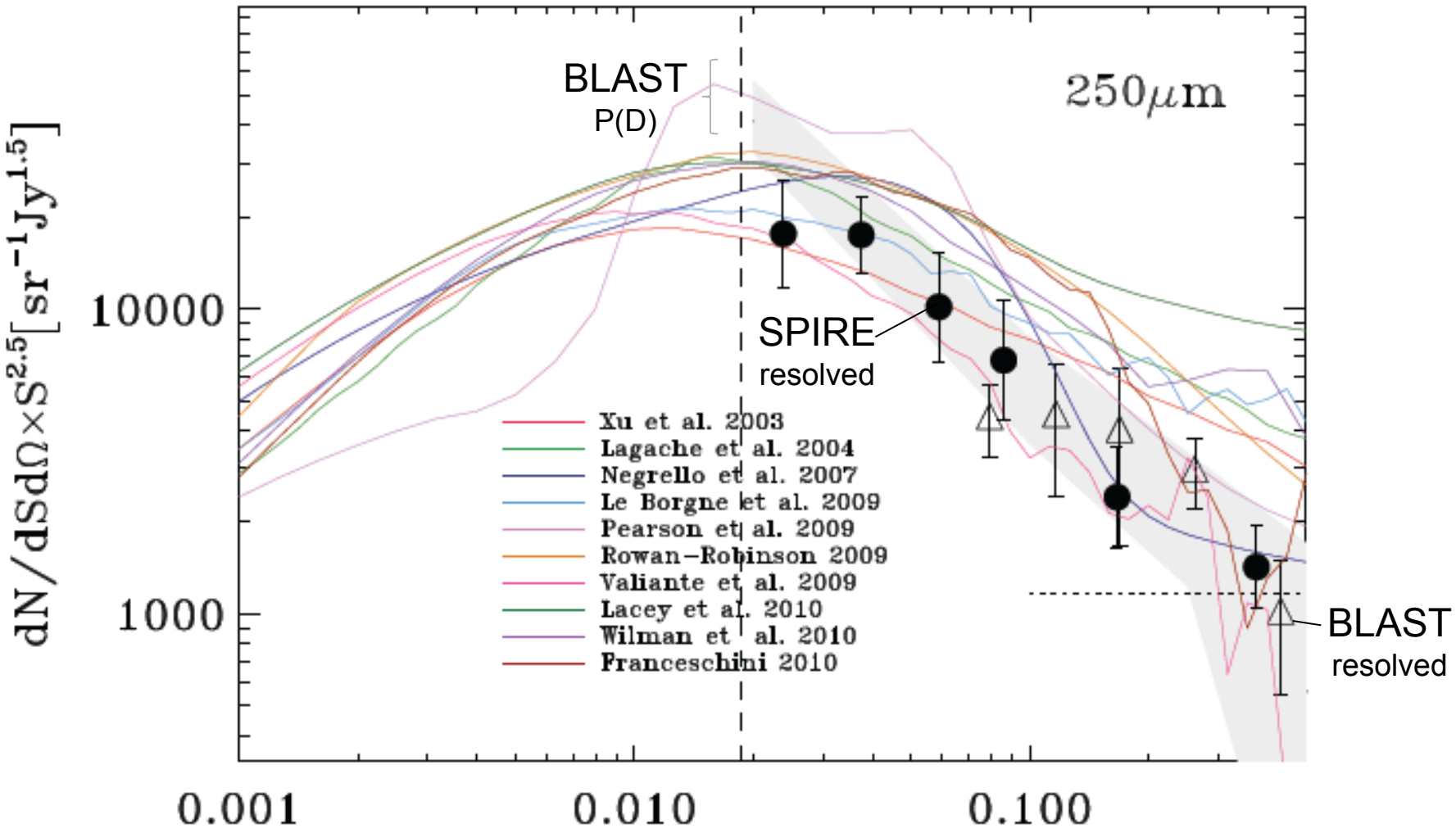


Science Demonstration Phase: 7 % of our total time

27,000 sources > 20 mJy @ 250 um

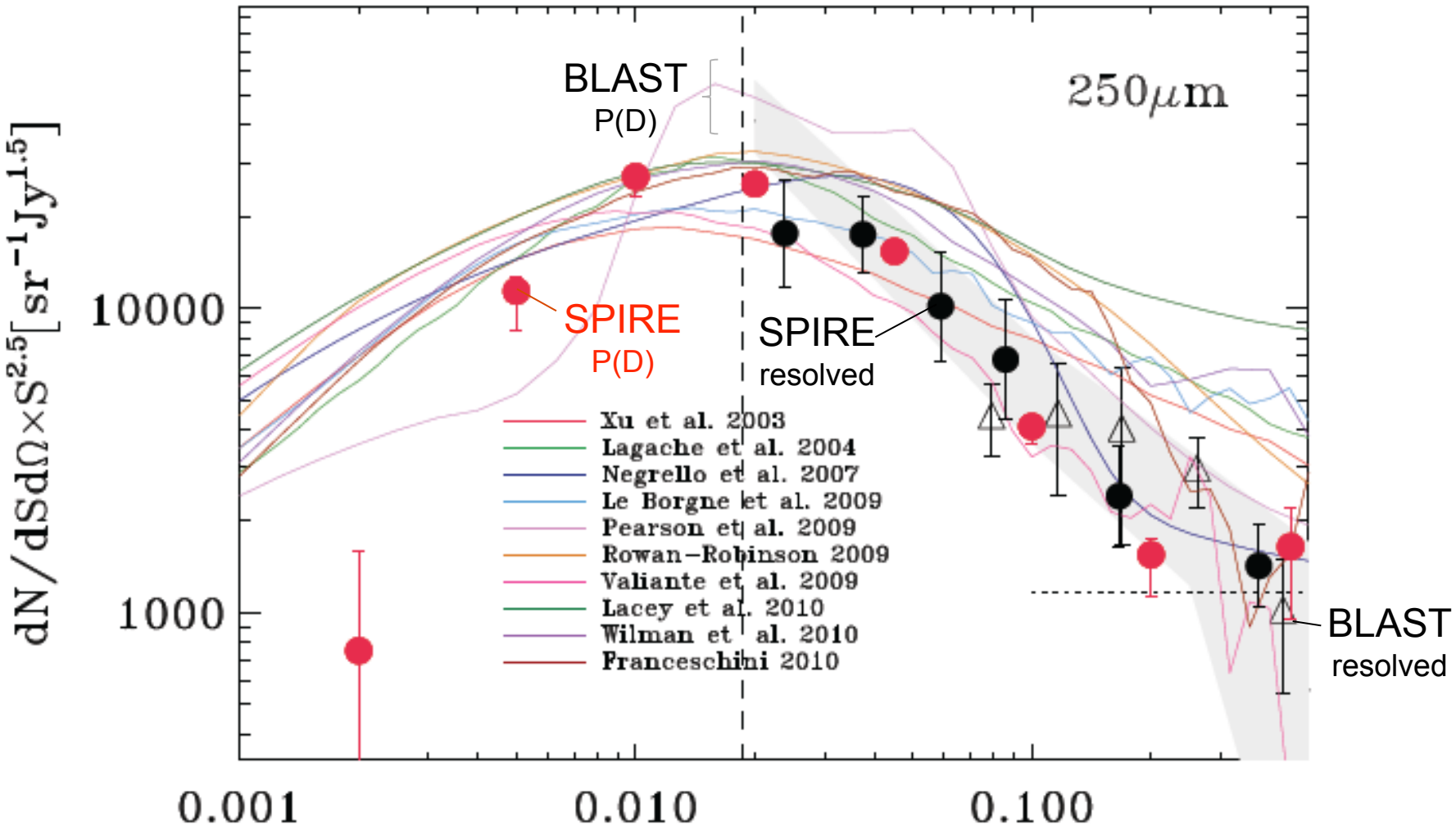
9 A&A papers + ~ 25 MNRAS papers in prep

SPIRE Source Counts



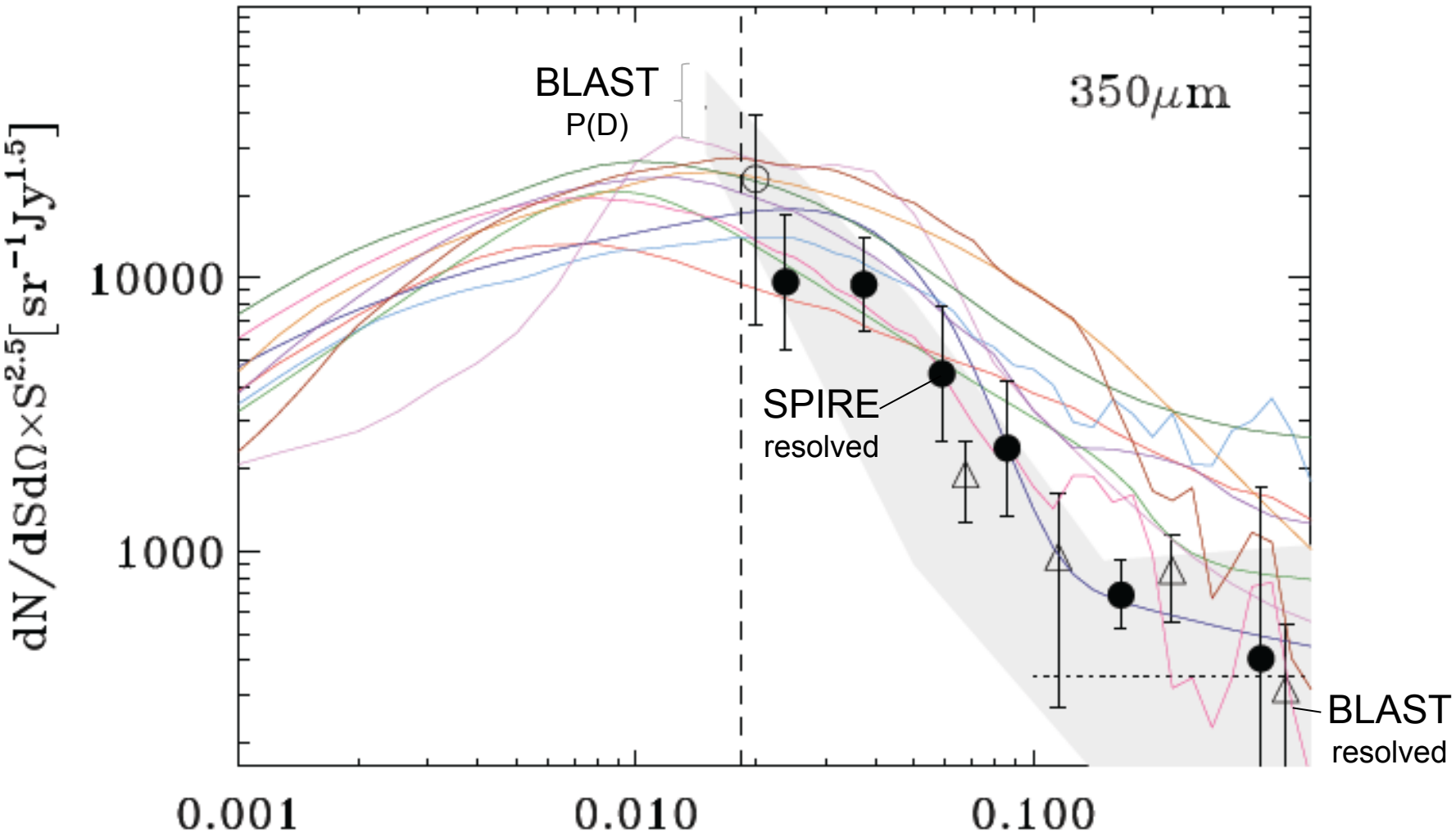
Oliver et al. 2010 A&A

SPIRE Source Counts



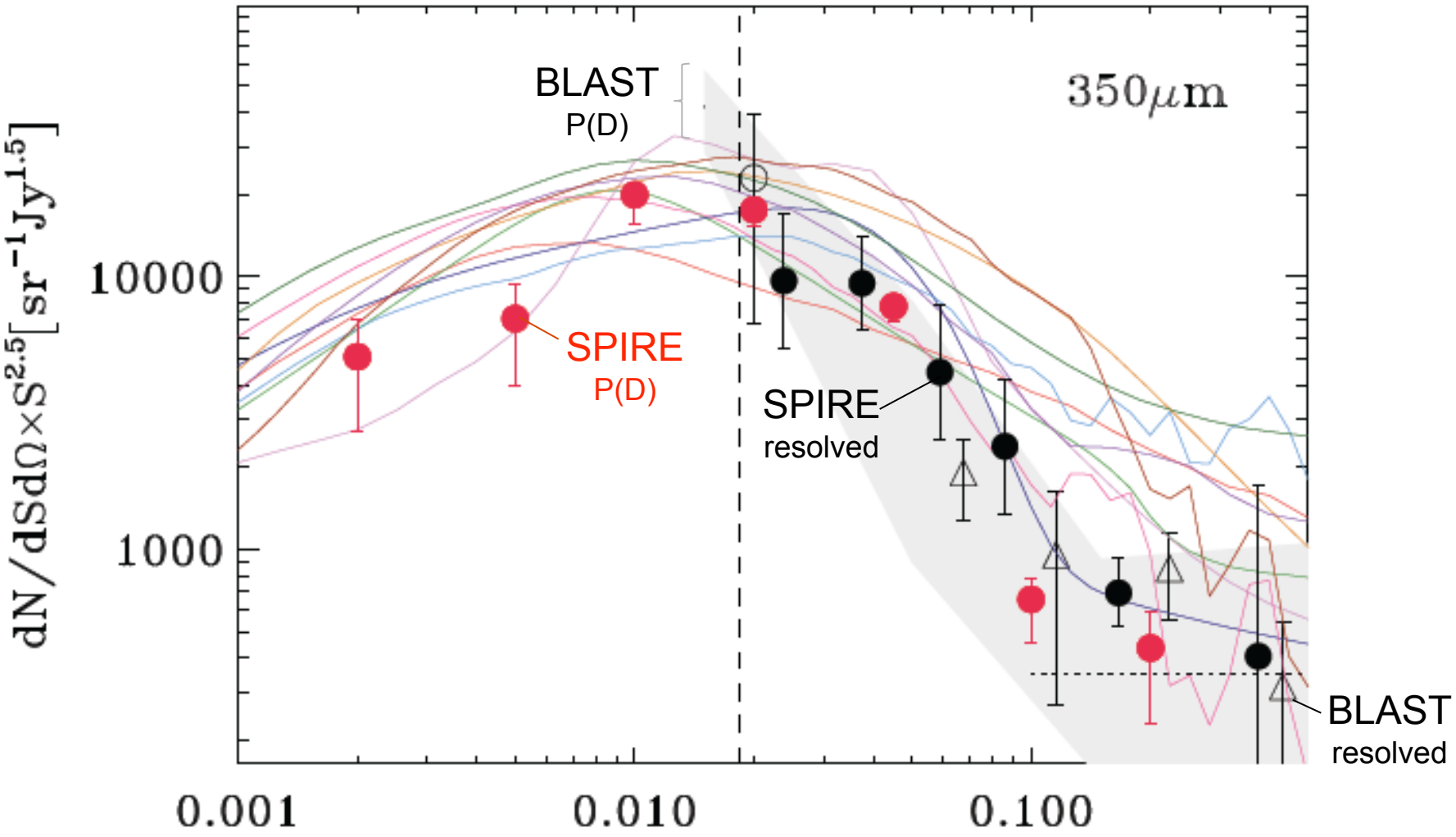
Glenn et al. 2010 MNRAS (in prep)

SPIRE Source Counts



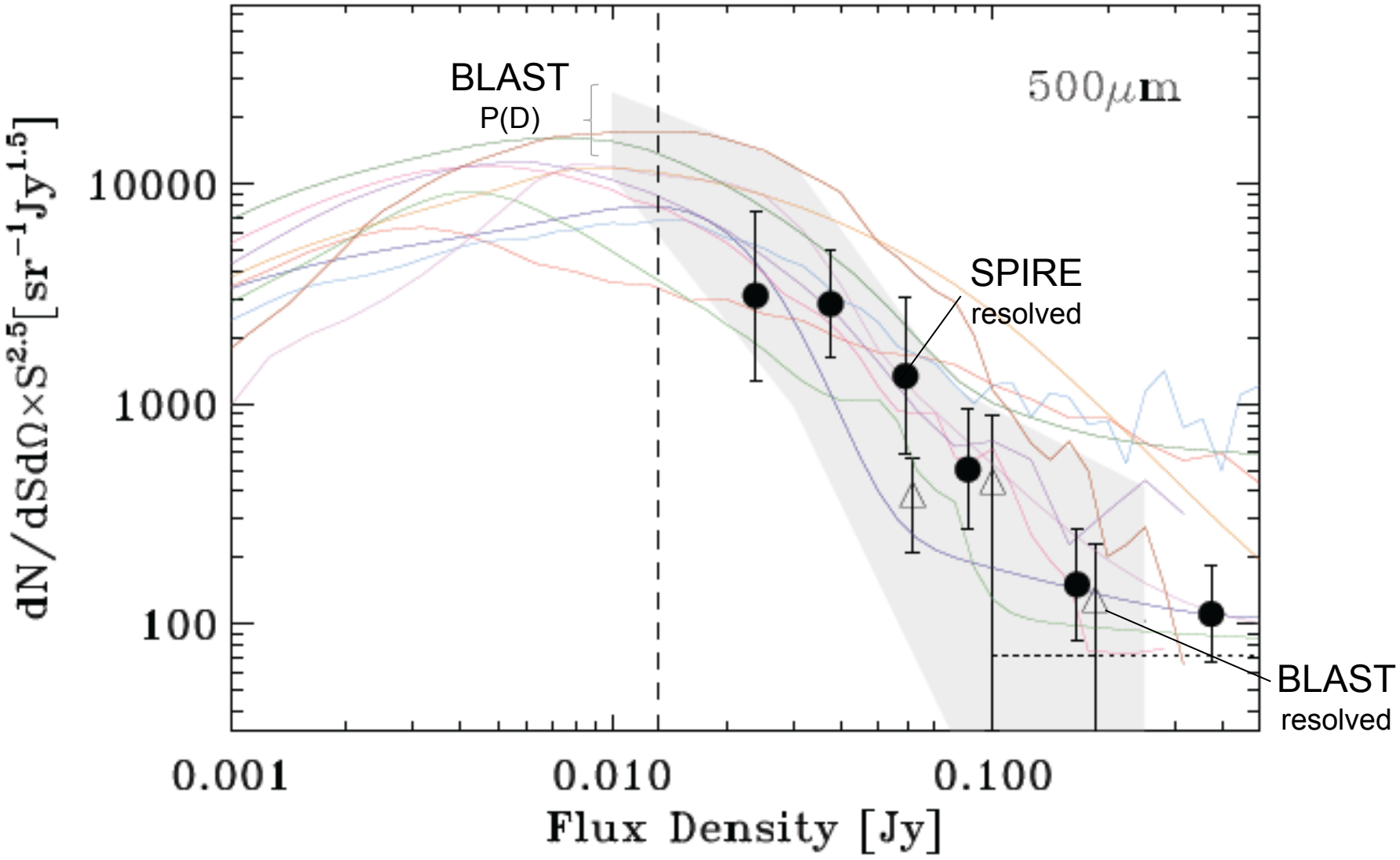
Oliver et al. 2010 A&A

SPIRE Source Counts



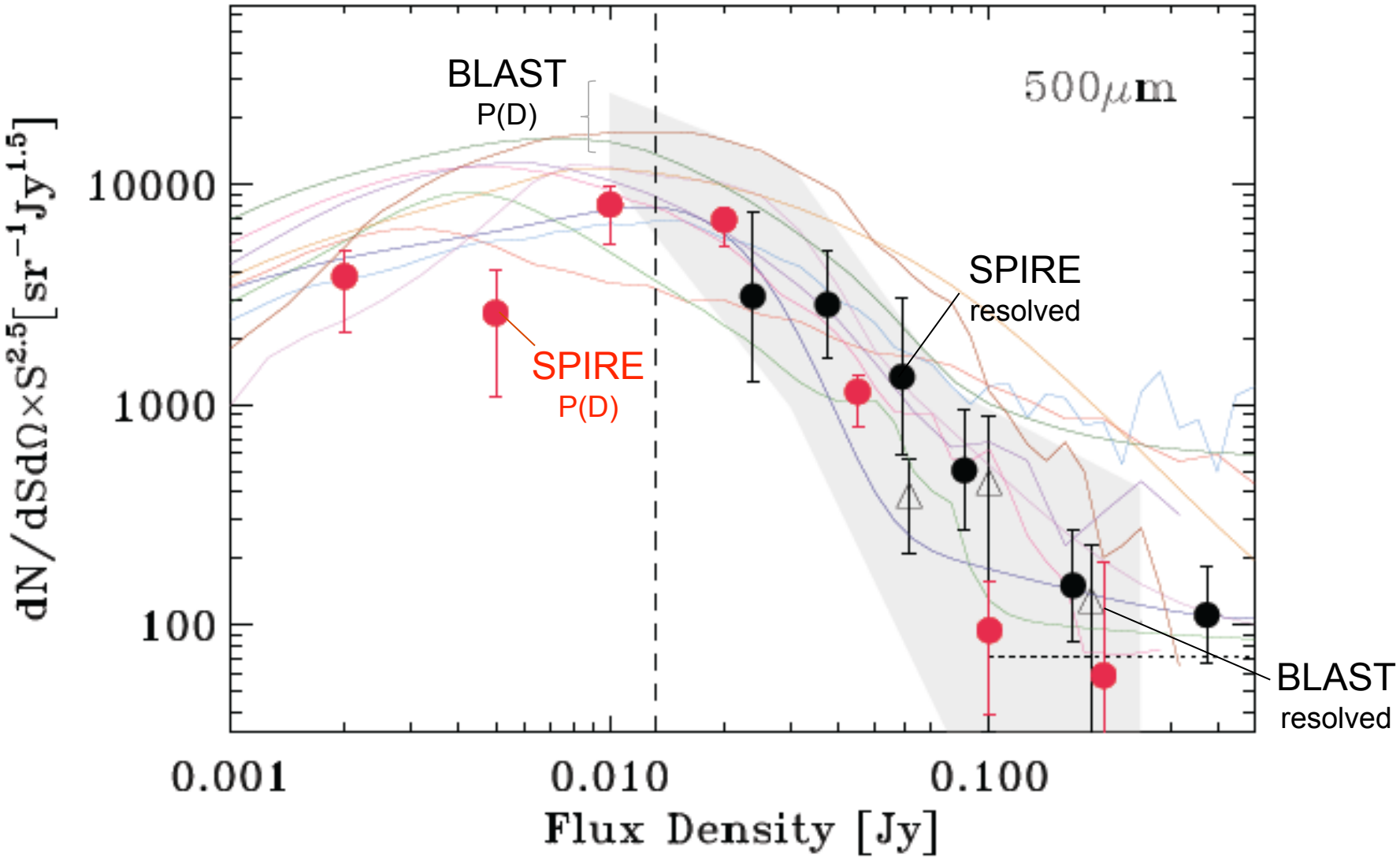
- Number counts of bright galaxies (ULIRGS+) over-predicted by models
- Bright-end counts are steeper than models generically

SPIRE Source Counts

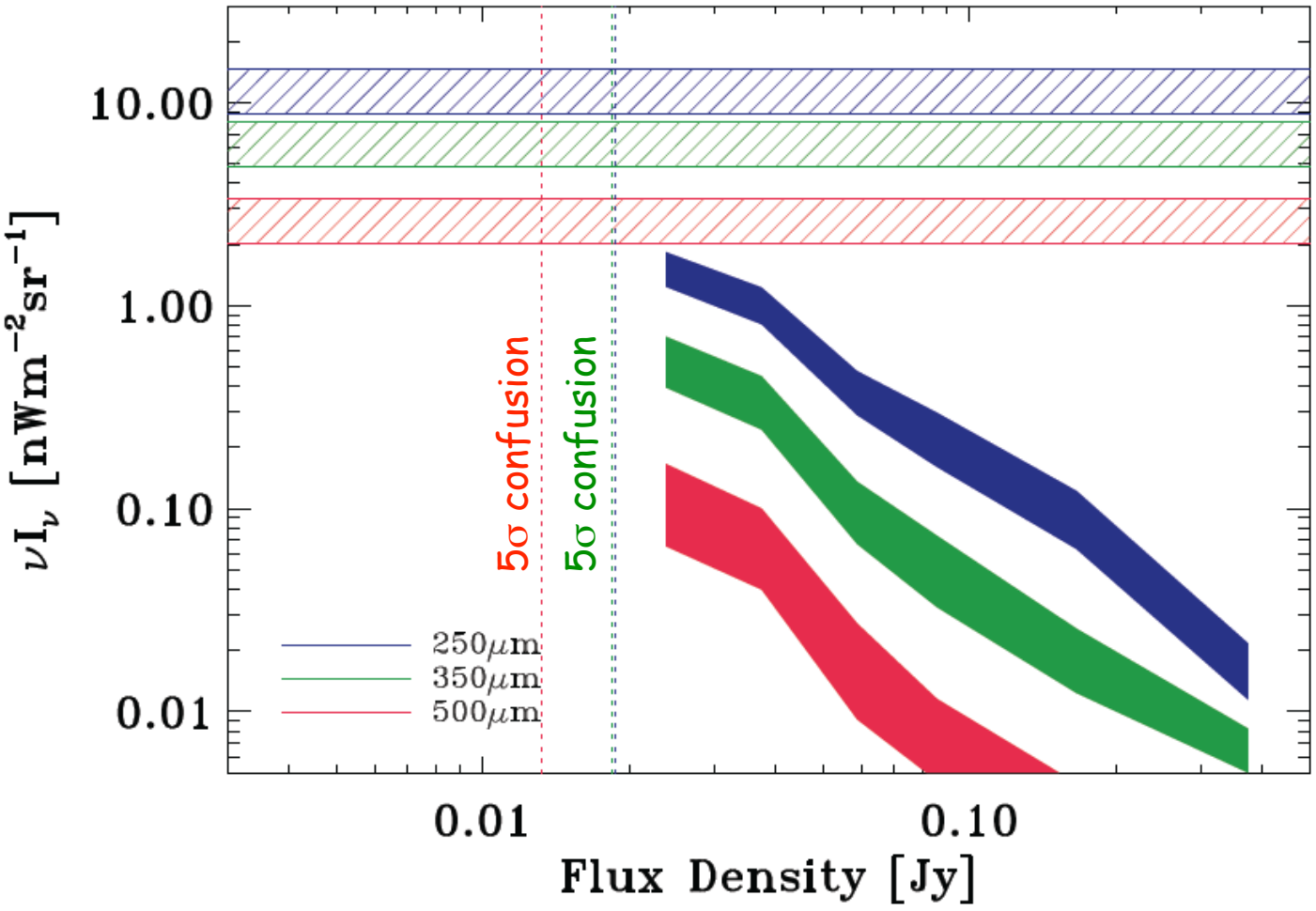


Oliver et al. 2010 A&A

SPIRE Source Counts



Resolving the FIR Background

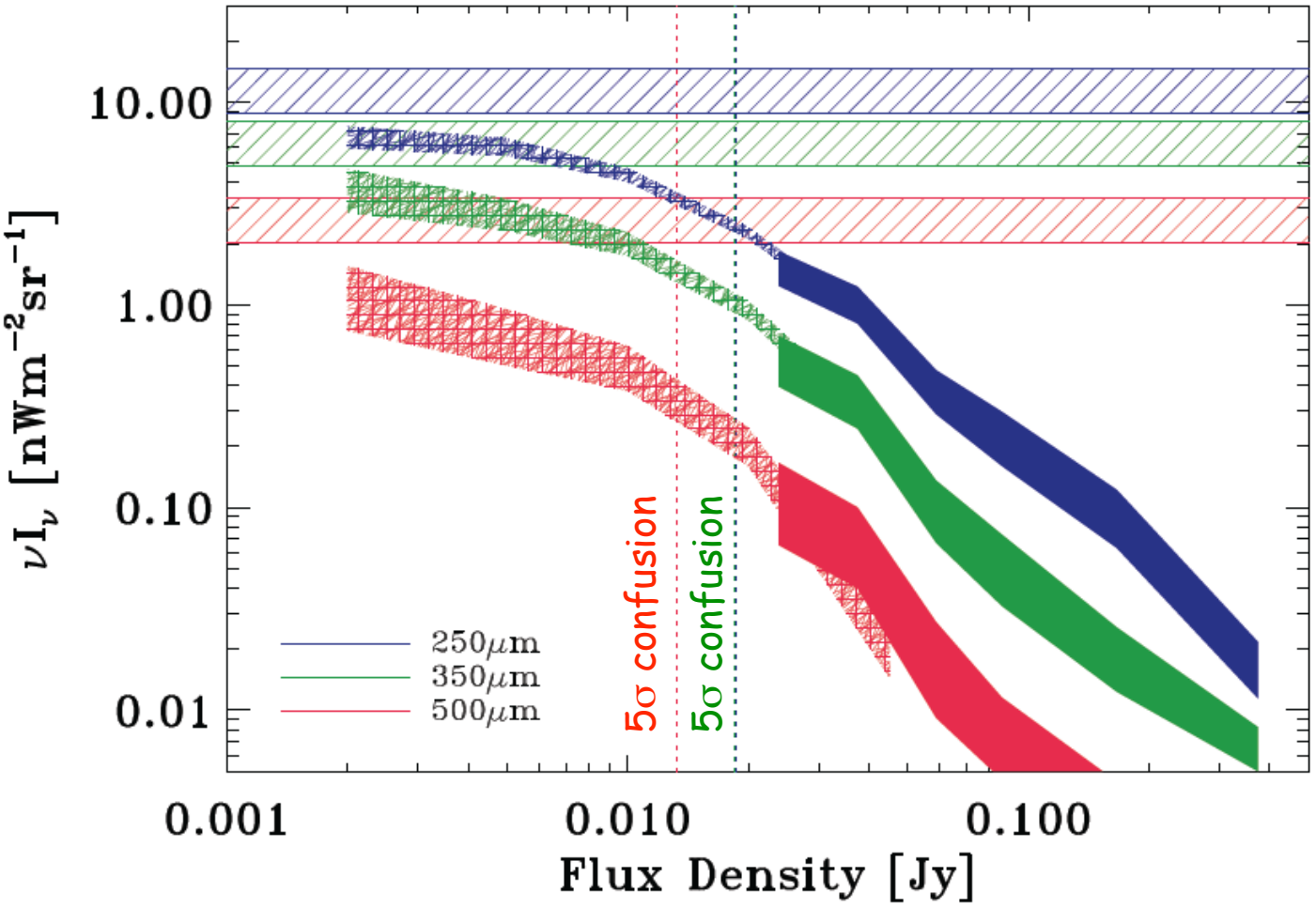


- **Source Counts**

250, 350, 500 μm

15%, 10%, 6%

Resolving the FIR Background



- **Source Counts**

  250, 350, 500 μm

  15%, 10%, 6%

- **P(D)**

  250, 350, 500 μm

  65%, 60%, 45%

- **Stacking**

  250, 350, 500 μm

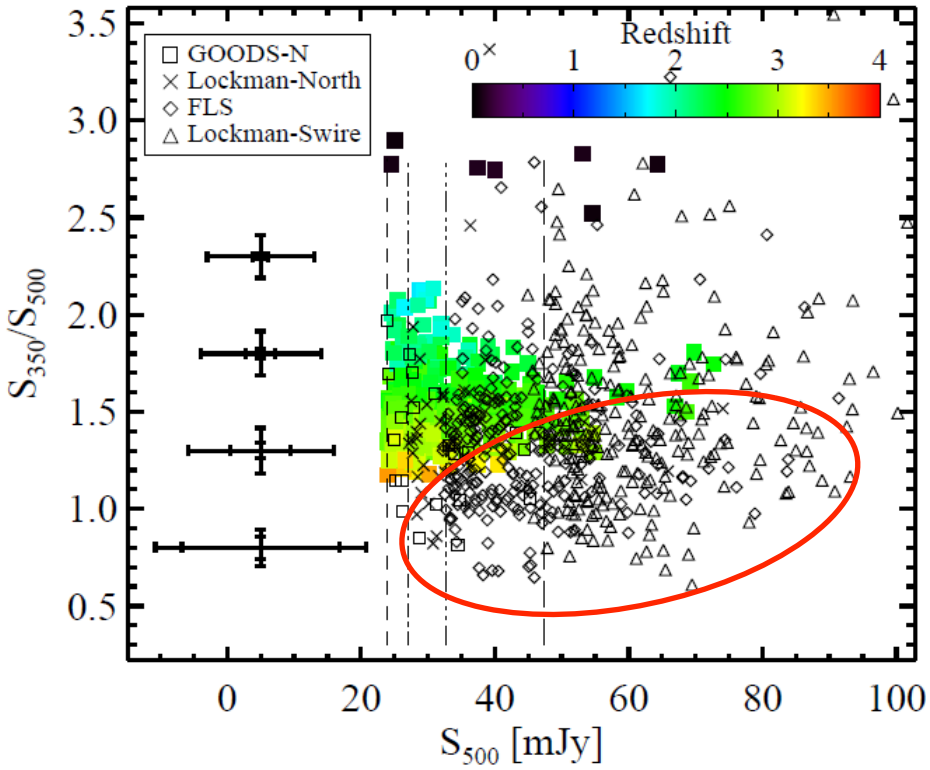
  80%, 80%, 85%

Of course: The remainder may be the most interesting sources!

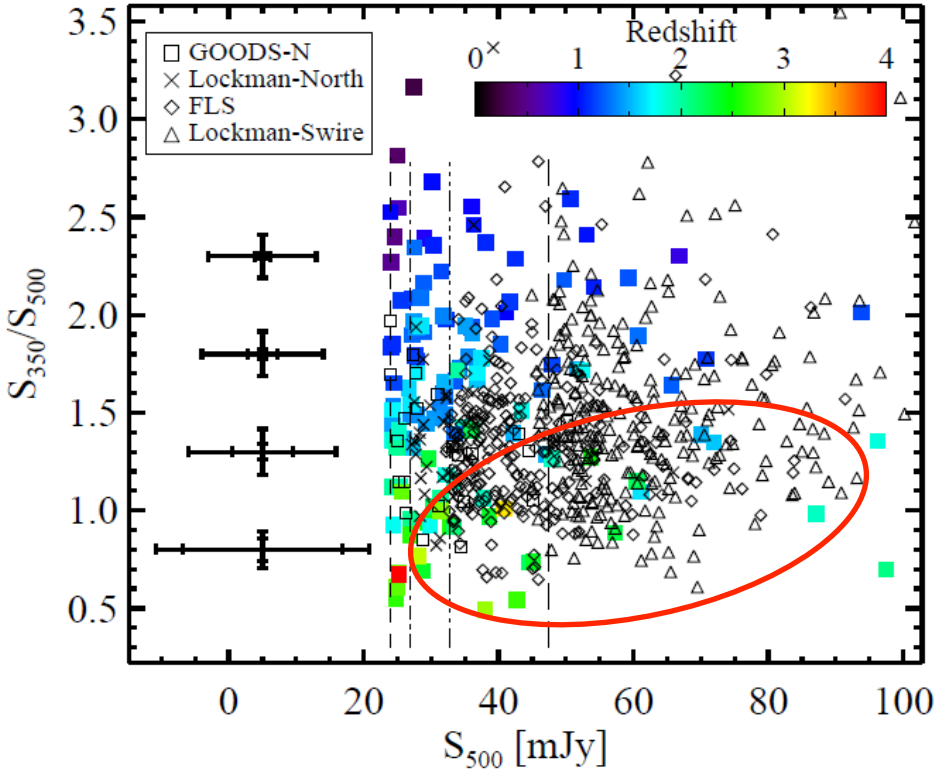
E.g. the z > 3 galaxy population.

SPIRE Galaxy Colors

Results Compared to Pearson Model



Results Compared to Xu Model

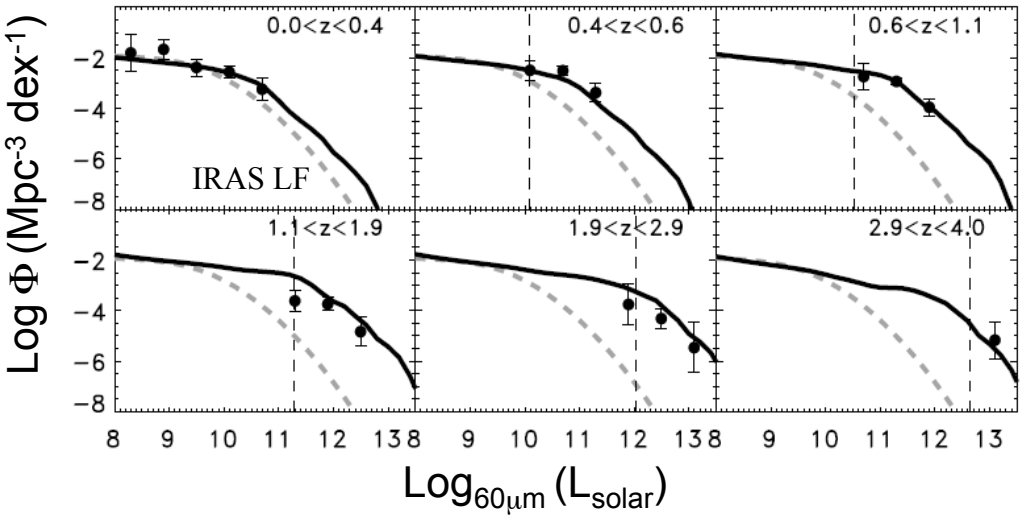


Schulz et al. 2010

Colors generally spread redder than models predict
- colder dust and/or higher z populations?

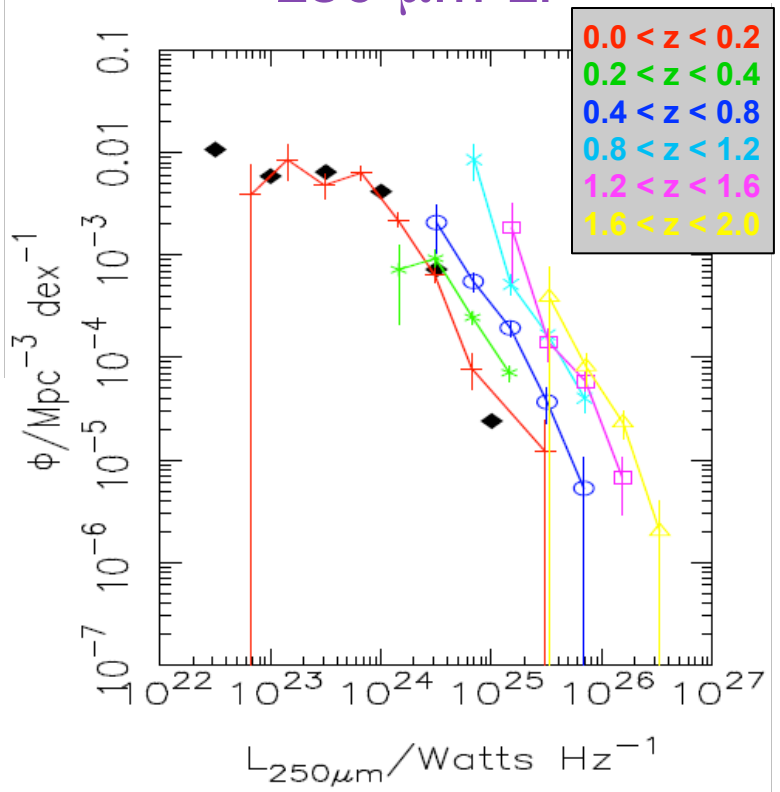
Strong Luminosity Evolution

PEP rest-frame 60 μm LF



Gruppioni et al. (2010)

HerMES rest-frame 250 μm LF



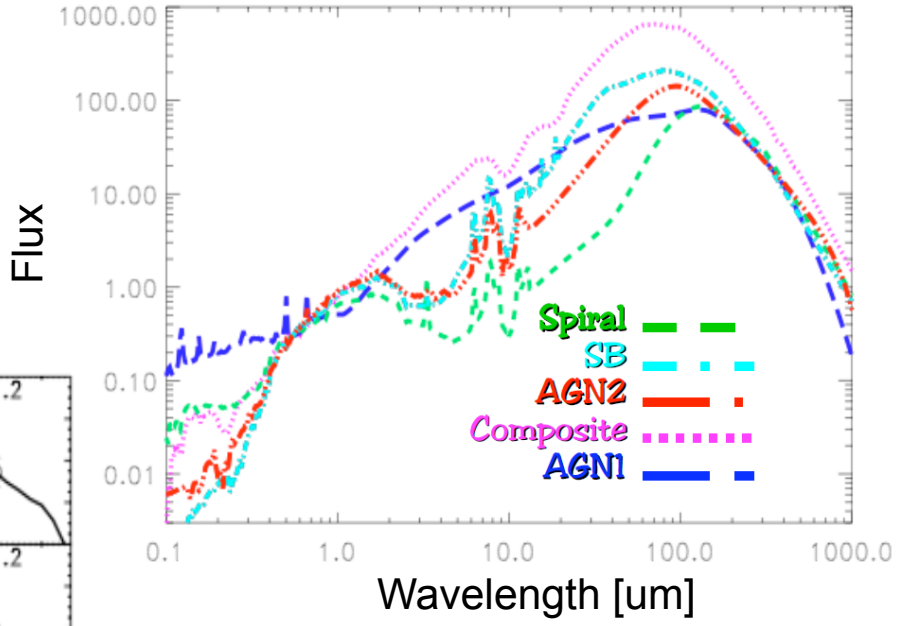
Eales et al. (2010)

- Strong evolution evident to z ~ 1
- Continued but weaker(?) to z ~ 2
- Next:
  - -Better statistics from bigger samples
  - -Reach to higher z with bigger samples
  - -Combined PACS & SPIRE for better-constrained bolometric SEDs

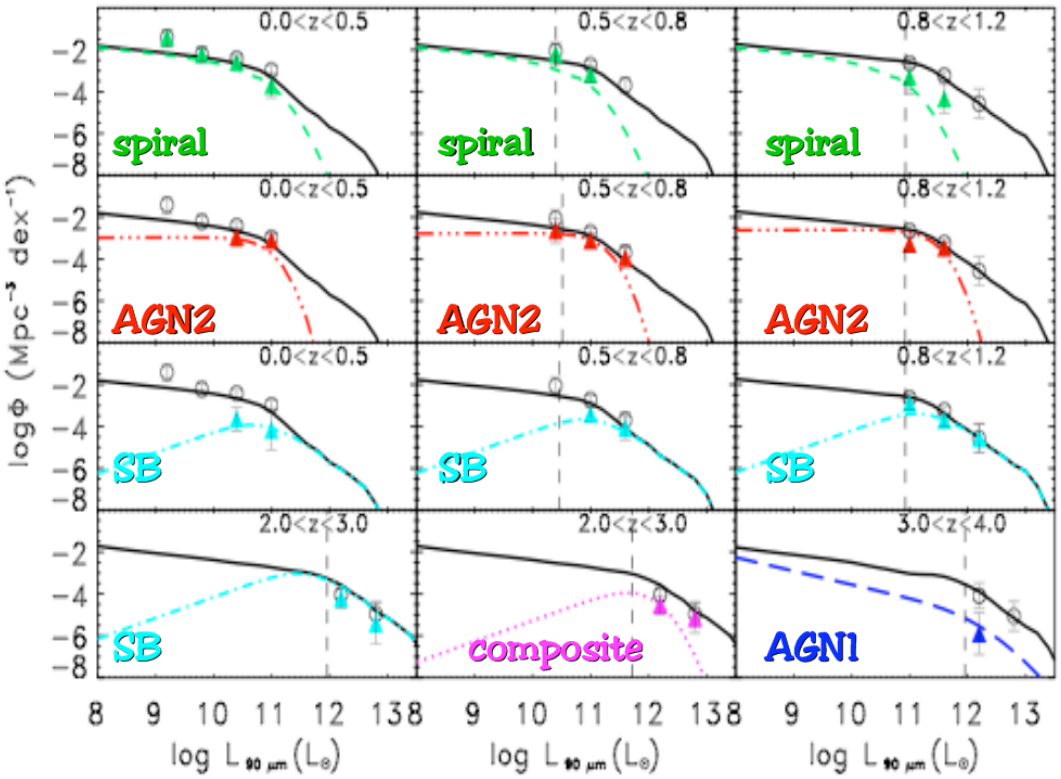
How Are Populations Evolving?

Fit sources to galaxy templates

(Does this really work?)



Derive LF by galaxy type

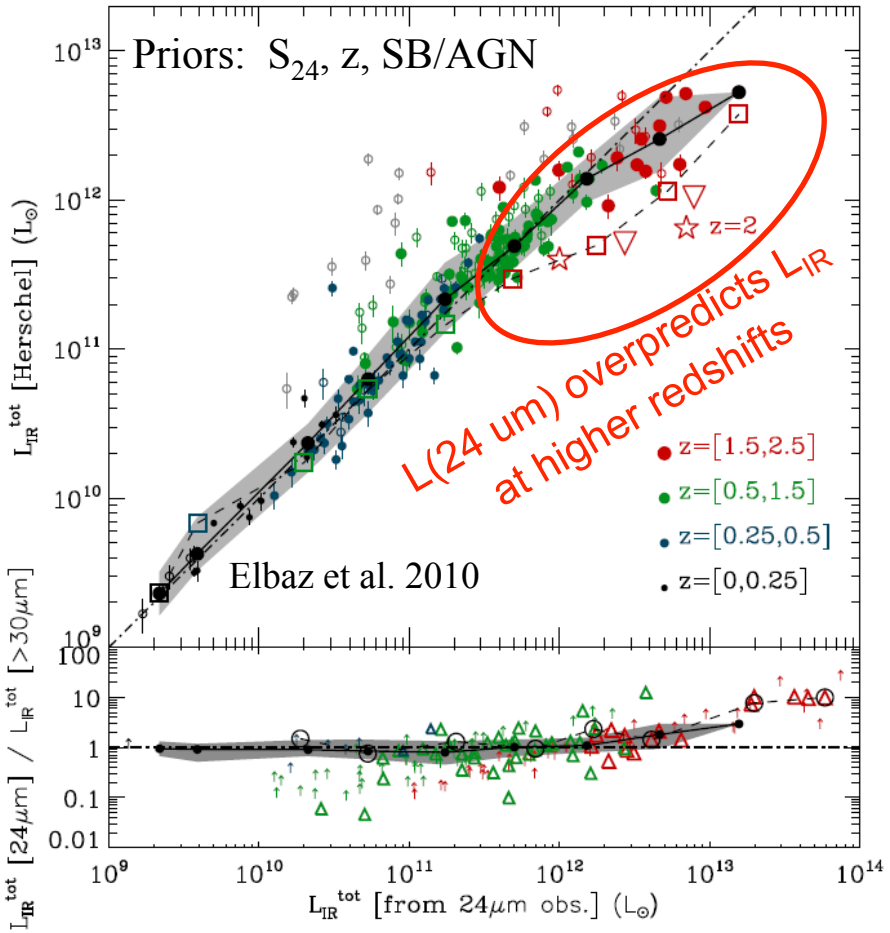


Gruppioni et al. 2010

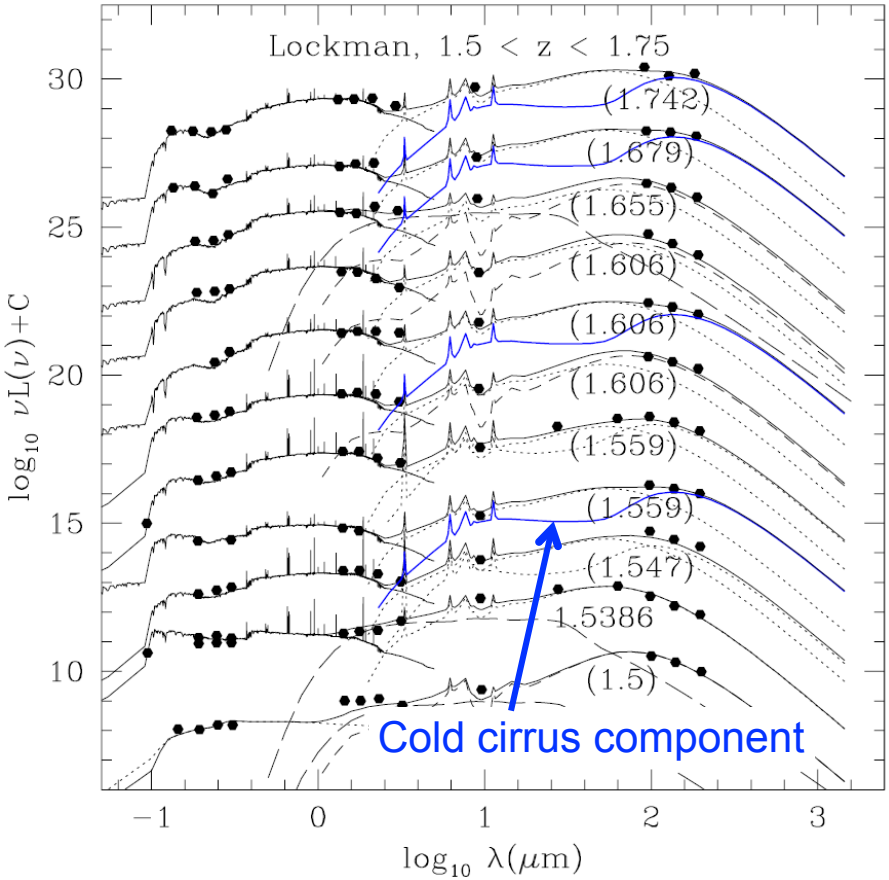
<u>Conclusion</u>: Starbursts dominate at high L and z

How Well Do Galaxy Templates Work?

L_{IR} for Starbursts and AGNs



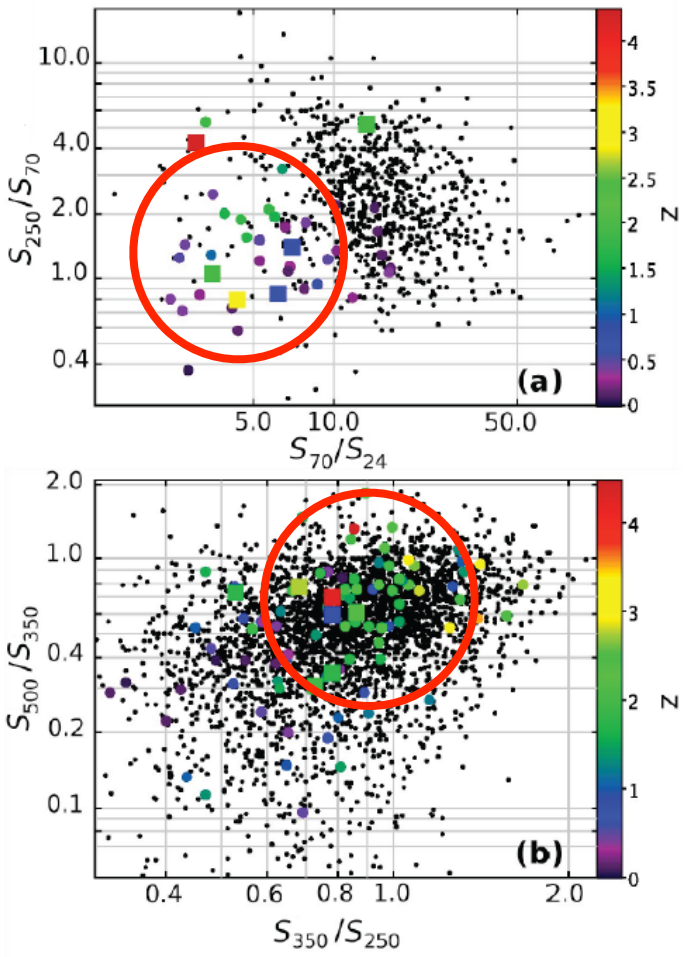
Multi-Wavelength SED Fits



Rowan-Robinson et al. 2010

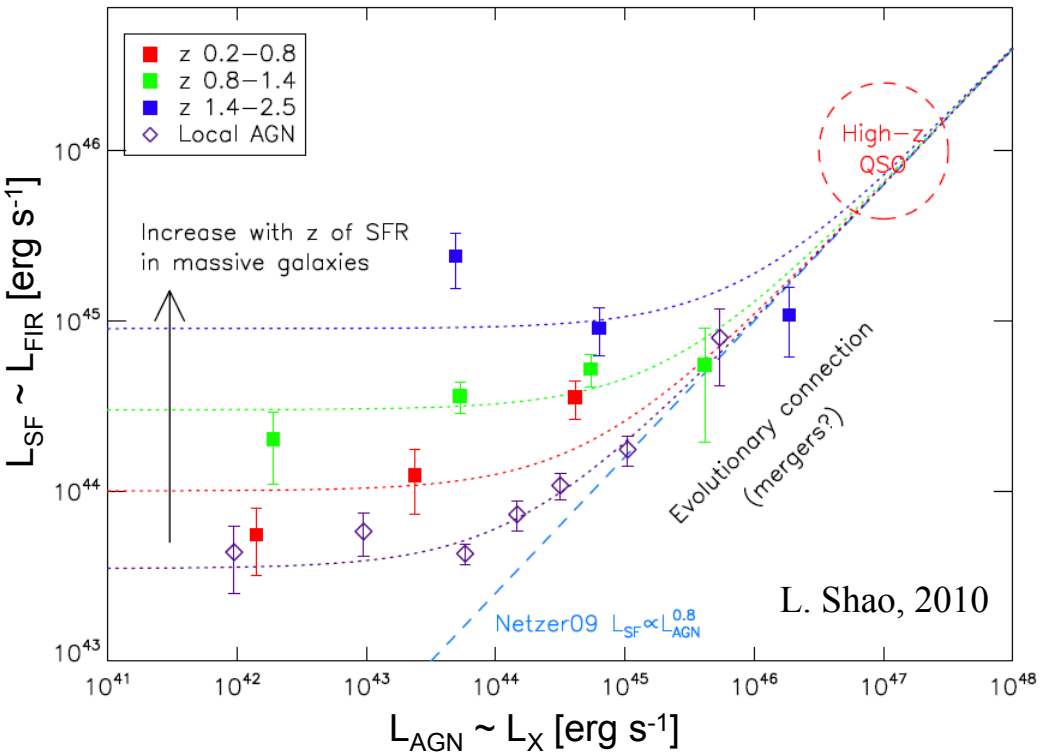
- *Herschel* provides a direct measure of bolometric luminosity and SFR
- L_{FIR} and SFR predicted from $\lambda \leq 24$ μm observations are inadequate
- ~Half the SEDs require lower temperature dust component (10 – 20 K)

AGNs and Far-IR Galaxies



E. Hatziminaoglou, 2010
J. Stevens, 2010

Two Modes of Host & AGN Evolution?



Distinct S_{70}/S_{24} colors, but not $S_{250}/S_{350}/S_{500}$
- FIR emission due to star formation

Higher FIR luminosity of Type 2s
- Inconsistent with unified AGN torus model
- Type 2 AGN associated with enhanced SF?

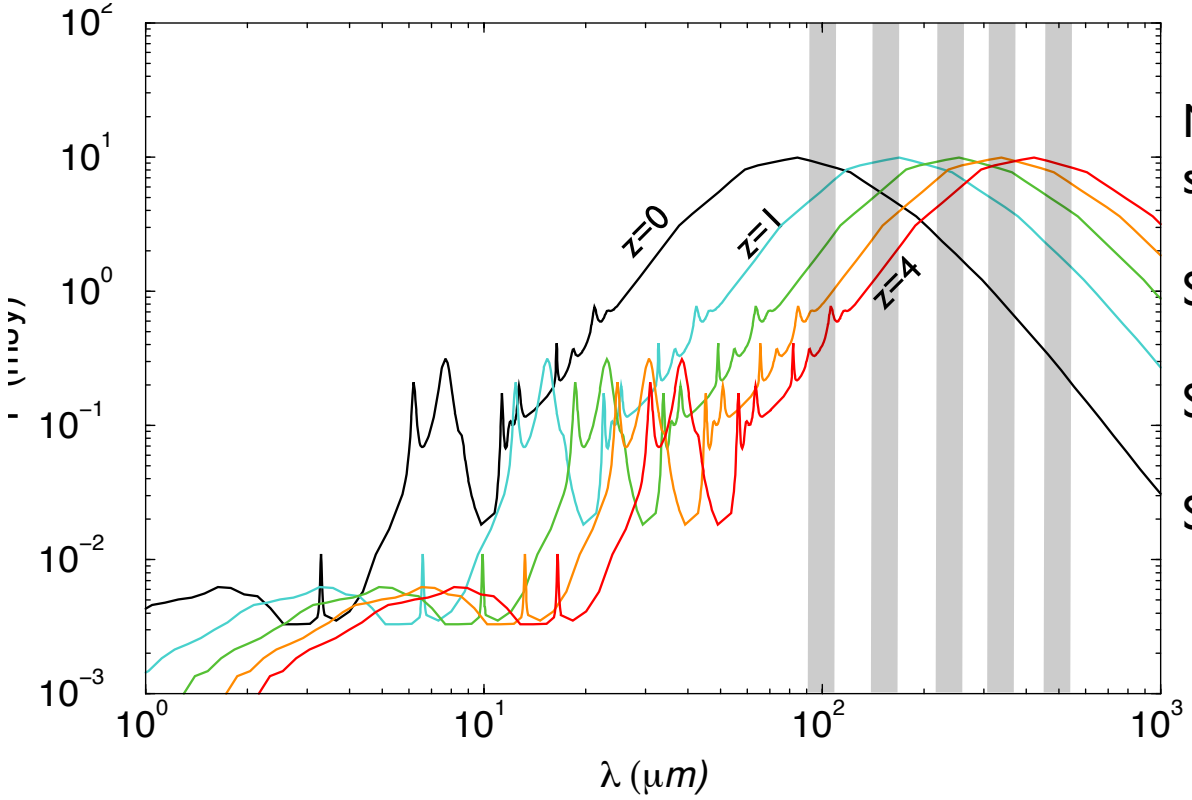
Low L_{AGN}: Increasing L_{SF} w/ z
- Follows behavior of FIR galaxies
- SF unrelated to AGN?

High L_{AGN}: Related to L_{SF}
- Trend is weaker
- Luminosities coupled by mergers?

Herschel-ATLAS

PACS & SPIRE parallel mode. 550 sq. degrees total.
14 sq. degrees of first data (GAMA 9-hour field).

~6800 sources down to 32, 36, 45 mJy (5σ) at 250, 350, 500 μm



Naive expectation based on sub-mm SED

$S_{250} > S_{350} > S_{500}$: z < 2

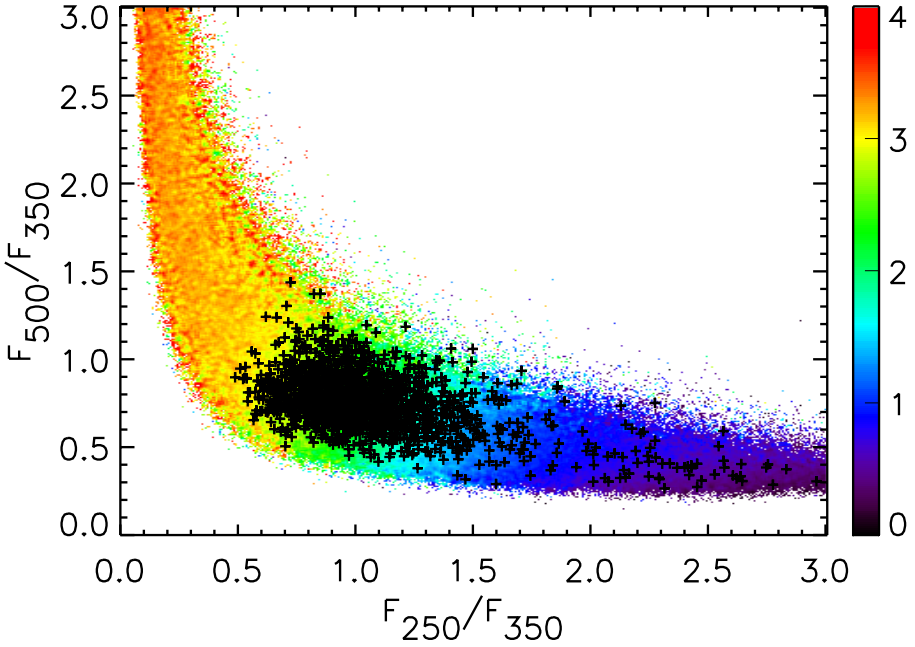
$S_{250} <\sim S_{350} > S_{500}$: z ~ 2 to 3

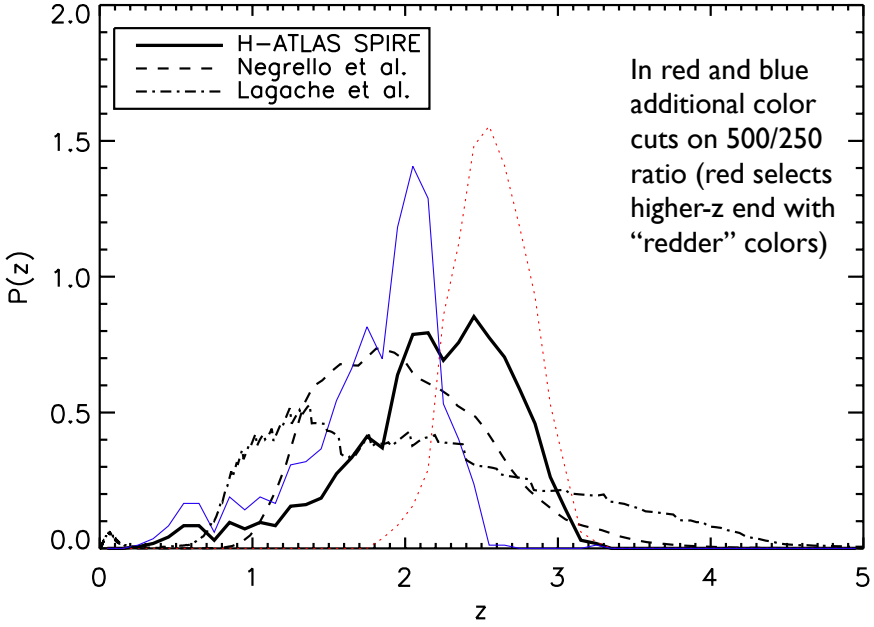
$S_{250} < S_{350} < S_{500}$: z > 4

sub-mm colors as a mechanism to select z > 2 galaxies

Herschel-ATLAS

350μm selected galaxies > 5σ are at mostly at z = 2.2 ± 0.6





The surface density of 350 μm selected sources (z~1.8 to 3) $S_{350} > 30$ mJy is ~350/deg^2

The "statistical" redshift distribution implied by SPIRE colors for the 1686 sources

[equivalent to fitting each SED with a single-temp model and marginalizing over T,β] *(Hughes et al 2002; Aretxaga et al. 2007)*

Amblard et al. 2010

Abundance of z > 3 sources?

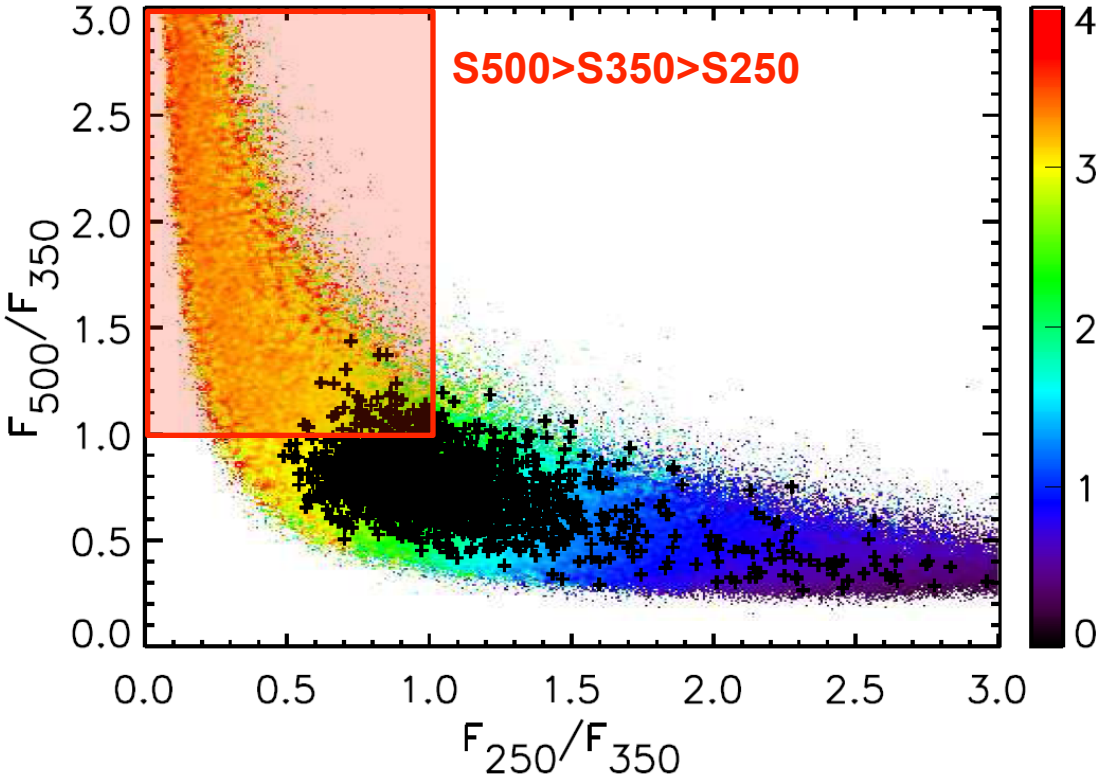
H-ATLAS:

281 sources with $S_{500} > S_{350}$

55 detected above 5σ (>45 mJy)

49 detected above 5σ in all 3 bands.

One of these is a blazar at z~1.02, in Fermi all-sky/WMAP catalog.



Amblard et al. 2010

Are all the 281 sources at z > 3?

Unclear! We need follow-up data, especially near-IR.

CO-line redshifts?

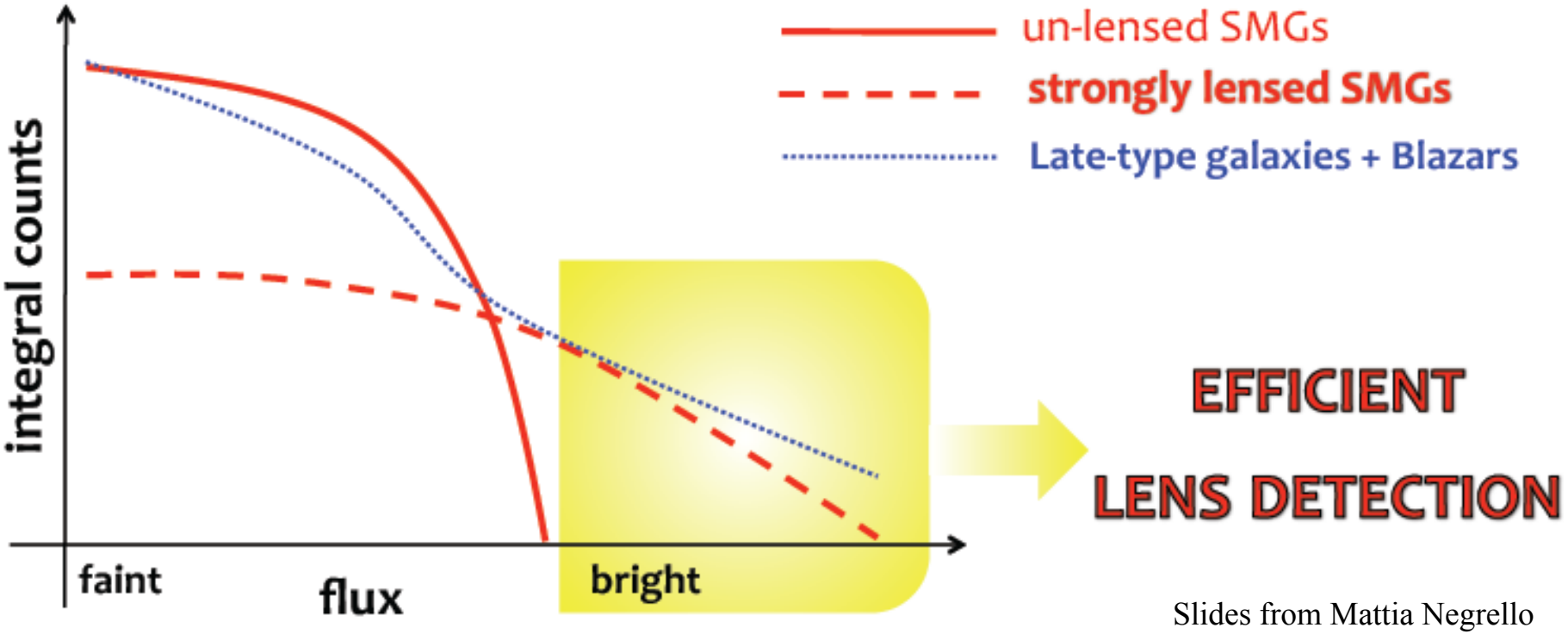
Assuming all 281 sources are z > 3, a rough lower limit on the surface density of z > 3 sources down to $S_{500} > 45$ mJy is ~20/deg^2

Blind Detection of Lensed Galaxies

Sub-mm surveys are ideal for finding lenses

Blain (1996), Perrotta et al. (2003), Negrello et al. (2007)

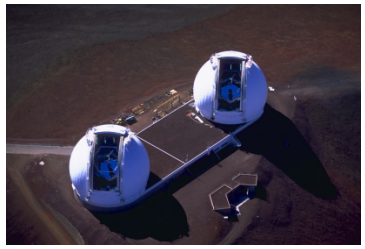
- **high redshift** → high efficiency for lensing
  Chapman et al. (2005)
- **steep counts** → strong *magnification bias*
  Coppin et al. (2006)

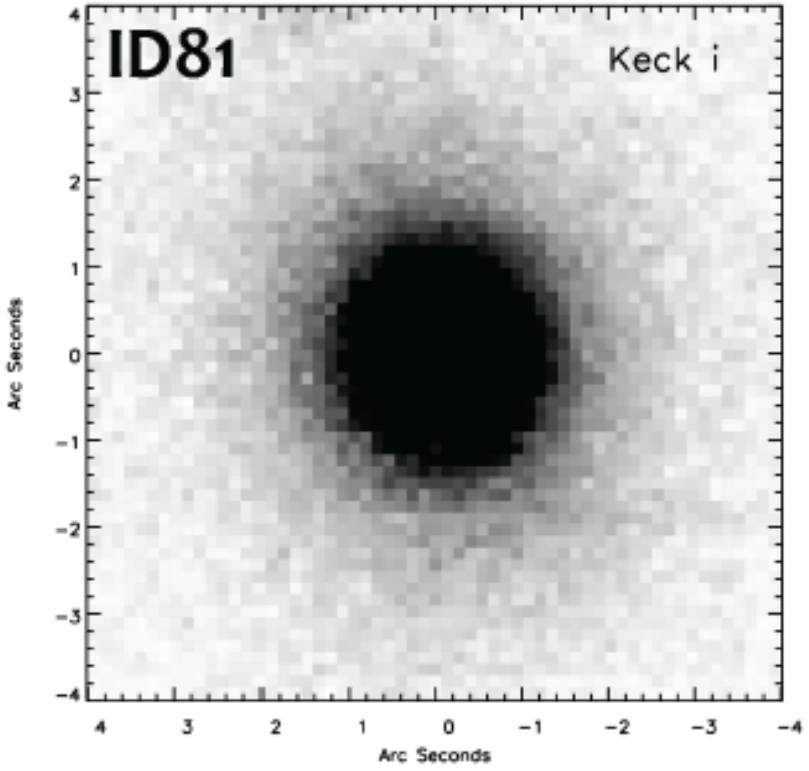


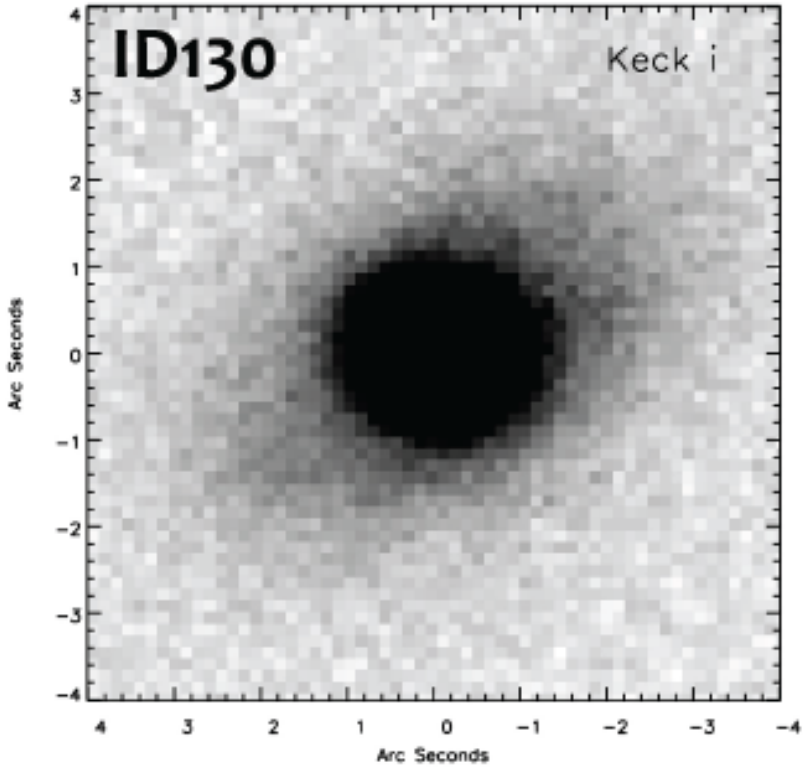
Slides from Mattia Negrello

Lensing Candidates ID81 & ID130

Keck imaging in **g** and **i** bands

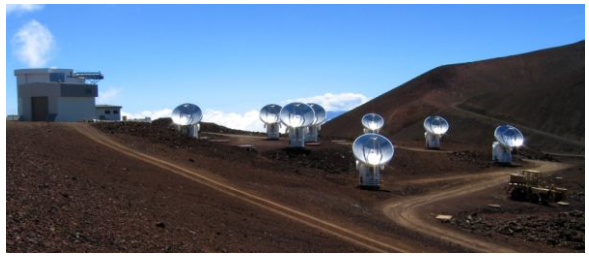


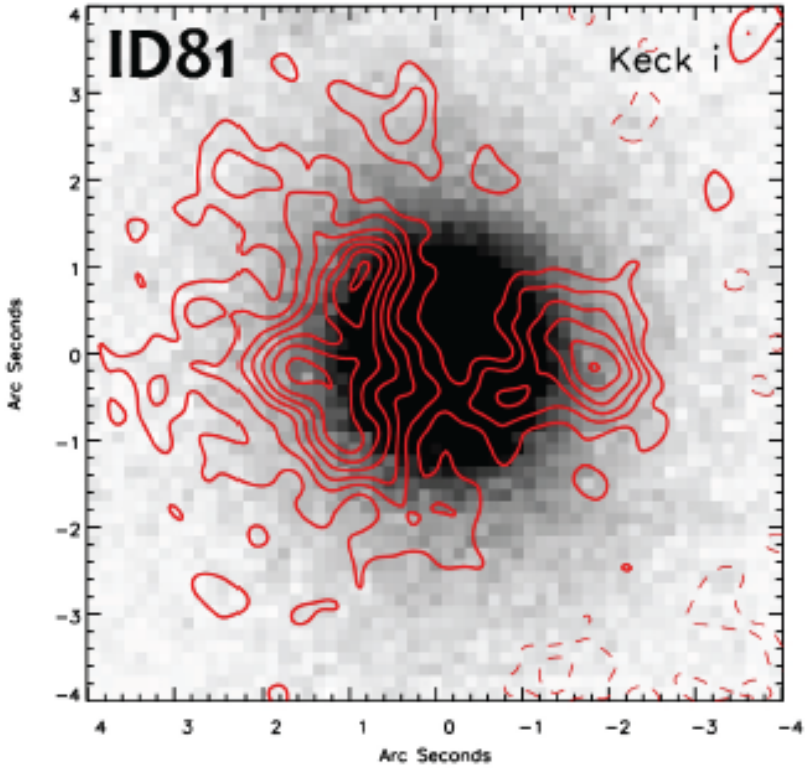


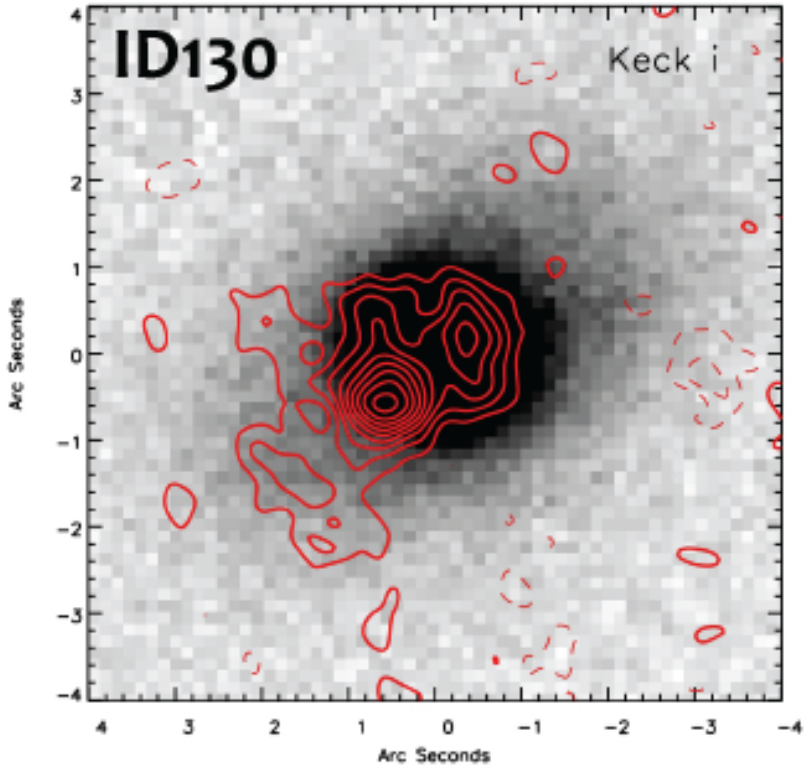


Lensing Candidates ID81 & ID130

Sub **M**illimeter **A**rray follow-up at **870 μm**
(*very-extended*, *sub-compact* and *compact* configurations)



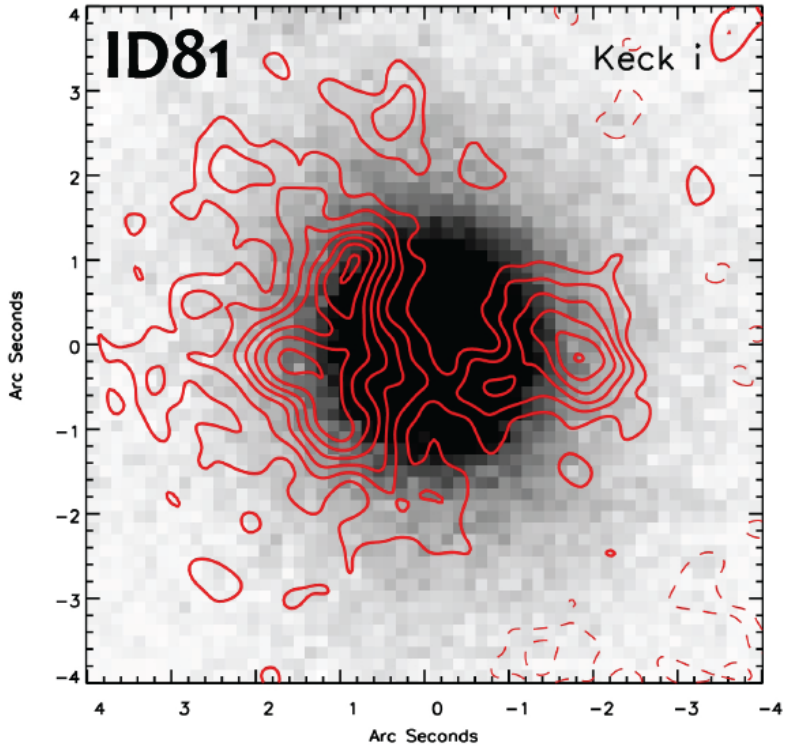


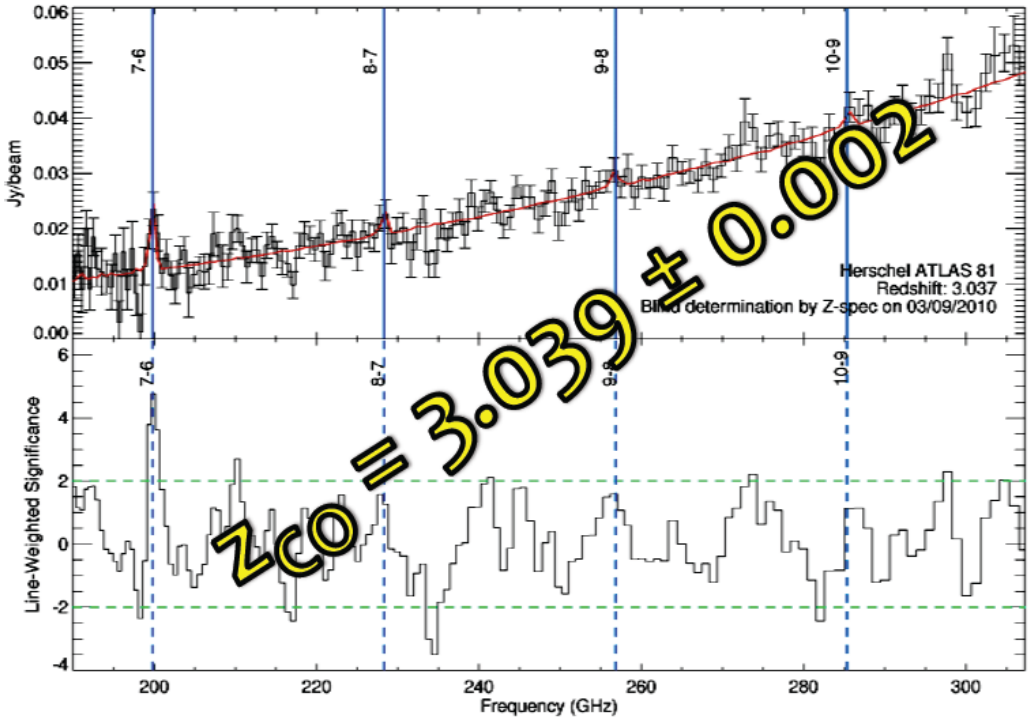


CREDITS: Mark Gurwell (CfA)

First Herschel CO Redshift: ID81

CSO/Z-spec blind redshift determination for **ID81**
from observations of the **CO ladder**

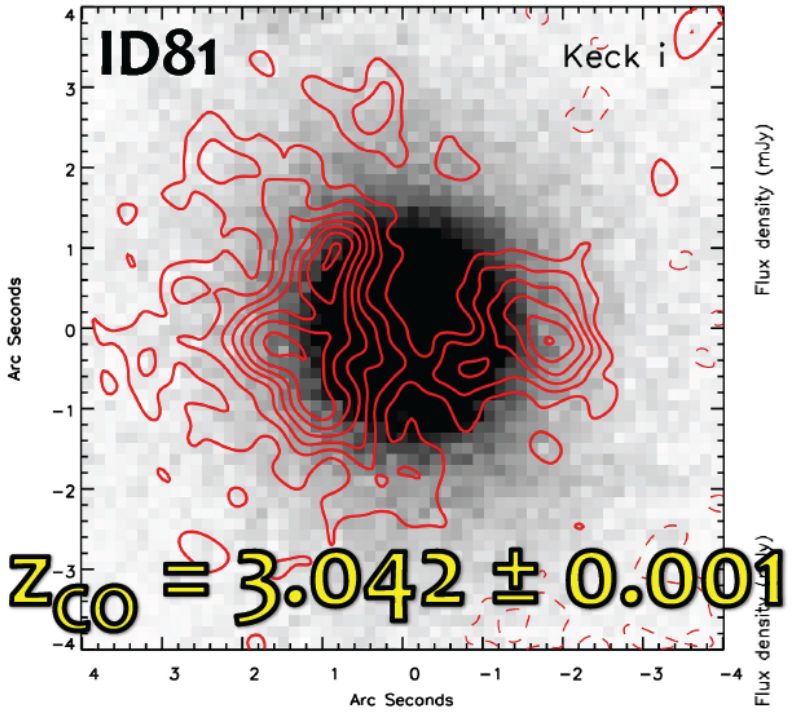


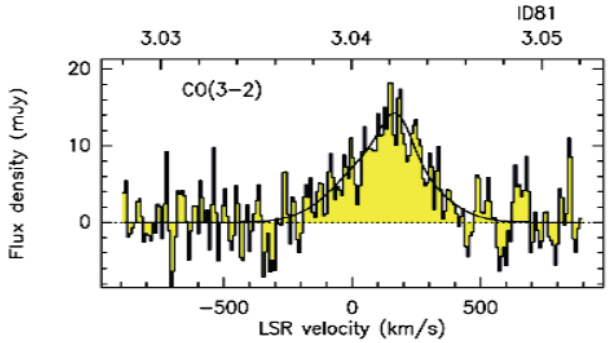


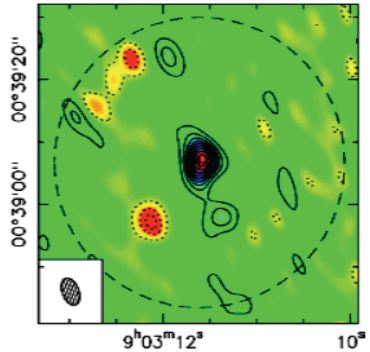
CREDITS: J.E. Aguirre, J. Bock, C.M. Bradford, L. Earle, J. Glenn, J.R. Kamenetzky, R.E. Lupu, P. Maloney, E. Murphy, H. Matsuhara, B. Naylor, H.T. Nguyen, K.S. Scott, J. Zmuidzinas

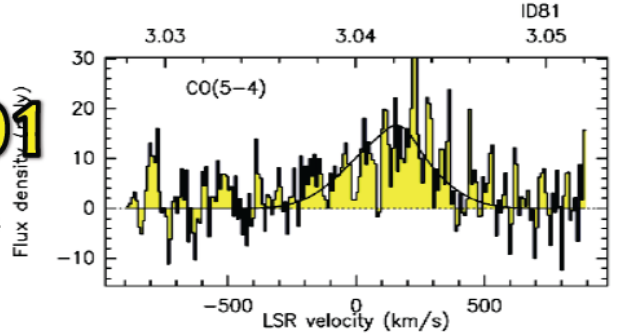
First Herschel CO Redshift: ID81

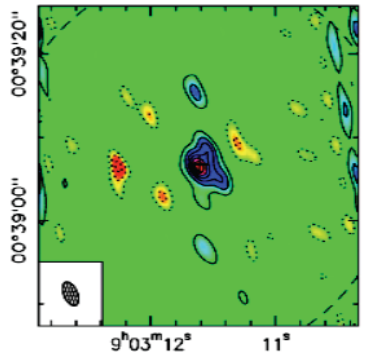
Redshift confirmed by **follow-ups** with the **PdB Interferometer** (March 23 2010) and **GBT/Zpectrometer** (March 25 2010)







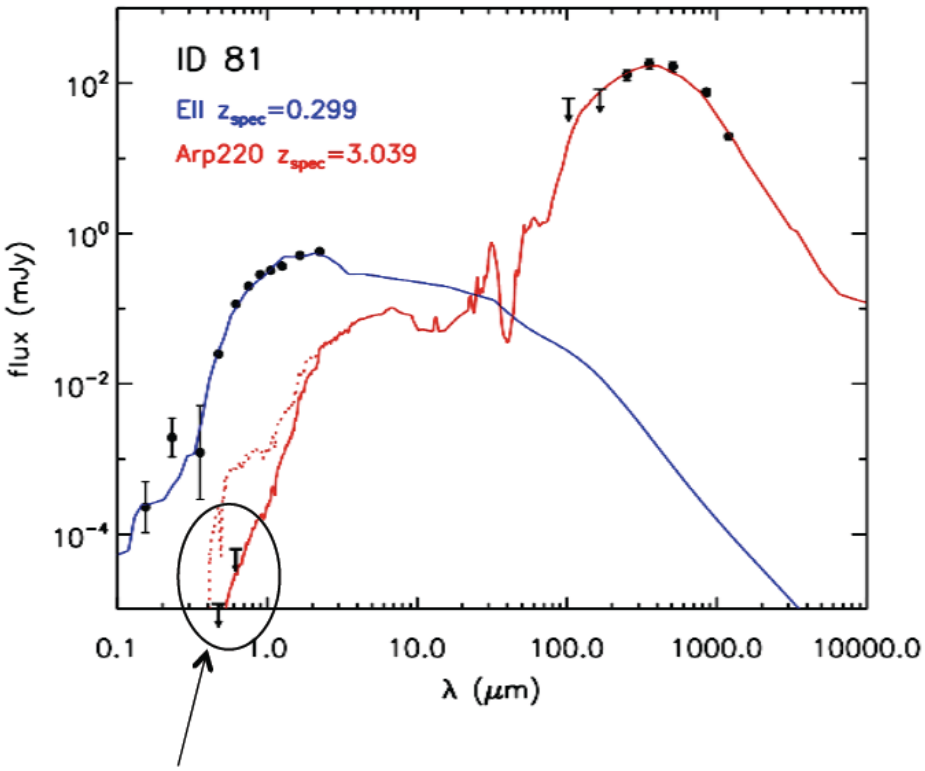




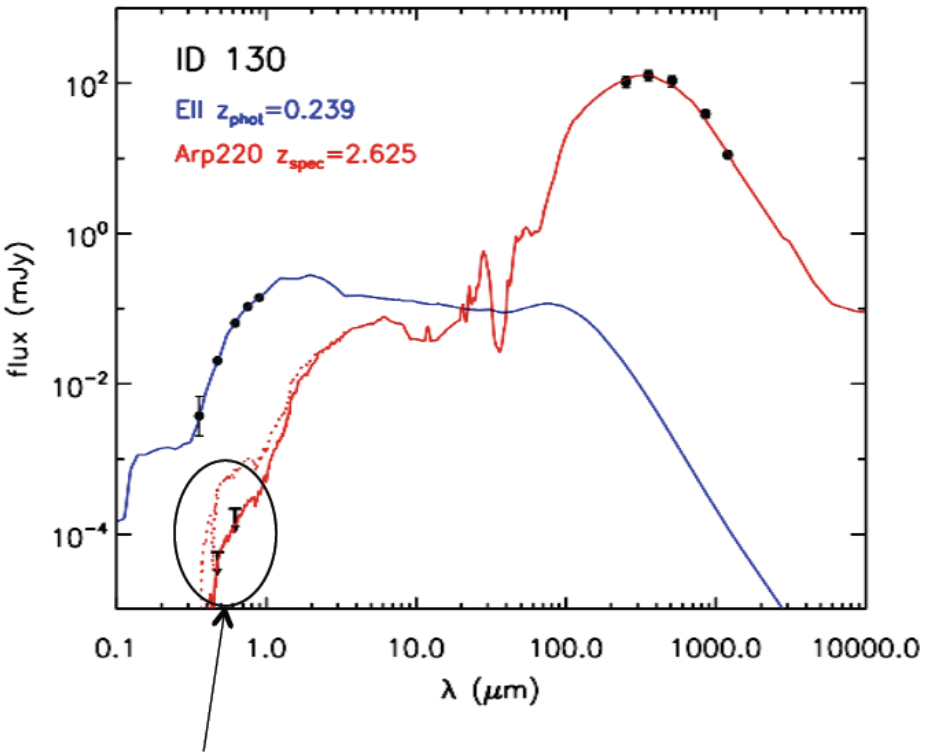
CREDITS: R. Neri, A. Omont, P. Cox, Beelen, Dannerbauer, F. Bertoldi

Atlas Gravitational Lenses

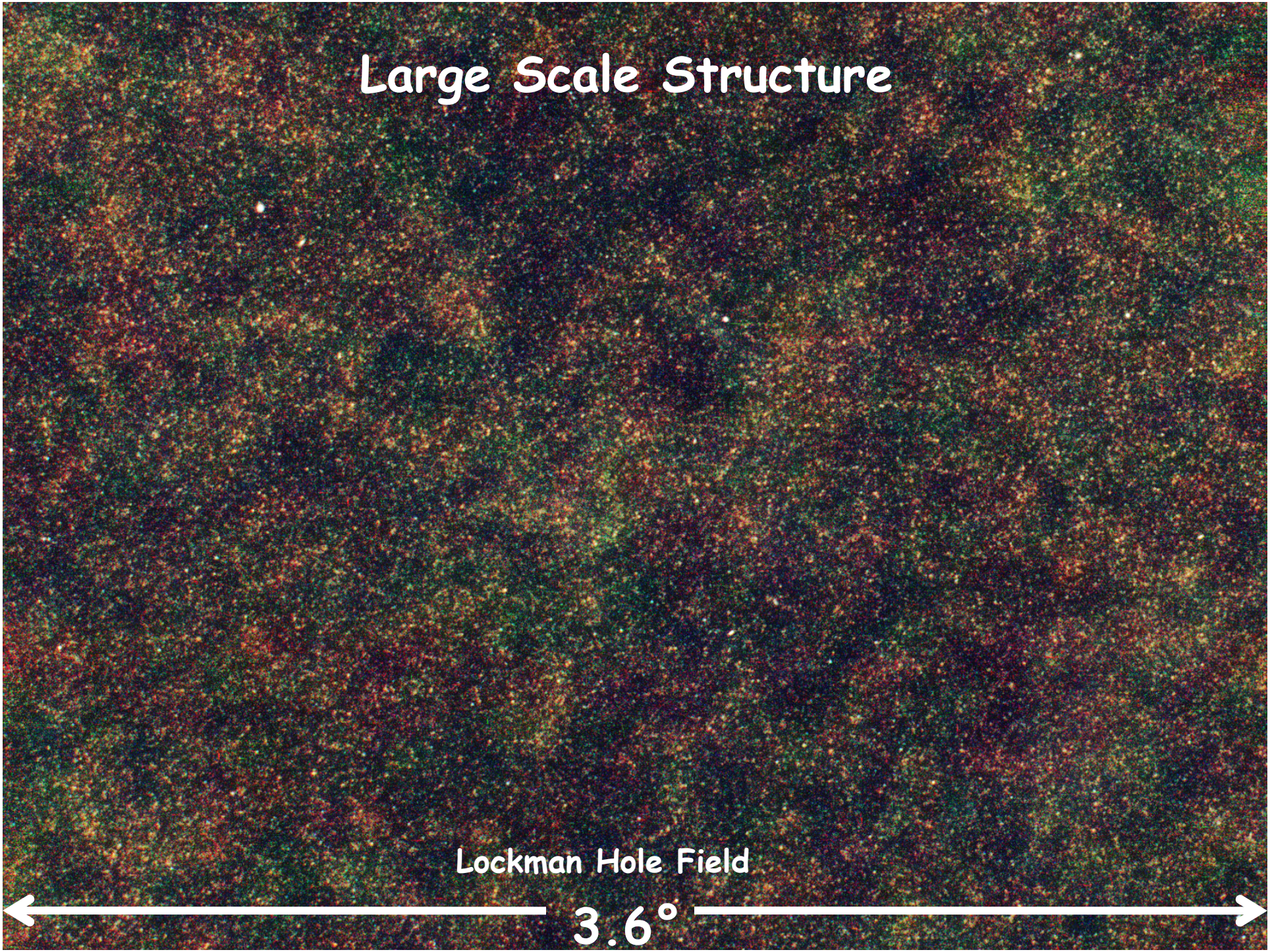
These systems are **missed in the optical !**



Keck 3σ upper limits

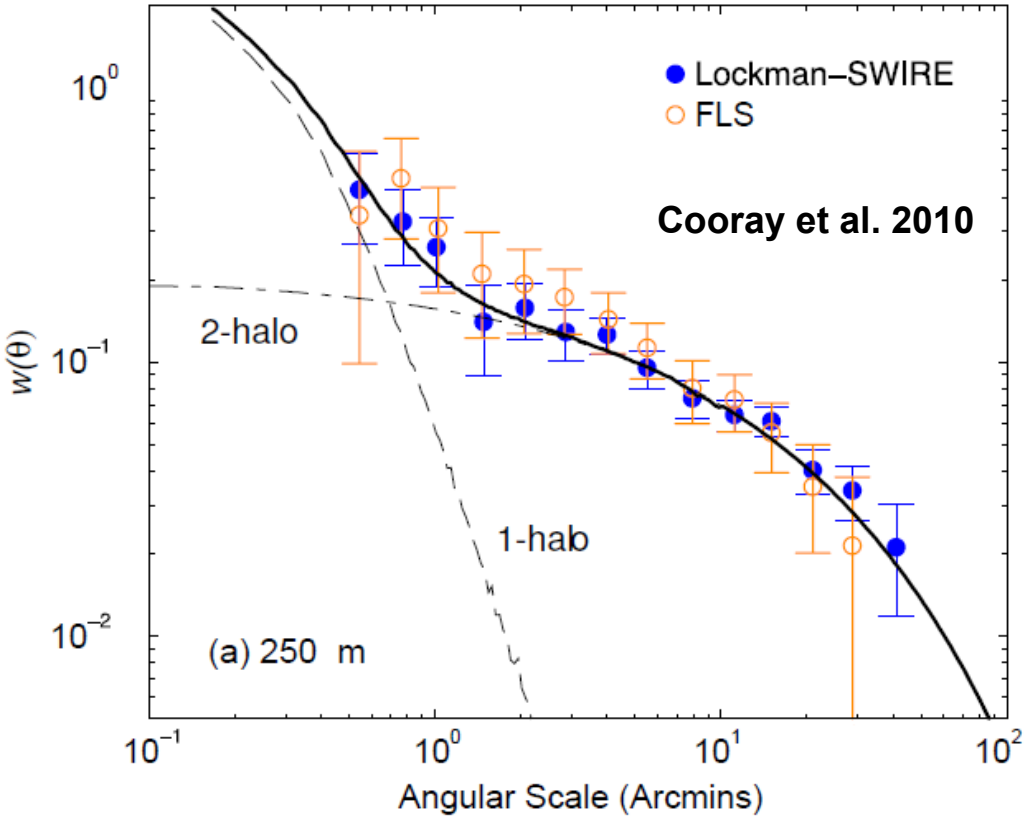


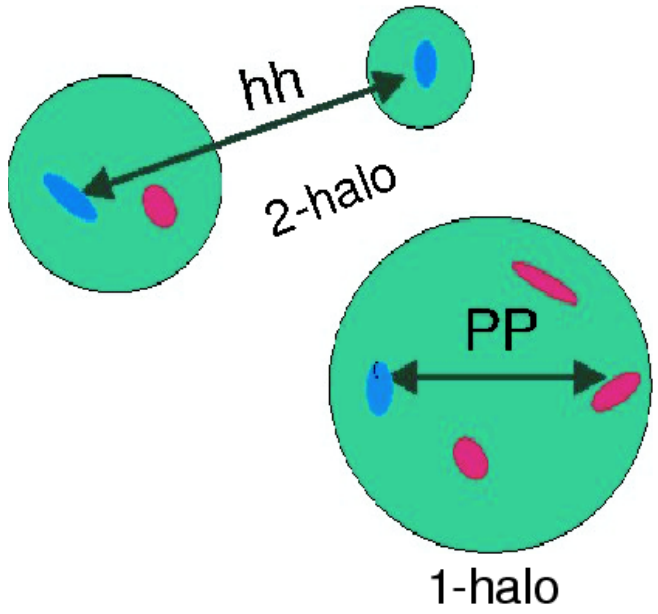
Keck 3σ upper limits


Large Scale Structure
Lockman Hole Field
3.6°

Large Scale Structure

Angular Correlation of Detected Galaxies

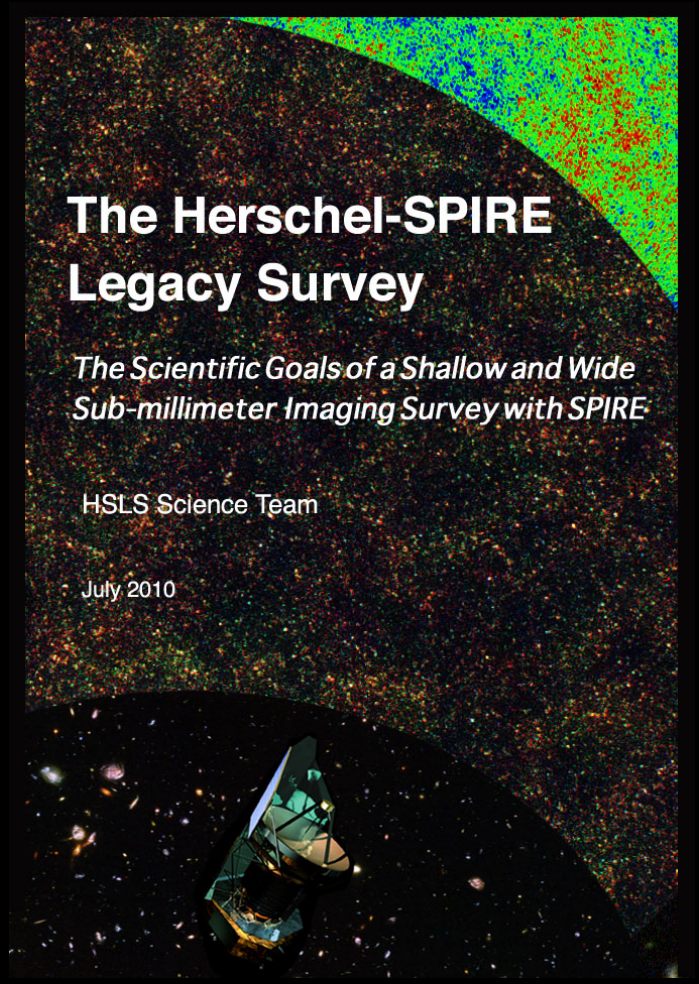




- Spatial clustering of (z~2) galaxies compared to halo model
- Halo needed to host a S_{250} > 30 mJy FIR galaxy: M = $10^{12.6}$ M_{solar}
- ~15% appear as satellites in more massive halos M ~ $10^{13.1}$ M_{solar}

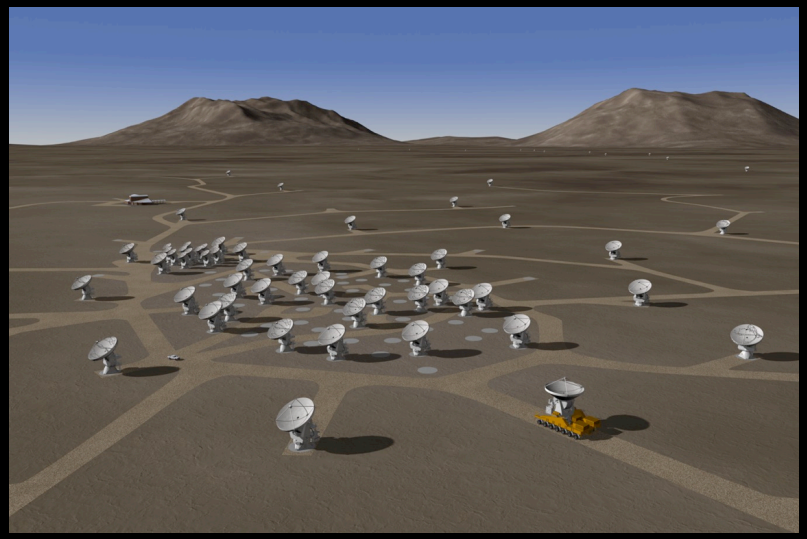
Herschel-SPIRE Legacy Survey (HSLS)

Map 4000 sq. degrees on the sky with SPIRE instrument in fast scan mode starting 2011.
780 hours to complete, single scans in SPIRE fast-mode (60"/sec)

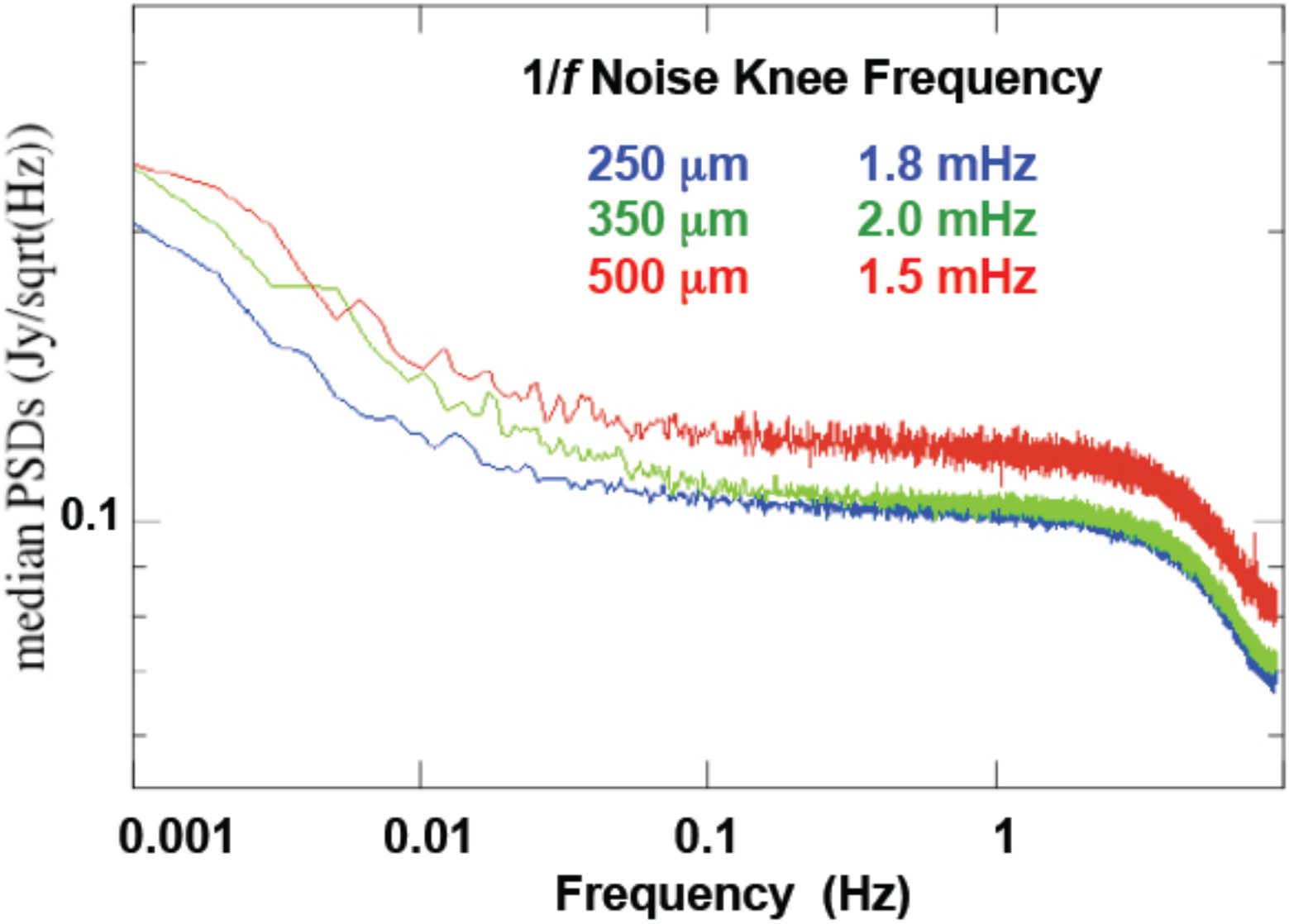


The HSLS will find 2.5 to 3 million dusty galaxies,
~1200 strongly lensed bright sources easily identified
~1.5 million at z~2, 10,000 at z>4. Follow-up targets for ALMA, SPICA etc.
a goldmine for cosmology!

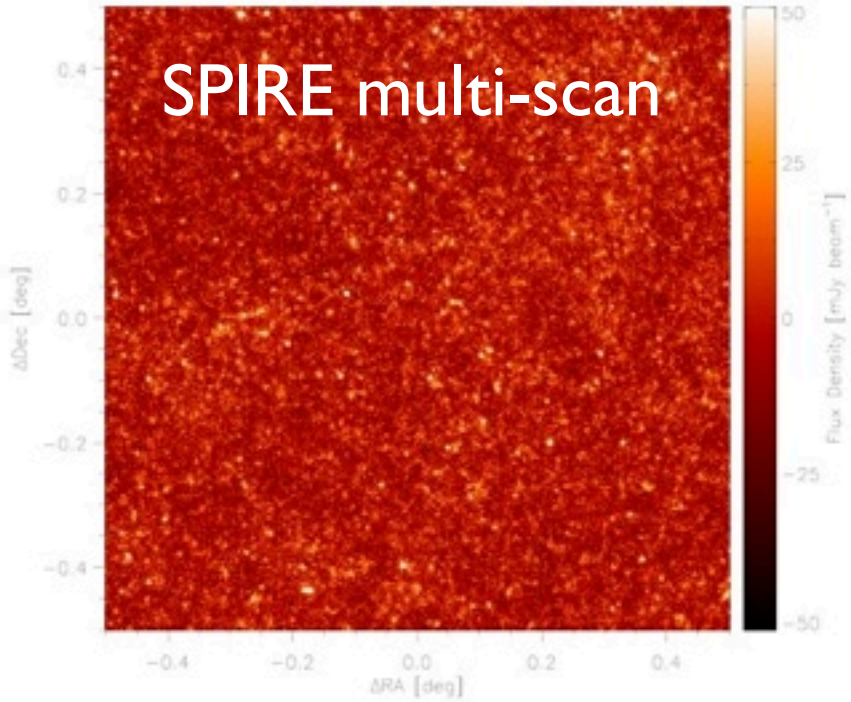
see the HSLS White Paper on the arxiv now; 250 team members covering all of CMB to Galactic communities.



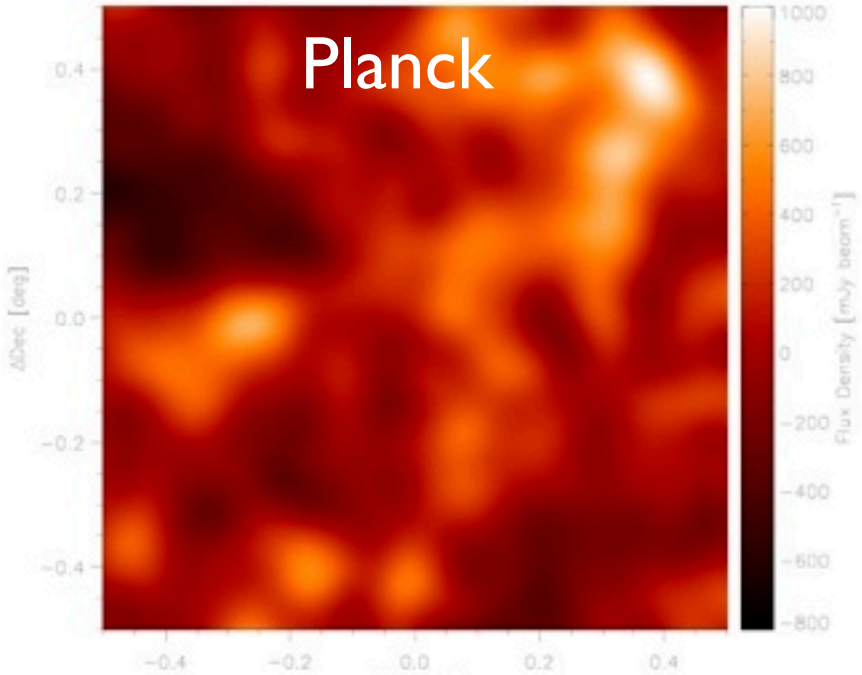
Scan Mapping with SPIRE

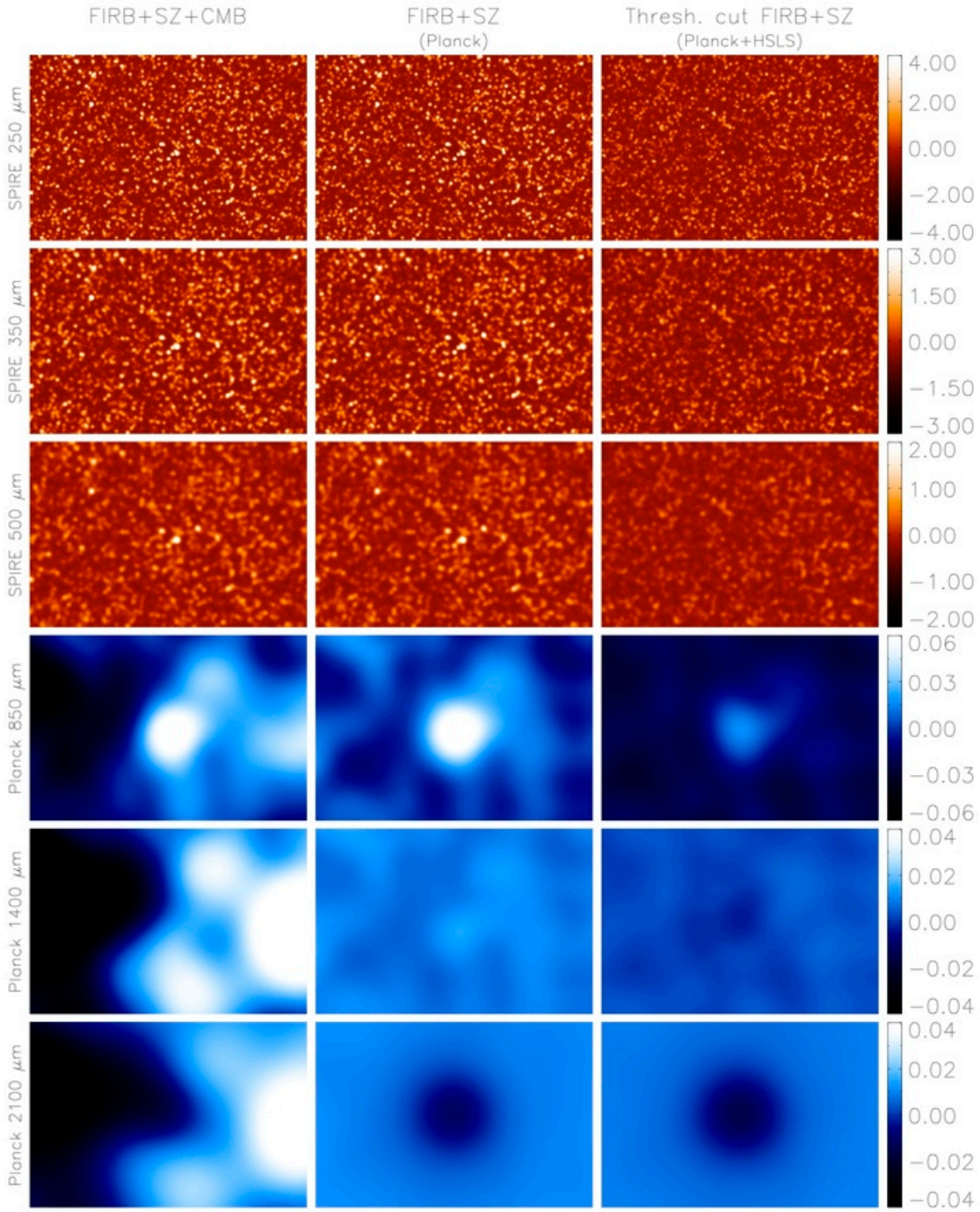


Low 1/f noise = high fidelity on all angular scales


SPIRE multi-scan
ΔDec [deg]
ΔRA [deg]
Flux Density [mJy beam⁻¹]


SPIRE single-scan
ΔDec [deg]
ΔRA [deg]
Flux Density [mJy beam⁻¹]


Planck
ΔDec [deg]
ΔRA [deg]
Flux Density [mJy beam⁻¹]



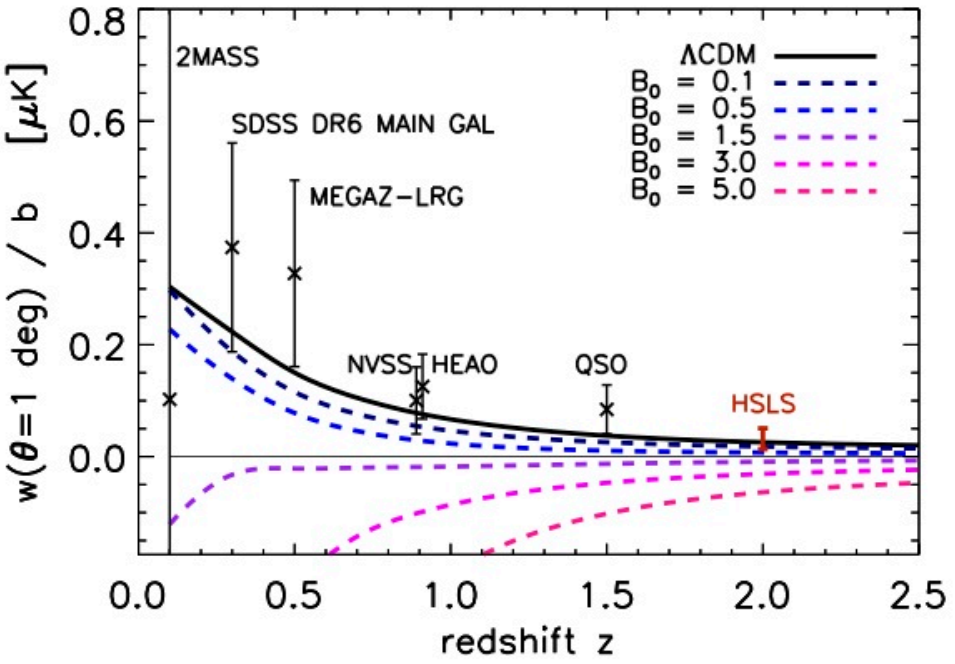
Cosmological Applications of HSLS sources and maps

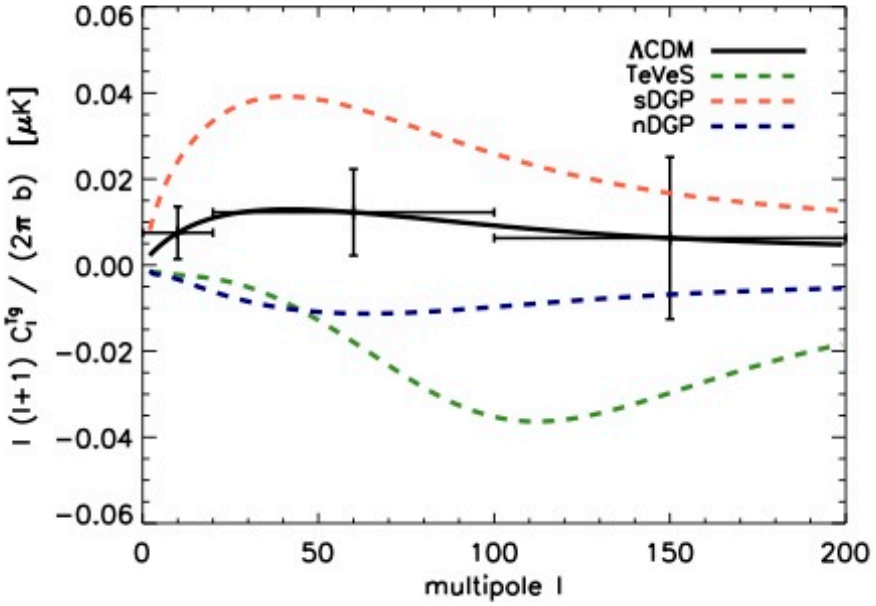
HSLS will "clean" Planck SZ clusters

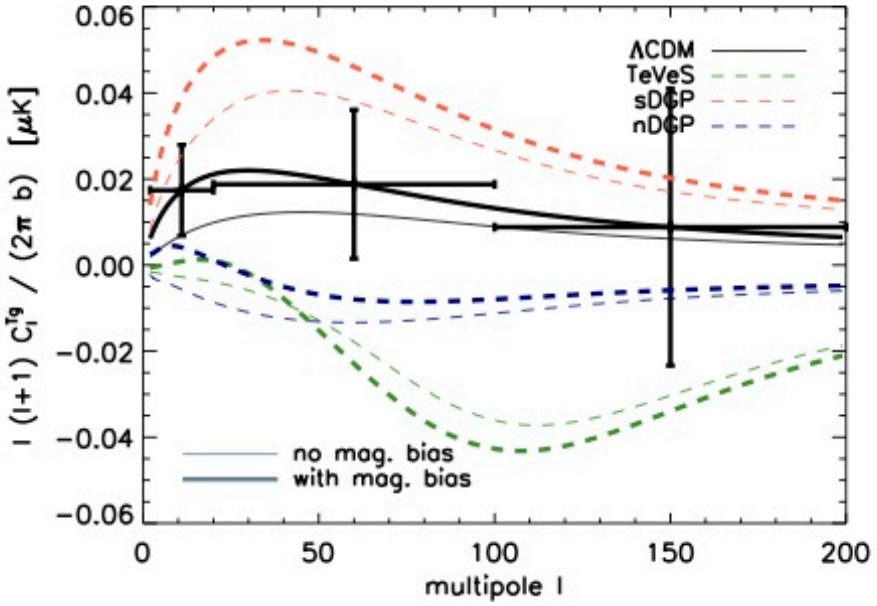
leading to peculiar velocities, gas temperature from relativistic corrections, more accurate cluster mass estimates.

z~2 ISW with Planck+HSLS

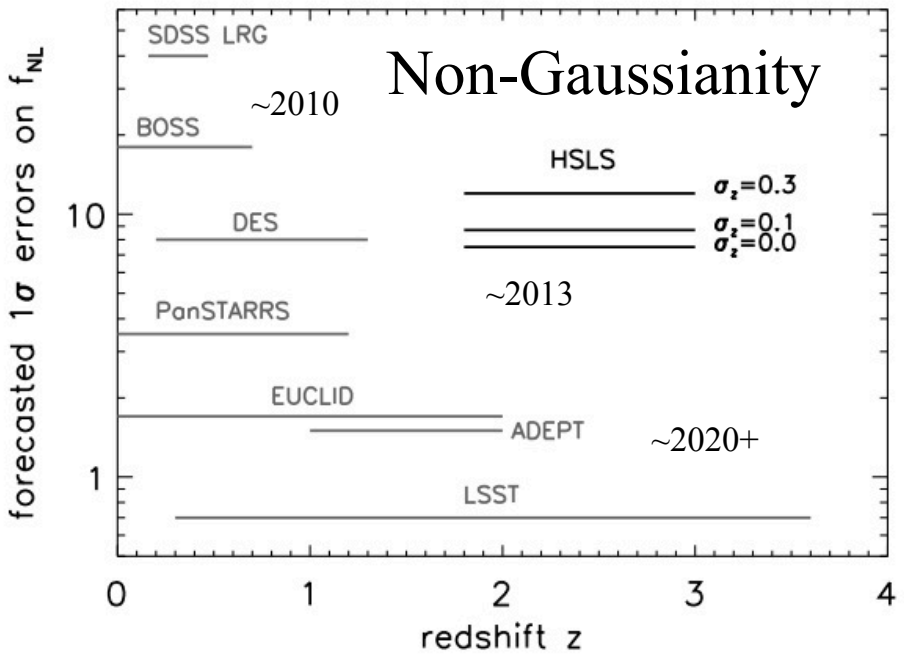
A strong probe of modified gravity theories for acceleration



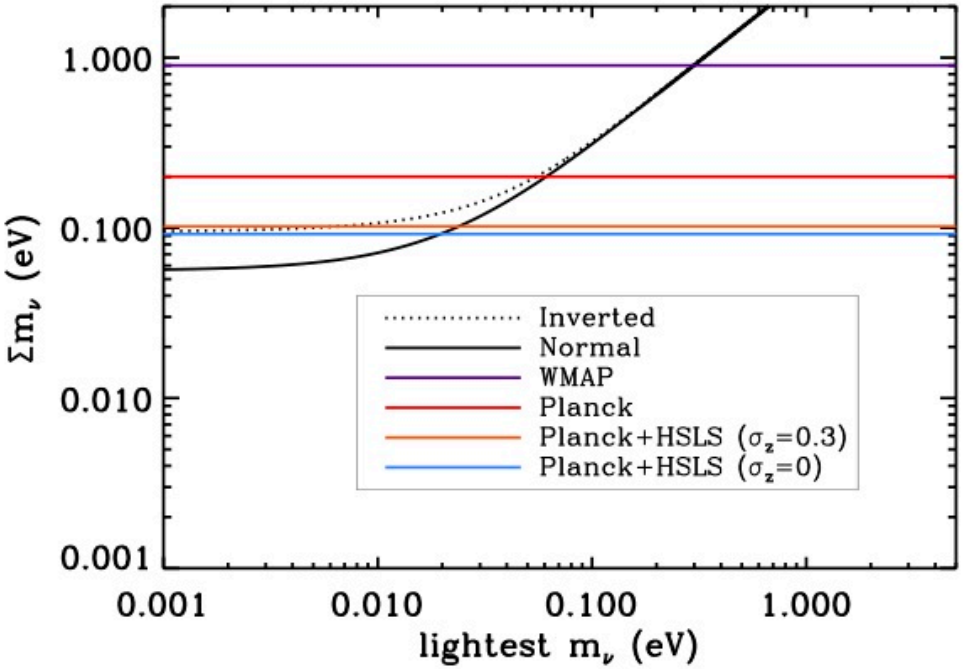


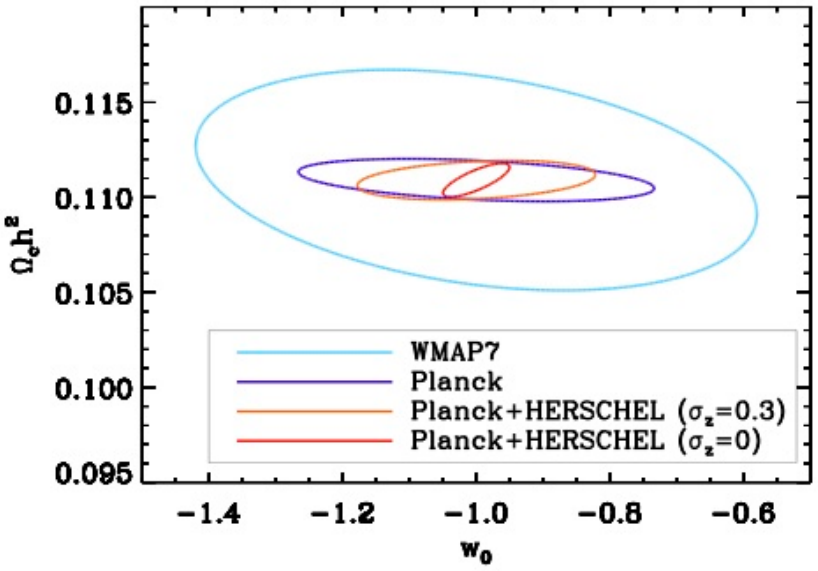


Cosmology with HSLS source clustering Planck CMB Lensing + HSLS

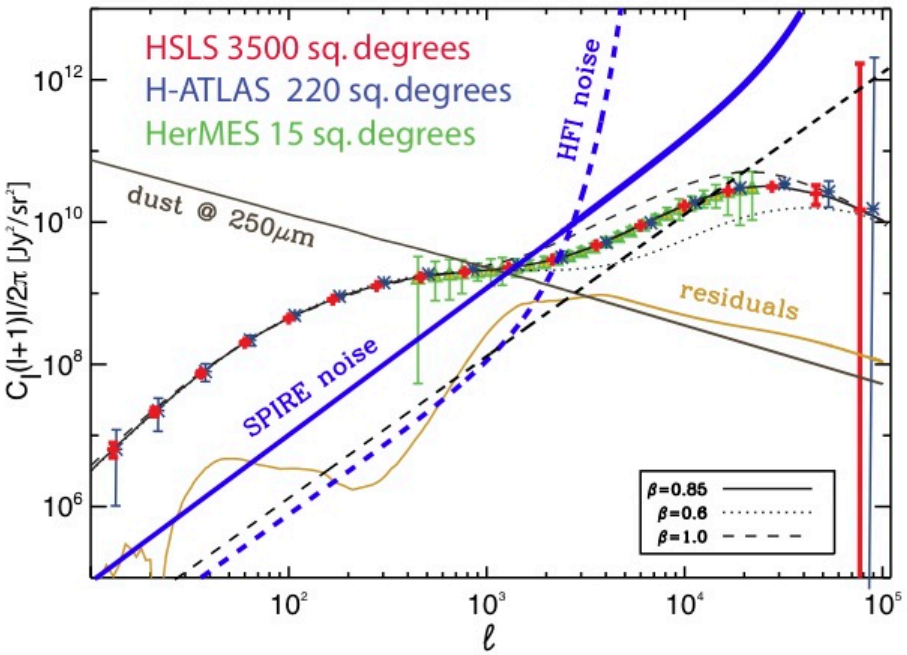


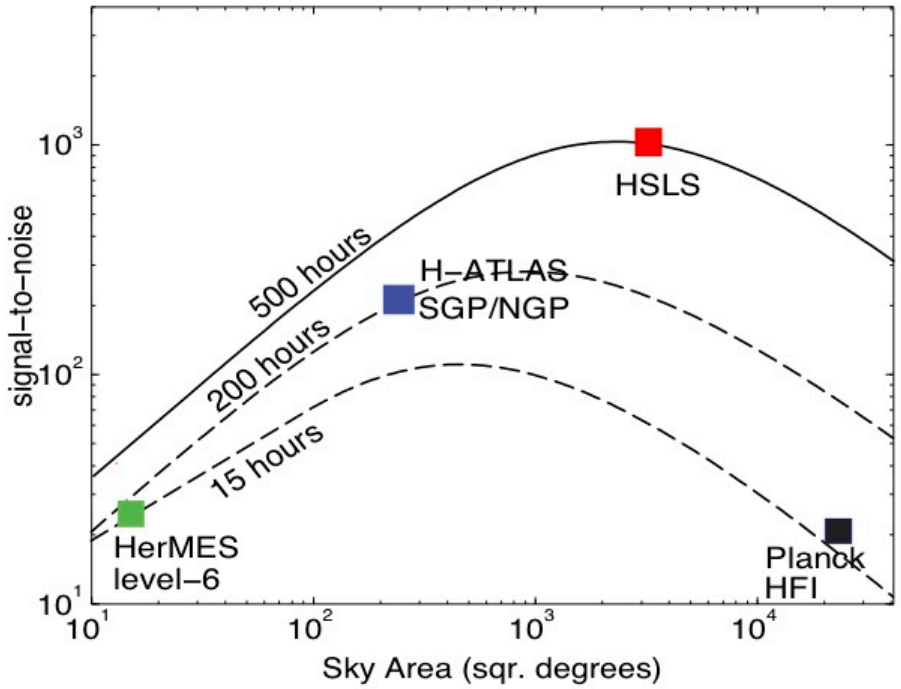
Neutrino masses

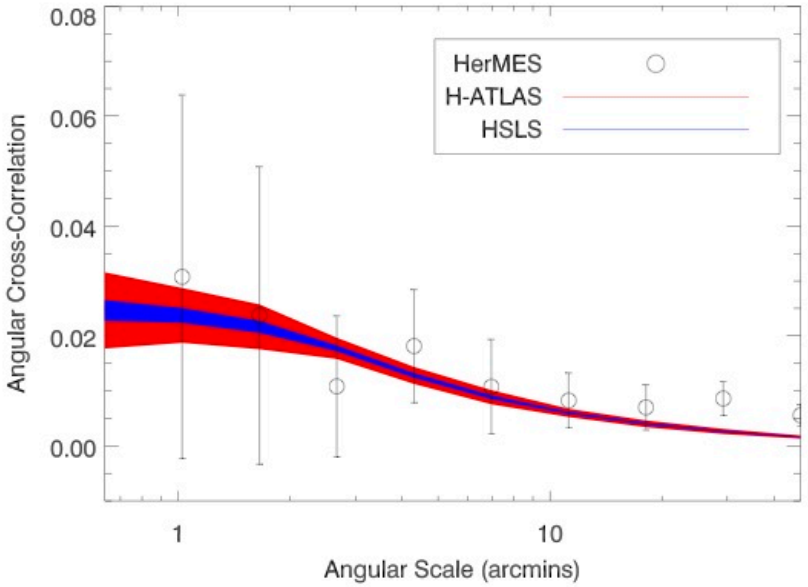




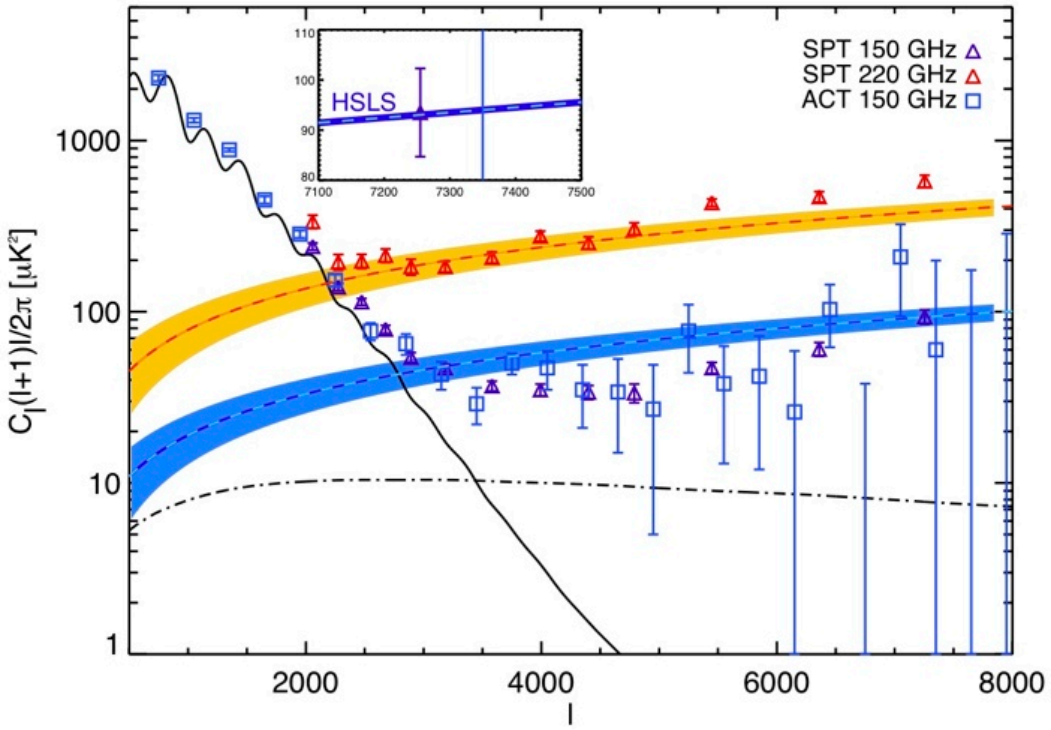
HSLS fluctuations and weak lensing magnification



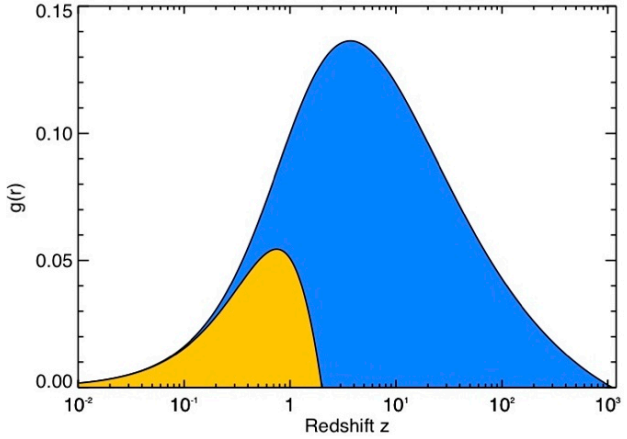


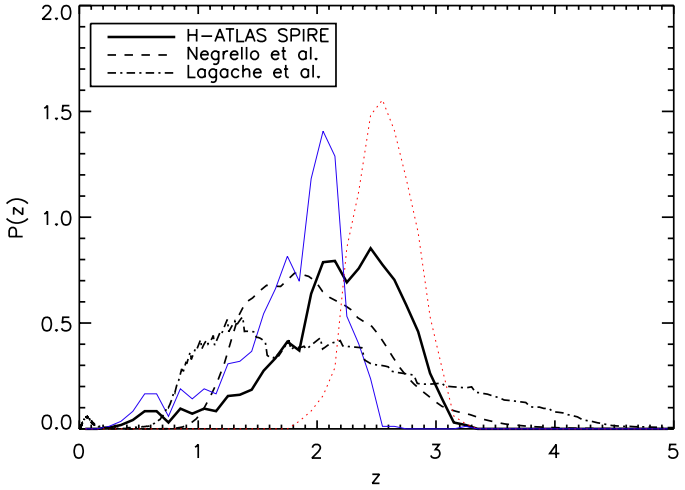


Relation to CMB experiments

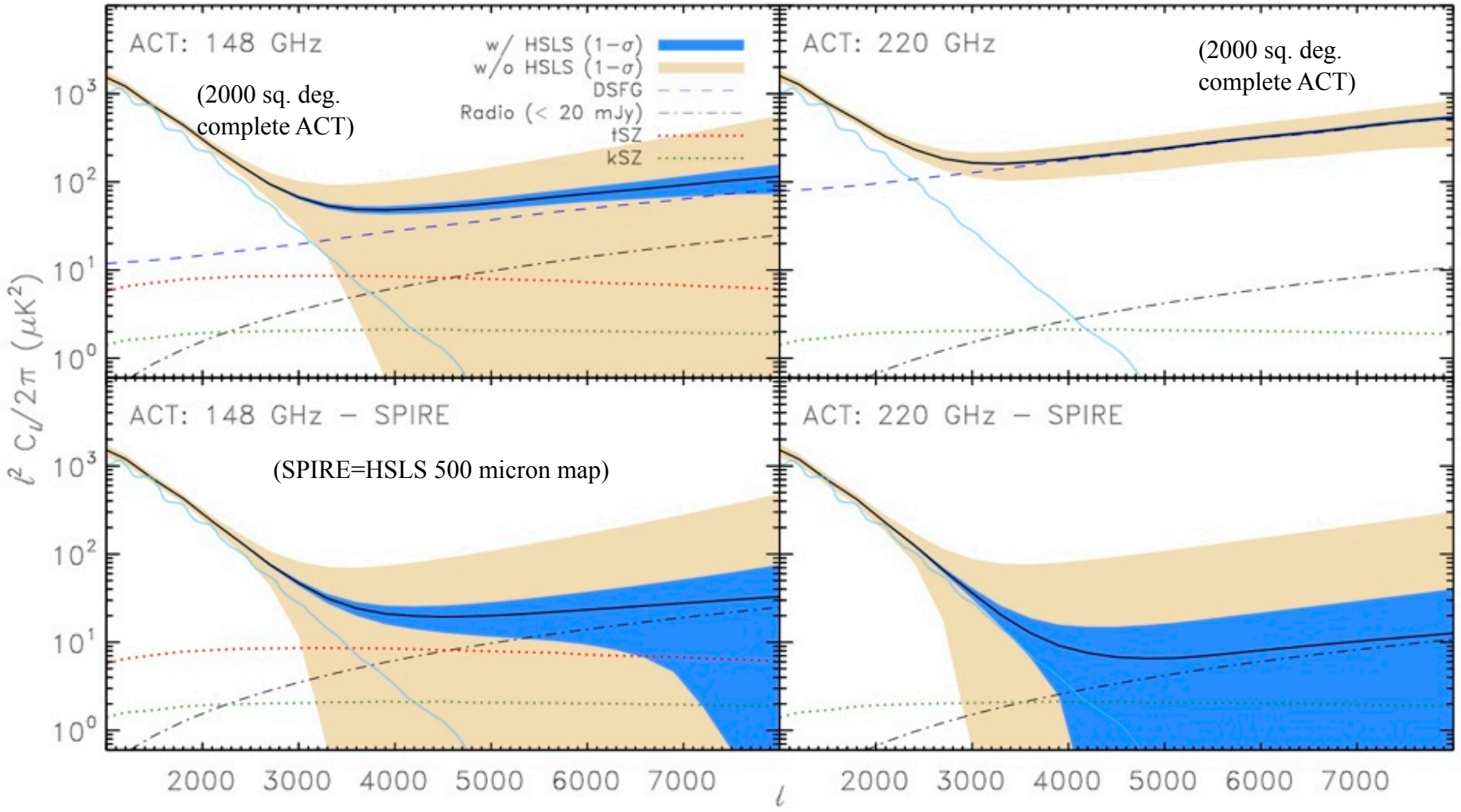


HSLS fluctuations (frequency scaled to 220 GHz) are consistent with SPT measurements.





HSLS source redshifts are well matched to CMB lensing kernel; ***HSLS will identify structures that lens CMB!***


ACT: 148 GHz
(2000 sq. deg. complete ACT)
w/ HSLS (1−σ)
w/o HSLS (1−σ)
DSFG
Radio (< 20 mJy)
tSZ
kSZ
ACT: 220 GHz
(2000 sq. deg. complete ACT)
ACT: 148 GHz − SPIRE
(SPIRE=HSLS 500 micron map)
ACT: 220 GHz − SPIRE
$\ell^2 C_\ell / 2\pi$ (μK^2)
10^0
10^1
10^2
10^3
2000 3000 4000 5000 6000 7000
ℓ

Exciting results already, many more to come!

- Special A&A journal issue on Herschel out
- Second wave of publications in preparation
- ESA First Results Symposium talks on line

open time deadline was yesterday 22 July

HSLS will bridge the gap between Planck and Herschel!