Unveiling the dusty Extragalactic Universe: Recent Results from HerMES and H-ATLAS

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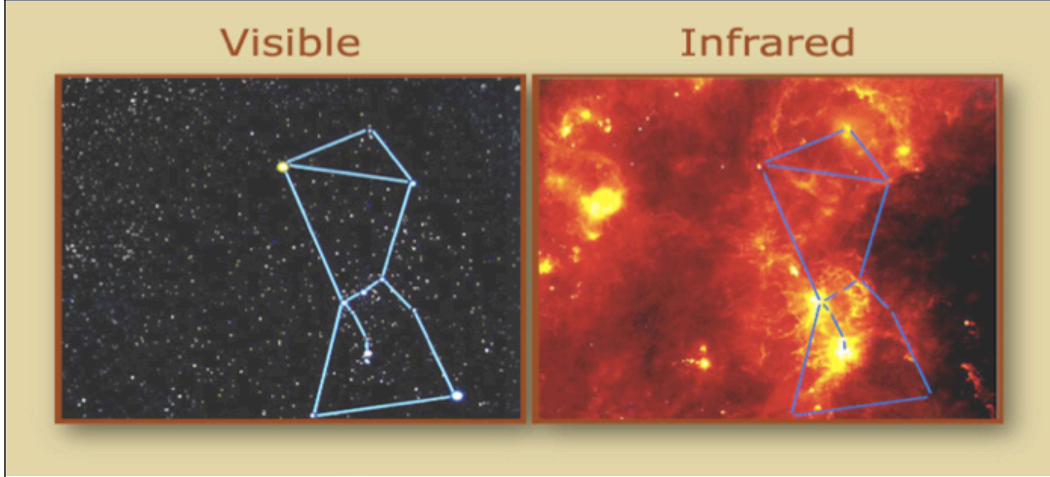
HERMES

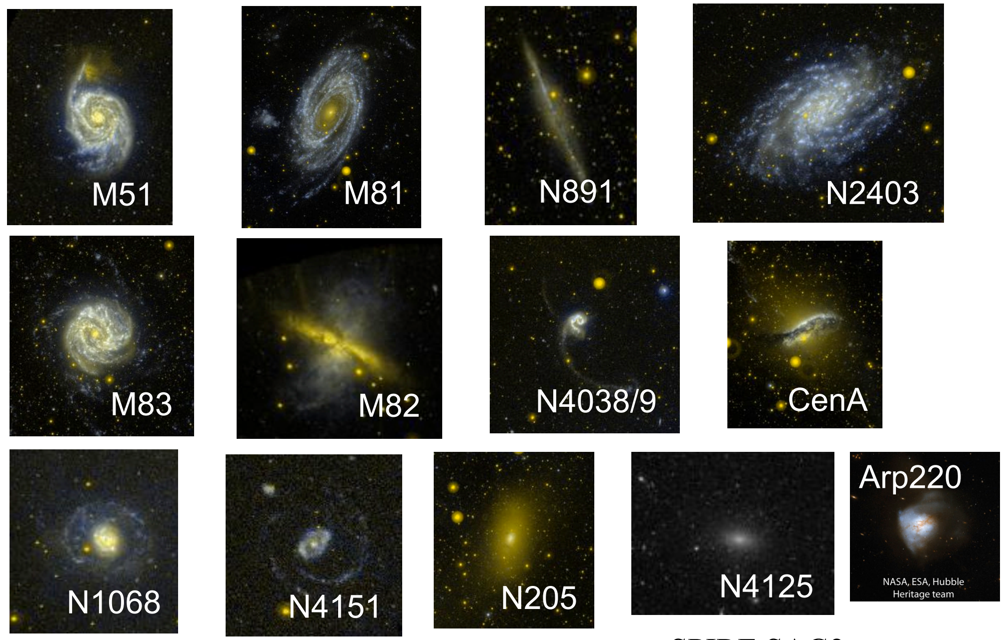
H-ATLAS

Infrared sky is active



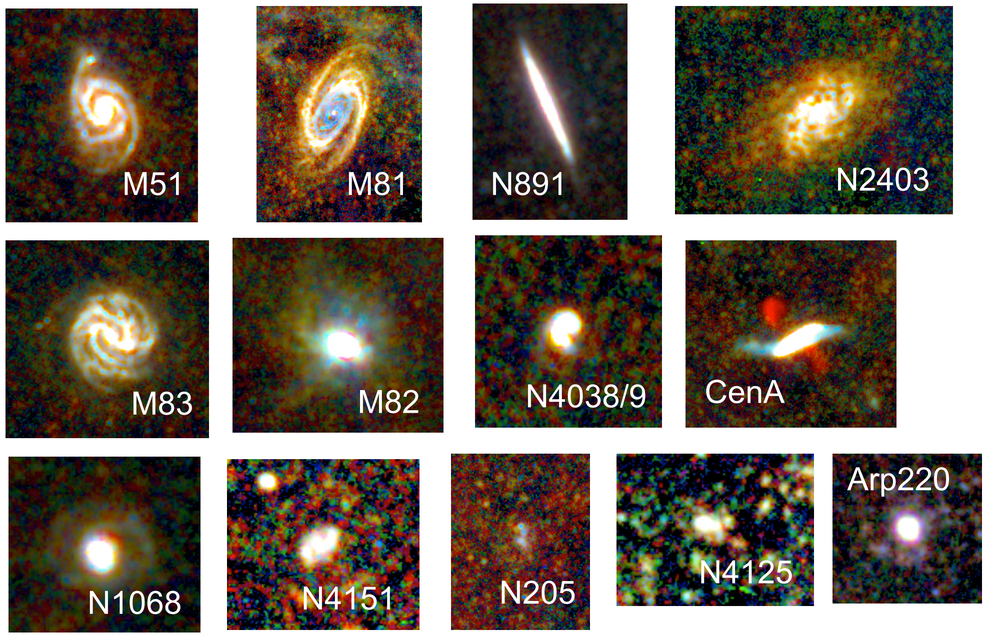
– **Herschel Opens up New Observational window for the first time**
– **55-672 μm – bridging the far-infrared & sub-millimeter bands**

GALEX images of the VNGS target objects

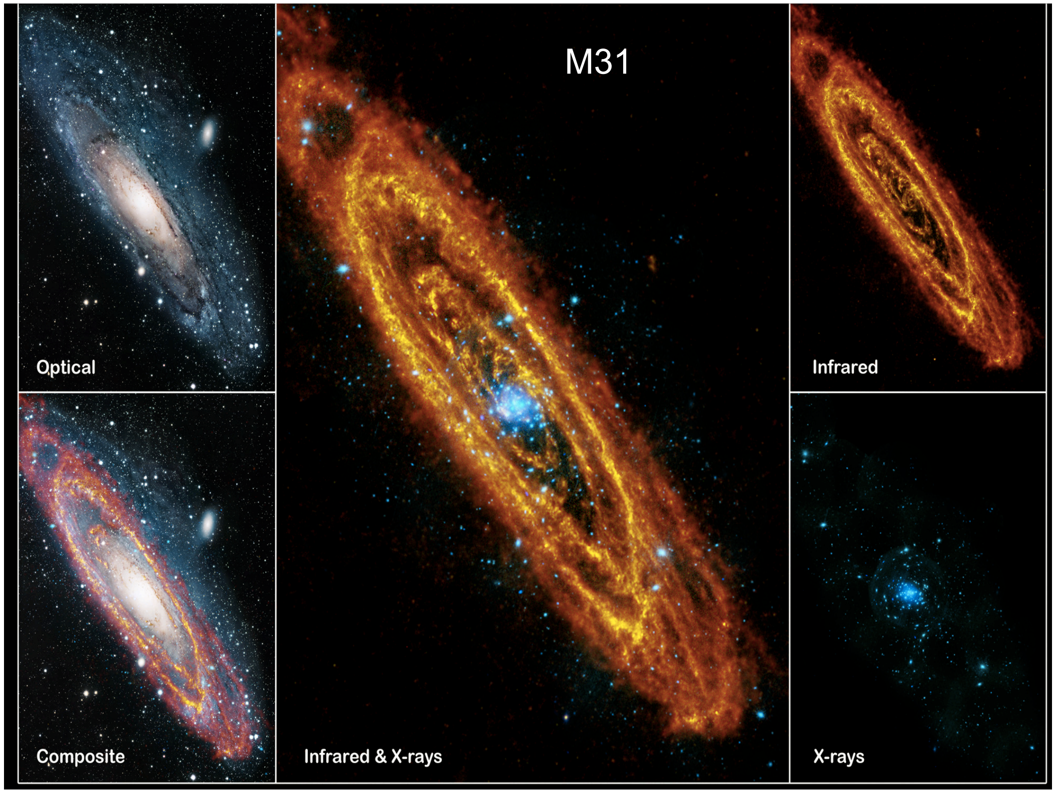


SPIRE SAG2

SPIRE images of the VNGS target objects



SPIRE SAG2


M31
Optical
Composite
Infrared & X-rays
Infrared
X-rays

SPIRE

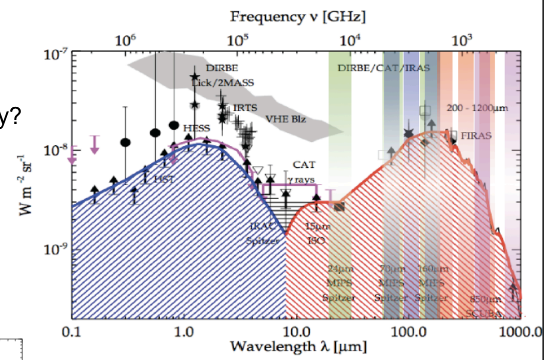
HERMES

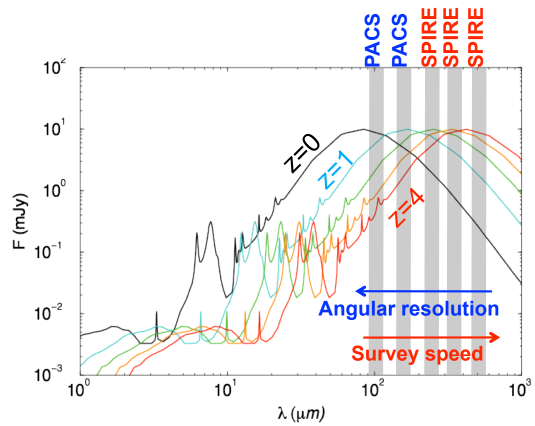
Bruno Altieri, Alex Amblard, Vinod Arumugam, Robbie Auld, Herve Aussel, Tom Babbedge, Alexandre Beelen, Matthieu Bethermin, Andrew Blain, Jamie Bock, Alessandro Boselli, Carrie Bridge, Drew Brisbin, Veronique Buat, Denis Burgarella, Nieves Castro-Rodriguez, Antonio Cava, Pierre Chanial, Ed Chapin, Scott Chapman, Michele Cirasuolo, Dave Celments, 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 Vigrouz, Lingyu Wang, Rupert Ward, Don Wiebe, Gillian Wright, Kevin Xu, and Mike Zemcov, + *Consultants and Working Members*

Faculty and Researchers, Postdocs, Students

HerMES Science Motivation

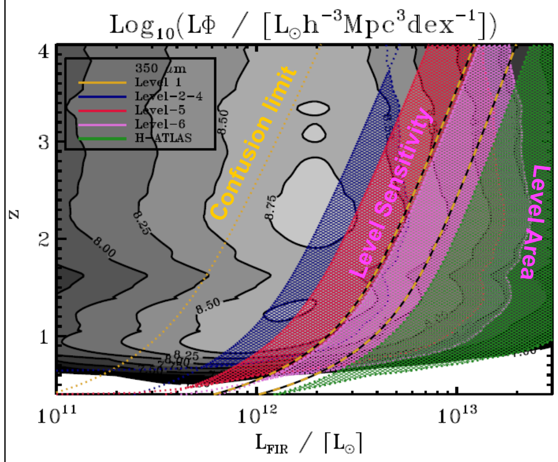
What is the history of Far-IR galaxies?
- How do they assemble and evolve over time?
- Where have luminous FIR systems gone today?
- How do FIR galaxies relate to dark matter?
- What is the role of dust in star formation?
- What is the connection between dusty star formation and AGNs?

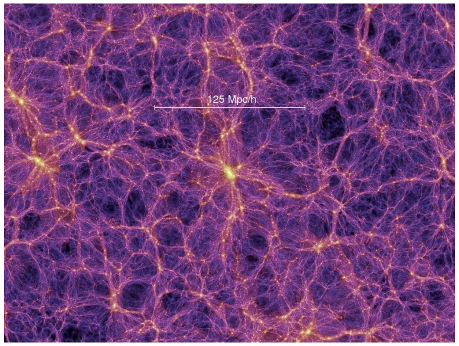




Herschel Extragalactic Surveys
- Observe at SED peak
- Bolometric far-IR luminosities
- Large and uniform samples

HerMES Survey Design





> 75 galaxies per $\Delta\log(L)*\Delta z = 0.1$ bin

Cover sufficient area to see large-scale structure and avoid sample variance

Lagache 2003 galaxy model

Oliver et al. 2011

HerMES = SPIRE GT Program

Spectral and Photometric Imaging Receiver

Photometer

- 250, 350, 500 μm (simultaneous)
- 4 x 8 arcminute field of view
- Diffraction limited beams (18, 25, 36")

Fast scan mapping at long wavelengths

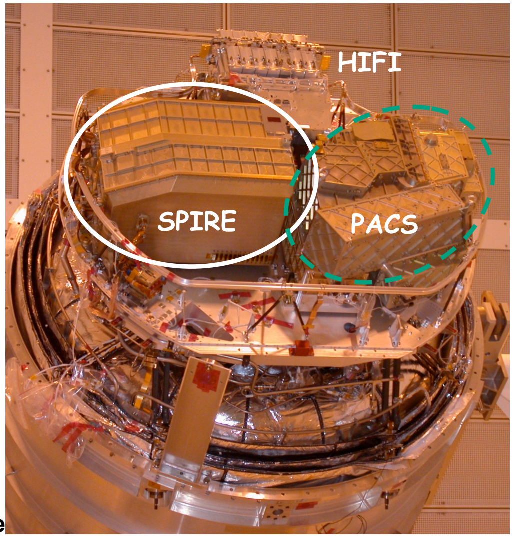
Imaging FTS

- 200 - 670 μm
- 2.6 arcminute field of view
- $\Delta\nu$ = 1.2 GHz high resolution mode
- $\Delta\nu$ = 25 GHz low resolution mode

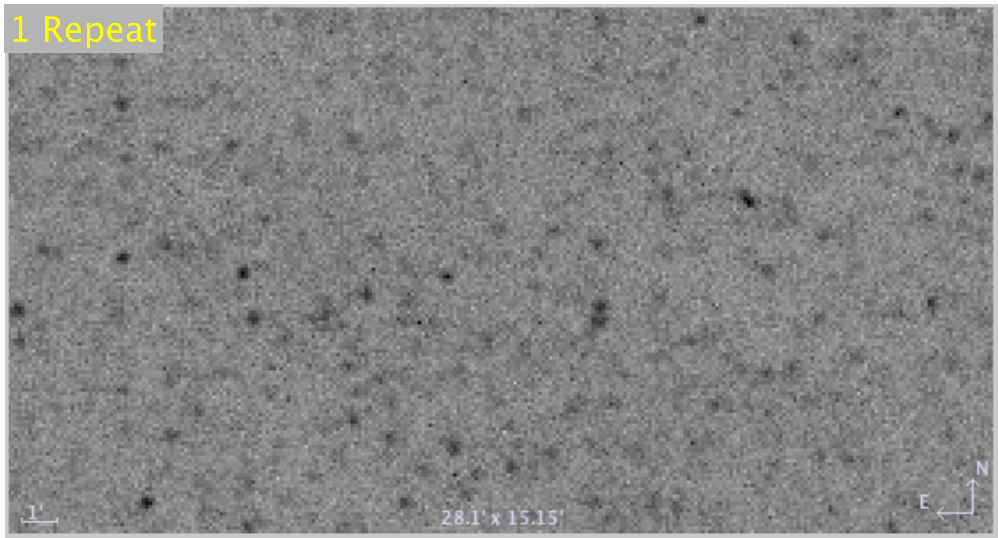
Wide instantaneous bandwidth, map making

Design Principles

- Sensitivity limited by thermal emission from the telescope
- ^{3}He cooled detector arrays (0.3 K)
- Feedhorn-coupled spider-web bolometers
- Minimal use of mechanisms
  Beam steering mirror; FTS mirror drive
- Optimized for scan-mapped surveys

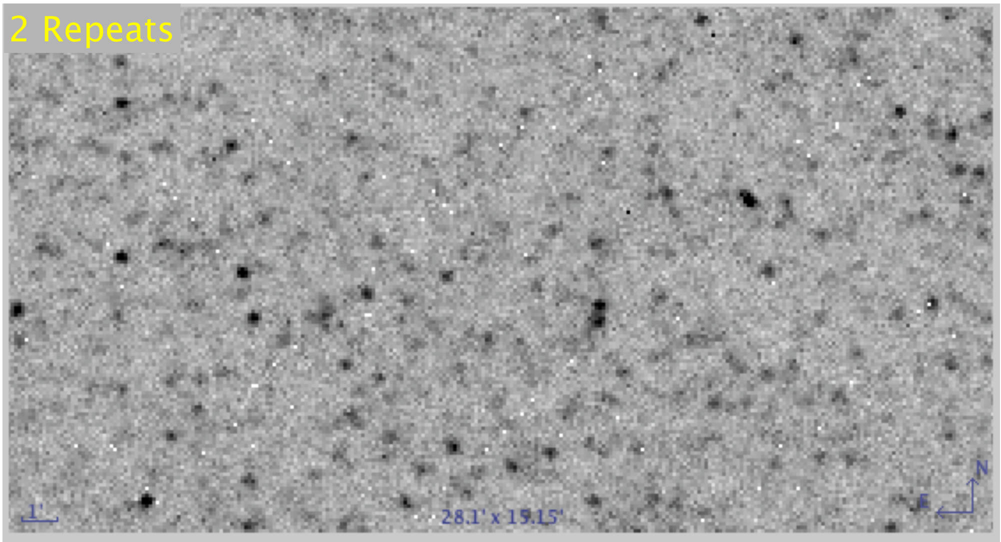


Mapping to the Confusion Limit



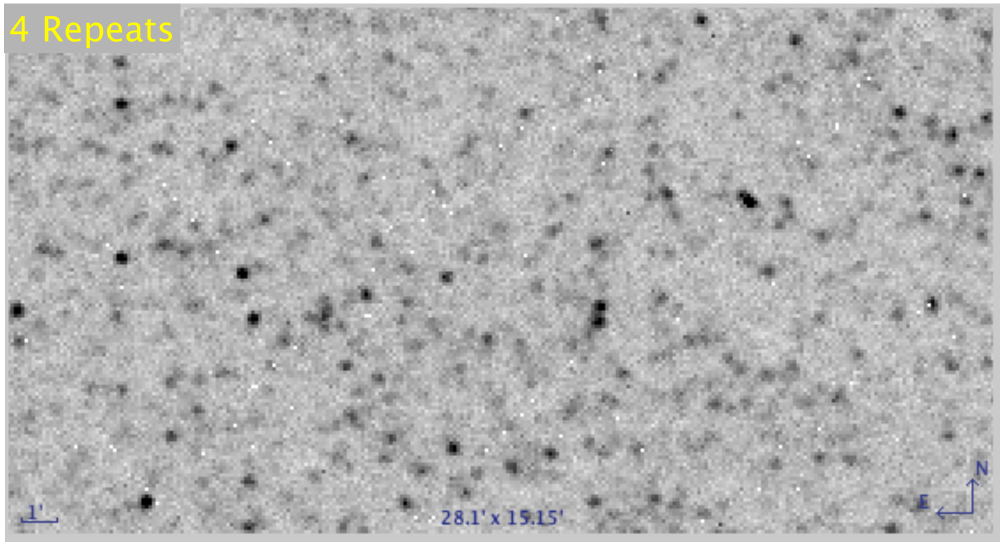
0.7 h for 1 sq. deg

Mapping to the Confusion Limit



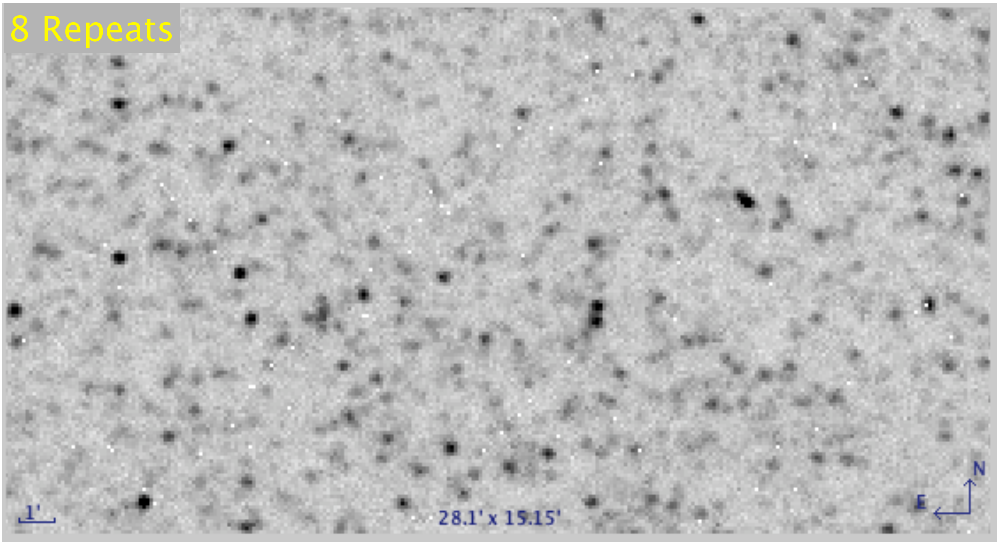
1.5 h for 1 sq. deg

Mapping to the Confusion Limit



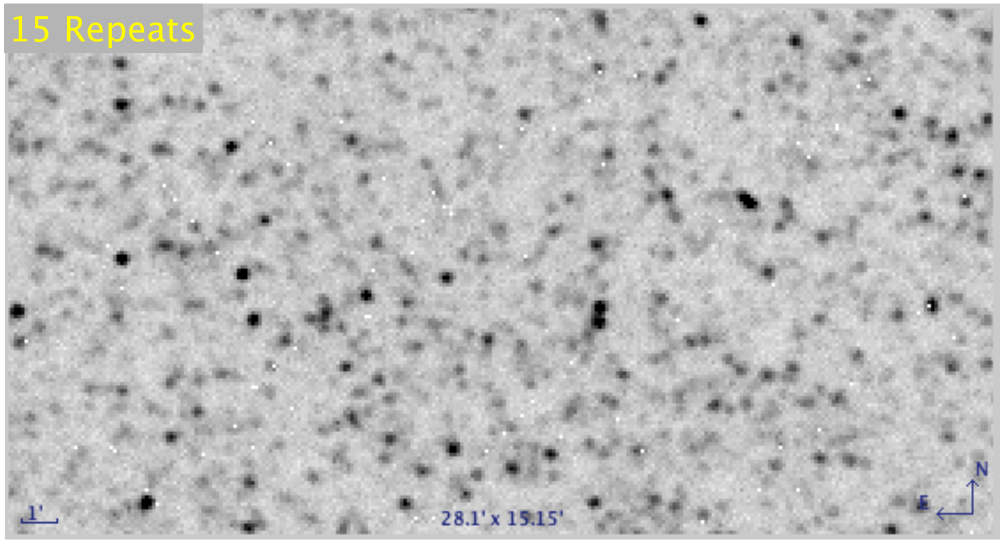
3 h for 1 sq. deg

Mapping to the Confusion Limit



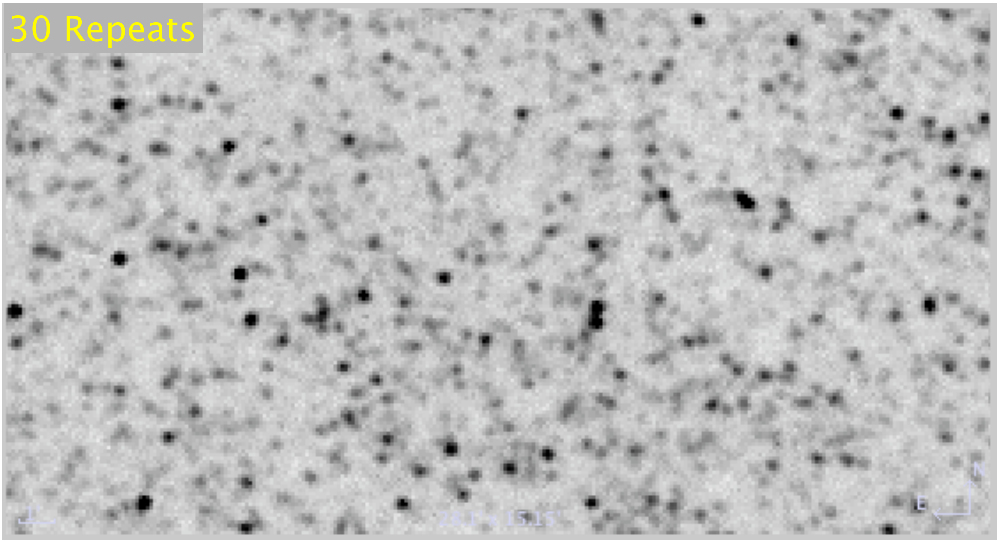
6 h for 1 sq. deg

Mapping to the Confusion Limit



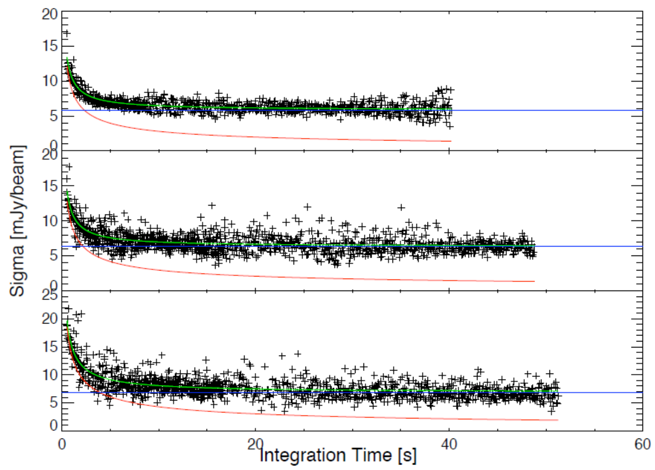
11 h for 1 sq. deg

Mapping to the Confusion Limit



22 h for 1 sq. deg

Mapping to the Confusion Limit



Band	Conf. (1σ*)	T/sq. deg
250 um	5.8	2.8 h
350 um	6.3	1.4 h
500 um	6.8	2.4 h

*after an iterative 5σ clip

Nguyen et al. 2010

SPIRE In-Flight Performance

Pre-launch (HSpot) estimates (instrument noise)

- Numbers referred to point source detection in a map in the absence of confusion noise
- For (250, 350, 500 μm)
  - 1-σ sensitivity for one scan repeat: (10, 13, 11) mJy/beam

Achieved instrument noise

- Standard map pixel sizes (6, 10, 14)”
  - 1-σ sensitivity for one 30”/s repeat: (9.0, 7.5, 10.8) mJy/beam

Nguyen et al. 2010

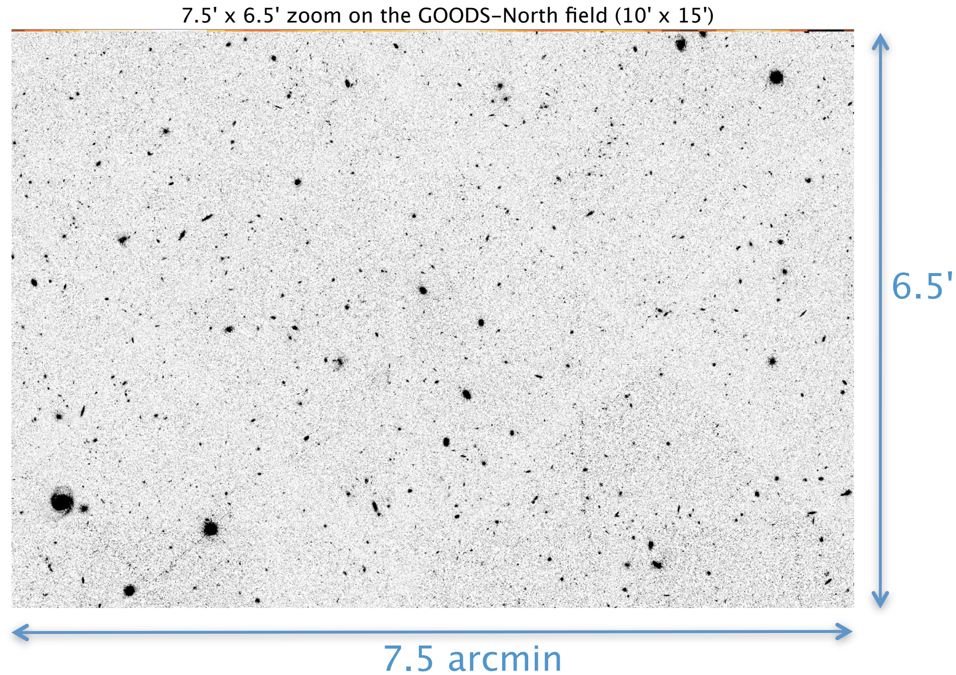
Extragalactic confusion levels

- Measured 1-σ confusion noise for (250, 350, 500 μm): (5.8, 6.3, 6.8) mJy/beam for (6, 10, 14)” map pixels

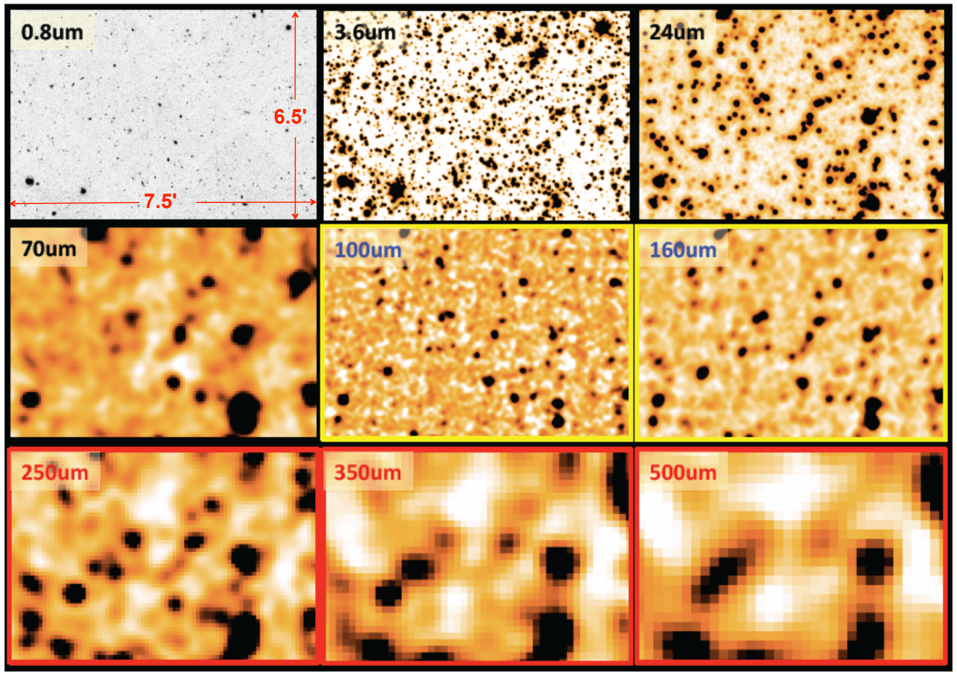
SPIRE instrument noise = confusion noise in < 2 repeats

The power of multi-wavelength imaging against confusion

500 350 250 160 100 24 3.6 0.8



The Confusion Challenge



D. Elbaz

Three Ways to Deal with Confusion

Herschel Source Photometry

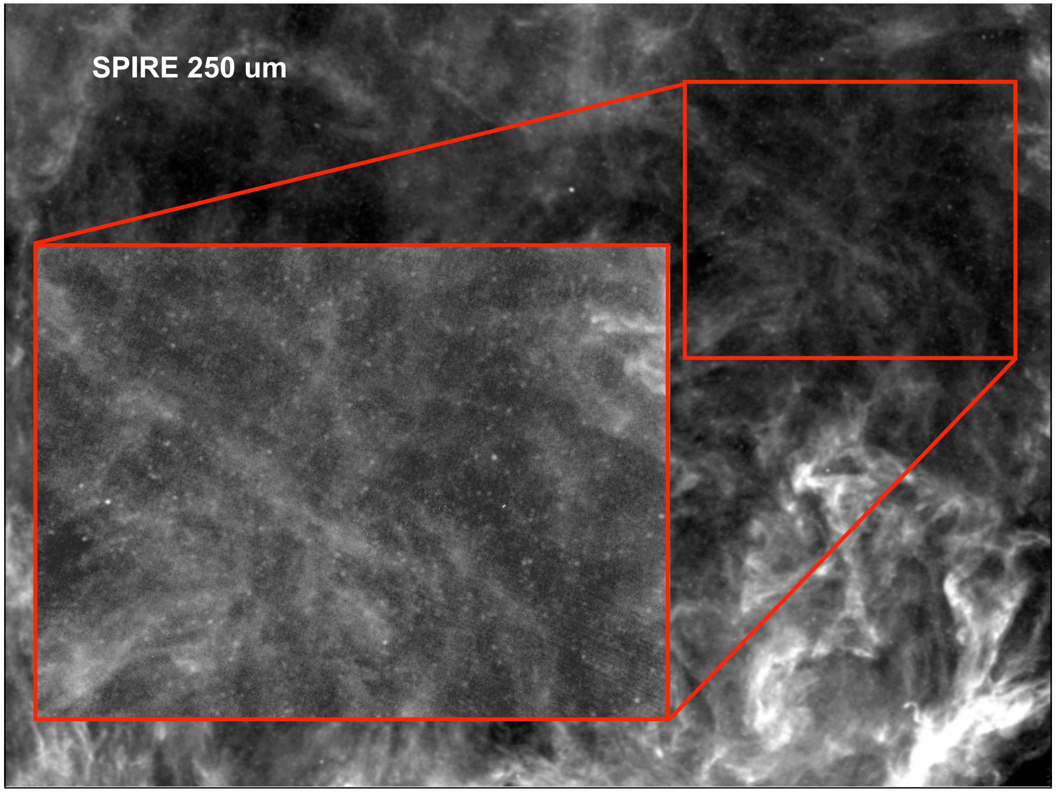
- Need to be careful about bias and source blending
- Blind follow-up in large beam is laborious (~SCUBA)
- However these are the most interesting source populations!

Pre-Existing Source Catalogs

- Assign Herschel flux of known ancillary source
- Reliable to within confusion noise
- Follows bias inherent in finder catalog

Map-Based Analysis

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

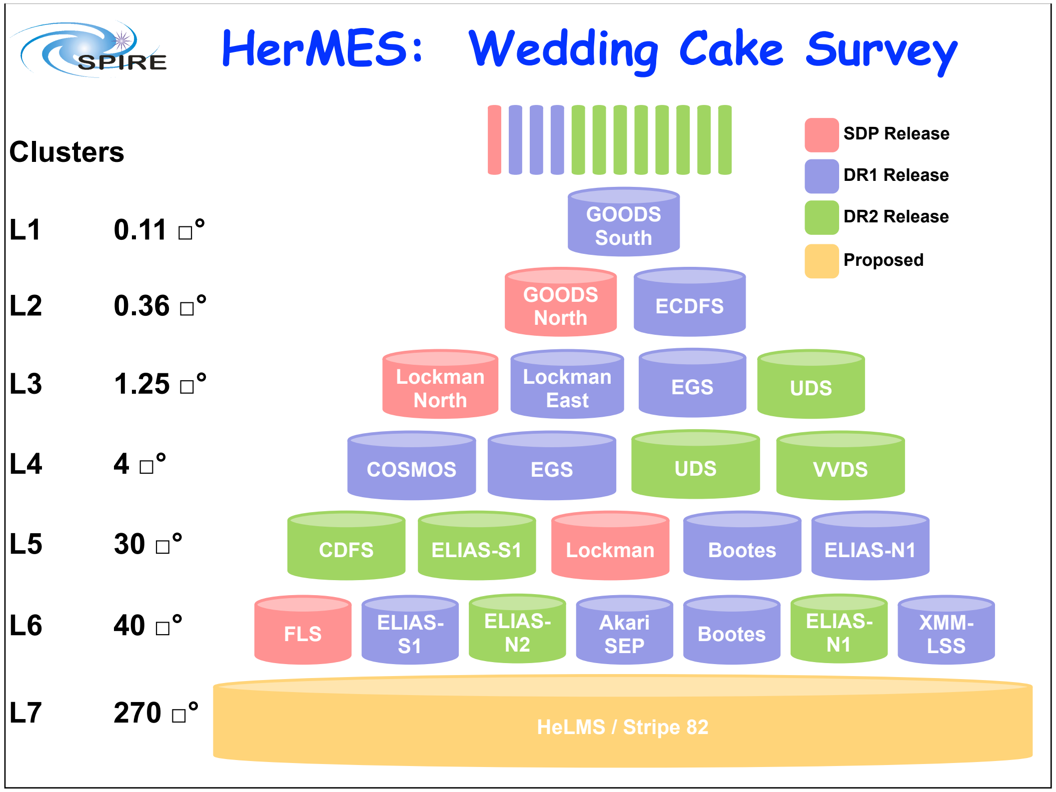

SPIRE 250 um

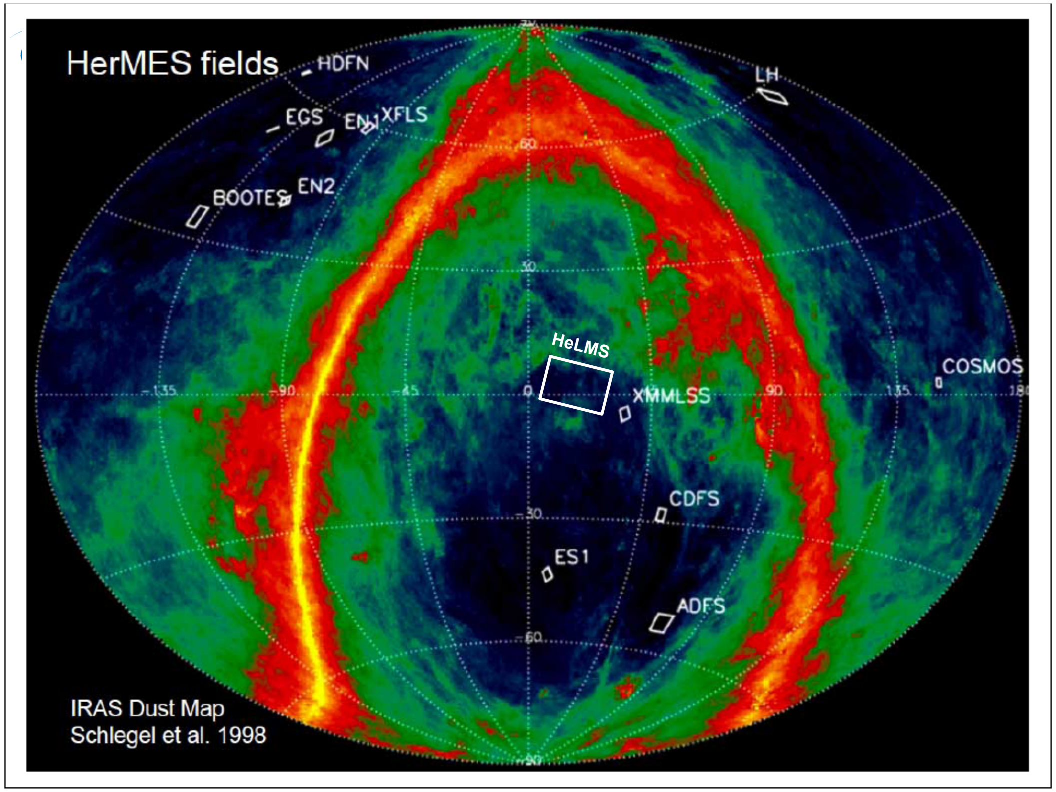
HerMES Survey Design Principles

Wedding Cake Design
- Probe a wide range of the luminosity function
- Deep fields for sub-confusion studies
- Wide fields for rare objects and fluctuations

Use Best Ancillary Fields Available
- Fields with Spitzer, Radio, Optical, NIR, X-ray, etc data

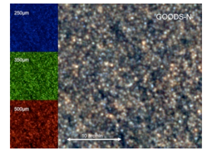
Do What Herschel Does Best
- SPIRE excels at large maps
- PACS best at small deep maps
- Collaborate with PEP for PACS data
- Use parallel mode where possible


HerMES: Wedding Cake Survey
Clusters
L1 0.11 □°
L2 0.36 □°
L3 1.25 □°
L4 4 □°
L5 30 □°
L6 40 □°
L7 270 □°
SDP Release
DR1 Release
DR2 Release
Proposed
GOODS South
GOODS North
ECDFS
Lockman North
Lockman East
EGS
UDS
COSMOS
EGS
UDS
VVDS
CDFS
ELIAS-S1
Lockman
Bootes
ELIAS-N1
FLS
ELIAS-S1
ELIAS-N2
Akari SEP
Bootes
ELIAS-N1
XMM-LSS
HeLMS / Stripe 82

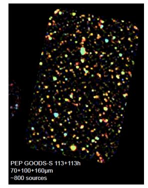

HerMES fields
HDFN
LH
ECS
EN1
XFLS
BOOTES
EN2
HeLMS
COSMOS
XMMLSS
CDFS
ES1
ADFS
IRAS Dust Map
Schlegel et al. 1998

Herschel Large High-z Surveys

HerMES: *Herschel* Multi-tiered Extragalactic Survey

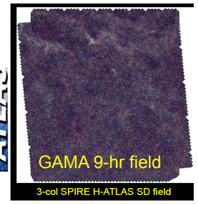


- PACS + SPIRE
- 70 sq deg from 20′×20′ to 3.6°×3.6° (900 hours) + 12 clusters
- Bolometric luminosities of galaxies, cosmic SFH
- Wedding cake to probe range of luminosities and environments



PEP: PACS Evolutionary Probe
- PACS only
- 2.7 sq deg from 10′×15′ to 85′×85′ (655 hours) + 10 clusters
- Resolve CFIRB; L_{FIR} & SFRs

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

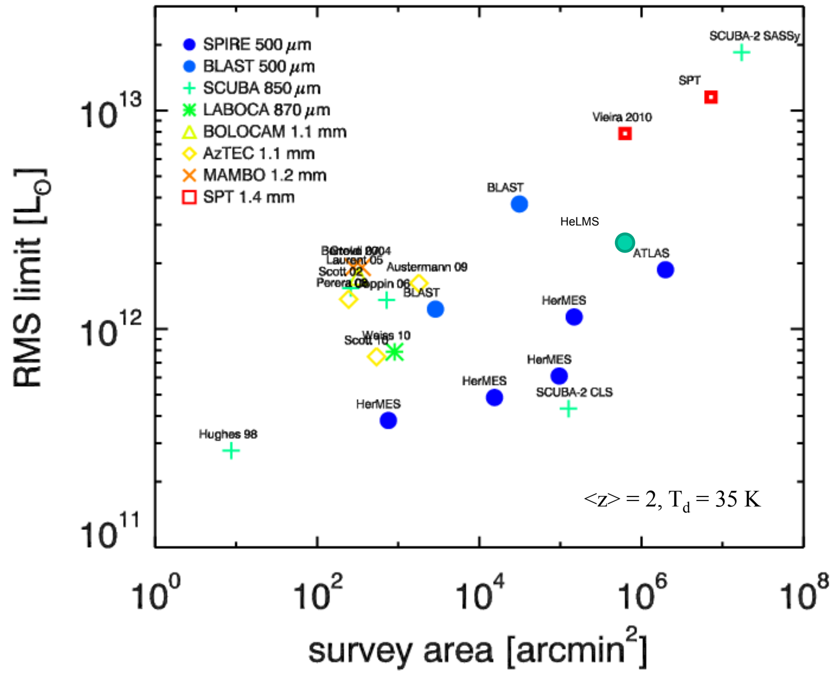


- PACS + SPIRE
- 550 sq deg (600 hours)
- Large-scale structure, AGN, rare objects
- Expect ~500,000 detections to z~3, majority at 250 & 350 um

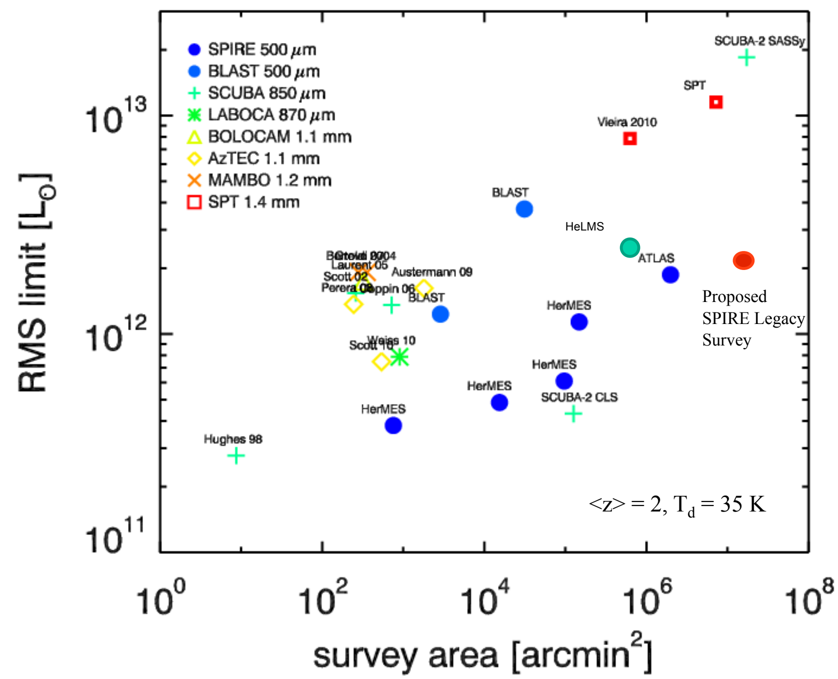
H-GOODS: Herschel-Great Observatories Origins Deep Survey

- PACS very deep imaging of the GOODS Field (330 hours)
- SPIRE deep imaging of the GOODS Field (30 hours)

HERMES vs. Previous Surveys



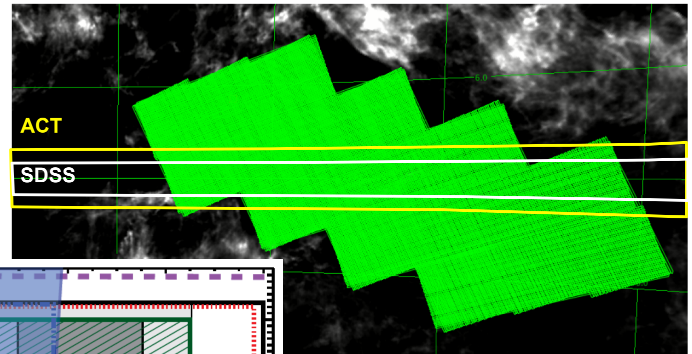
HERMES vs. Previous Surveys

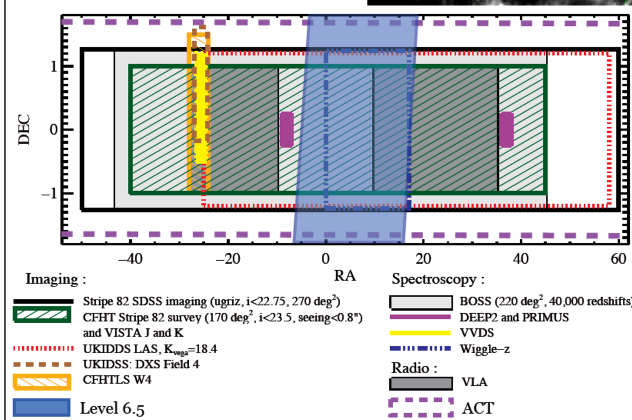


HeLMS: A Cross-Linked Shallow Survey

Why did SPIRE GTO end up with Extra Time?

HerMES designed pre-launch
Reduced depth on clusters
Eliminated PACS on VVDS





Specifications

Total area = 270 sq. deg.
Total time = 103 h
SPIRE fast scanning
2x redundancy
AOR blocks = 16° x 3.8°
Some ancillary coverage
Minimal cirrus

Marco Viero & Asantha Cooray

HeLMS: Science Highlights

Luminous Sources

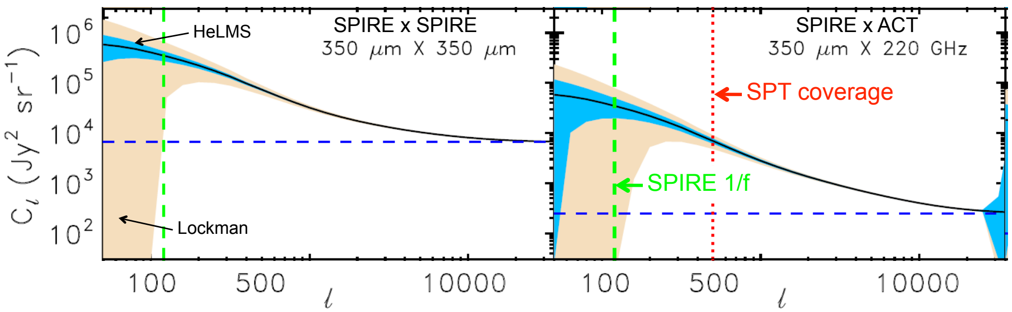
- ~25,000 galaxies at 5σ at 250 um
- ~250 lensed galaxies

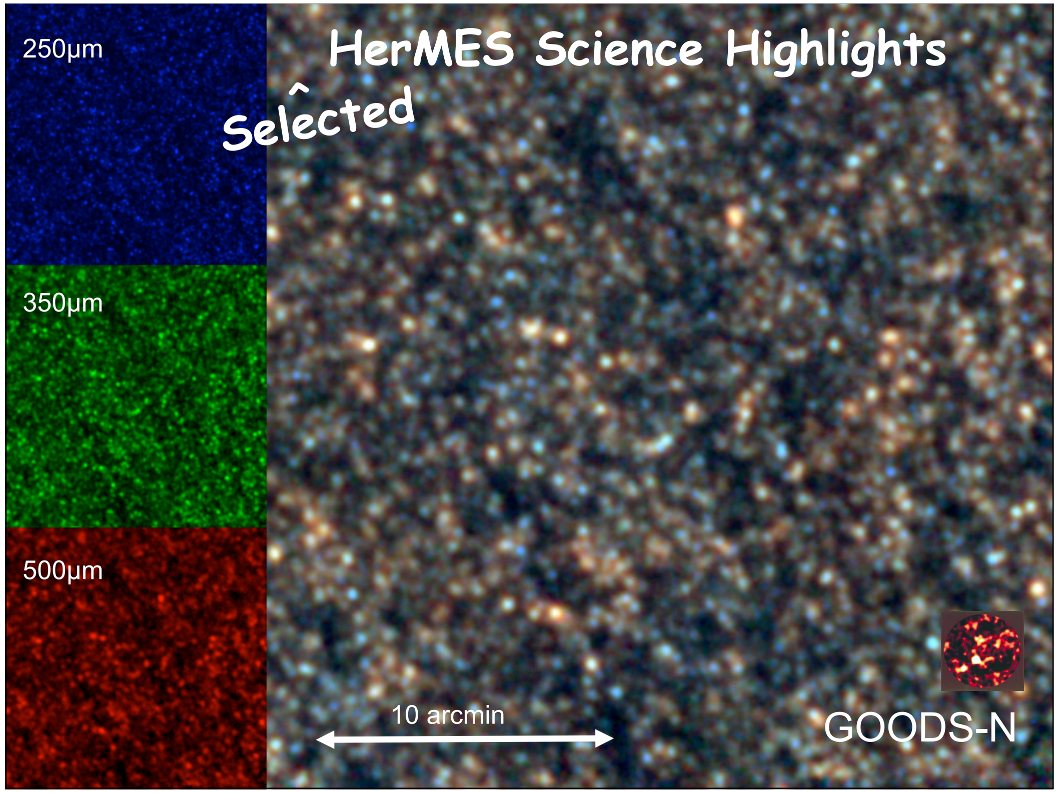
Ancillary Data Science

- BOSS: ~10^6 LRGs, z = 2 quasars
- Hetdex: Ly-α galaxies out to z ~ 4
- SDSS, UKIDSS, VLA, Wiggle-z
- Great legacy value

Background Fluctuations:

- Extends galaxy x galaxy coverage to ℓ ~ 100
- CMB secondary anisotropies x FIR galaxies
- CMB lensing x FIR galaxies




HerMES Science Highlights
Selected
250μm
350μm
500μm
10 arcmin
GOODS-N

The HerMES Bibliography

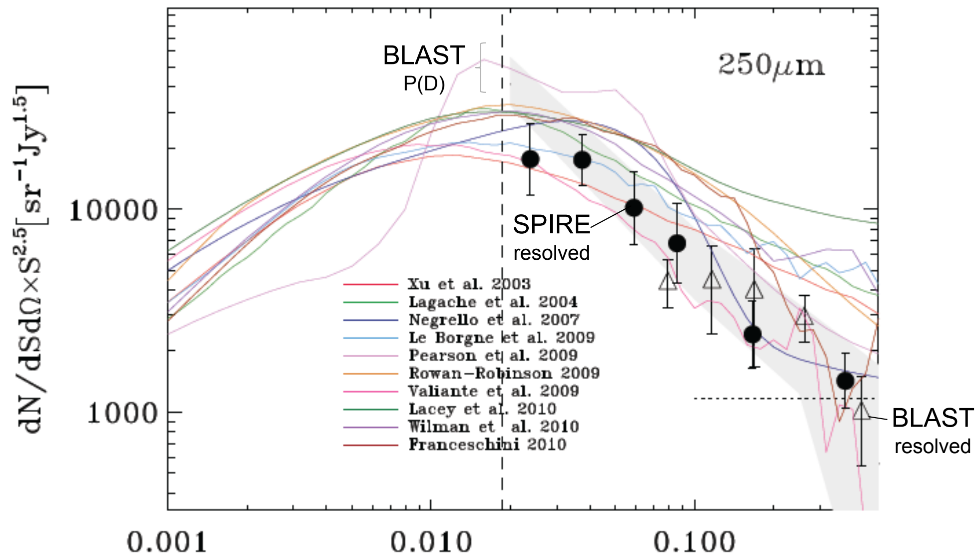
Science Demonstration Phase Papers

HerMES: The SPIRE confusion limit Nguyen et al. A&A 518, L5
The HerMES SPIRE submillimeter local luminosity function Vaccari et al. A&A 518, L20
HerMES: SPIRE galaxy number counts at 250, 350, and 500 μm Oliver et al. A&A 518, L21
Halo occupation number and bias properties of dusty galaxies from clustering measurements , Cooray et al. A&A 518, L22
First results from HerMES on the evolution of the submillimetre luminosity function, Eales et al. A&A 518, L23
Herschel unveils a puzzling uniformity of distant dusty galaxies, Elbaz et al. A&A 518, L29
The far-infrared/radio correlation as probed by Herschel, Ivison et al. A&A 518, L31
HerMES: The submillimeter spectral energy distributions of Herschel/SPIRE-detected galaxies, Schulz et al. A&A 518, L32
HerMES: Far infrared properties of known AGN in the HerMES fields, Hatziminaoglou et al. A&A 518, L33

Papers After SDP but Prior to DR1

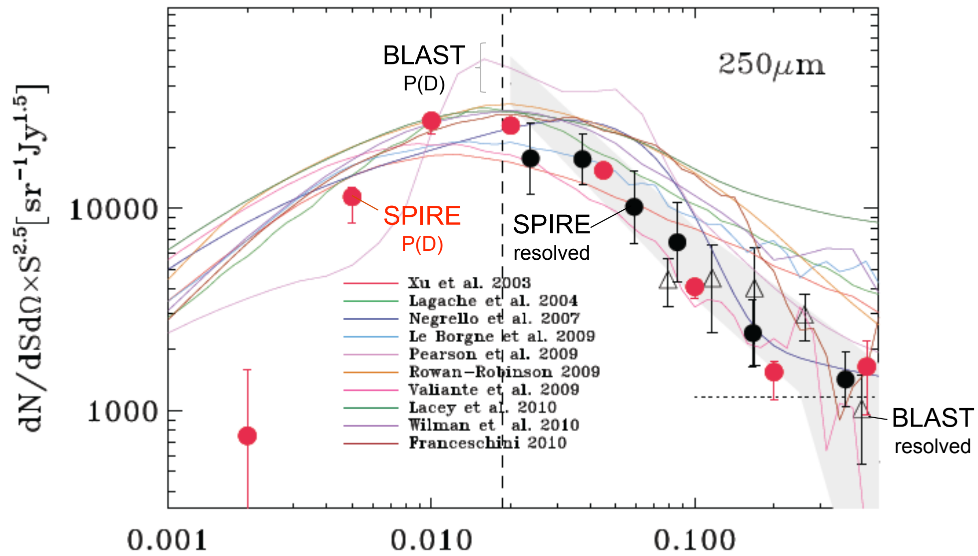
HerMES: Lyman-Break Galaxies Individually Detected at 0.7 < z < 2.0 in GOODS-N, Burgarella et al., ApJL 2011, in press
Modeling of the Hermes J105751.1+573027 Lensed by a Foreground Group of Galaies, Gavazzi et al., ApJ in press
Dynamical Structure of the Molecular interstellar Medium in a Multipy-Lensed z~3 Herschel Galaxy, Riechers et al. ApJ, 733, 12L.
Redshift Determination and CO Line Excitation Modelling for the Multiply-Lensed Galaxy HLSW-01, Scott et al., ApJ, 733, 29.
Discovery of a Multiply-Lensed Submillimeter Galaxy in Early Hermes Data, Conley et al., ApJ. 732, 35L.
HerMES: Cosmic Magnification of Sub-mm Galaxies Using Angular Cross-Correlation, Wang et al., MNRAS, in press.
HerMES: SPIRE Emission from Radio-Selected Active Galactic Nucleii, Seymour et al., MNRAS, in press.
Sub-millimetre Galaxies Reside in Dark Matter Halos with M > 3e11 Solar Masses, Amblard et al, Nature, 470, 510.
Measures of star formation rates from FIR and UV emissions of galaxies in HerMES fields, Buat et al. 2010, MNRAS 409, L1.
HerMES: Far-Infrared observations of Lyman Break Galaxies, Rigopoulou 2010, MNRAS 409, L7
The Deep SPIRE HerMES Survey: Secure SEDs and their Astrophysical Indications, Brisbin et al. 2010, MNRAS 409, 66.
Herschel-SPIRE, Far-Infrared Properties of Millimetre-Bright and -Faint Radio Galaxies, Chapman et al. 2010, MNRAS 409.
HerMES : SPIRE detection of high redshift massive compact galaxies in GOODS-N field, Cava et al. 2010, MNRAS 409, L19.
Cold dust and young starbursts: SEDs of SPIRE sources from HerMES, Rowan-Robinson et al. 2010, MNRAS 409, 2.
Herschel reveals a T_{dust} - unbiased selection of z≈2 ULIRGs, Magdis et al. 2010 MNRAS 409, 22.
HerMES: Source Extraction and Cross-IDs in Confusion-Limited SPIRE Images, Roseboom et al. 2010, MNRAS 409, 48.
Evolution of Dust Temperature of Galaxies through Cosmic Time as seen by Herschel, Hwang et al. 2010 MNRAS 409, 75.
HerMES: SPIRE Science Demonstration Phase Maps, Levenson et al. 2010 MNRAS 409, 83.
HerMES: Deep Galaxy Number Counts from P(D) of SPIRE SDP Observations, Glenn et al. 2010, MNRAS 409, 109.

SPIRE Source Counts



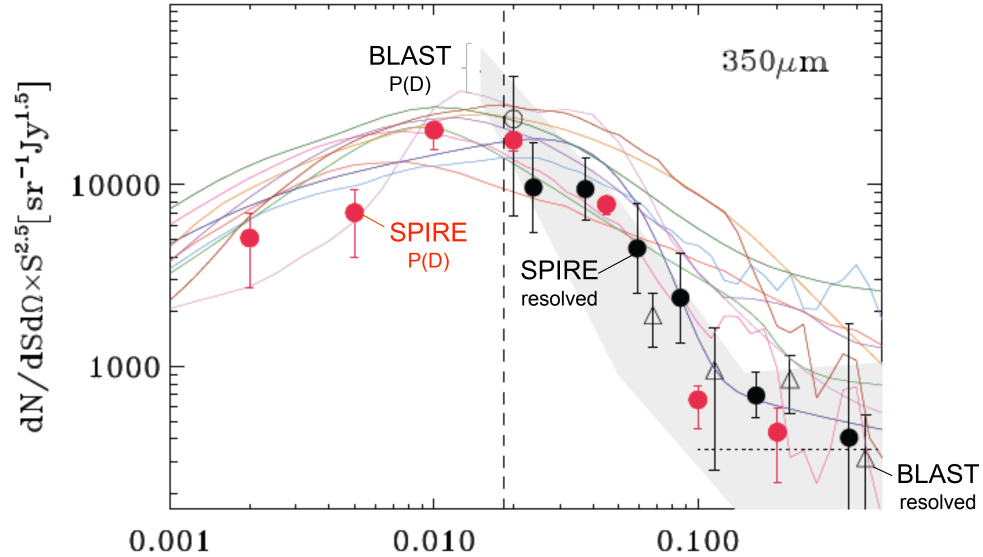
Oliver et al. 2010 A&A

SPIRE Source Counts

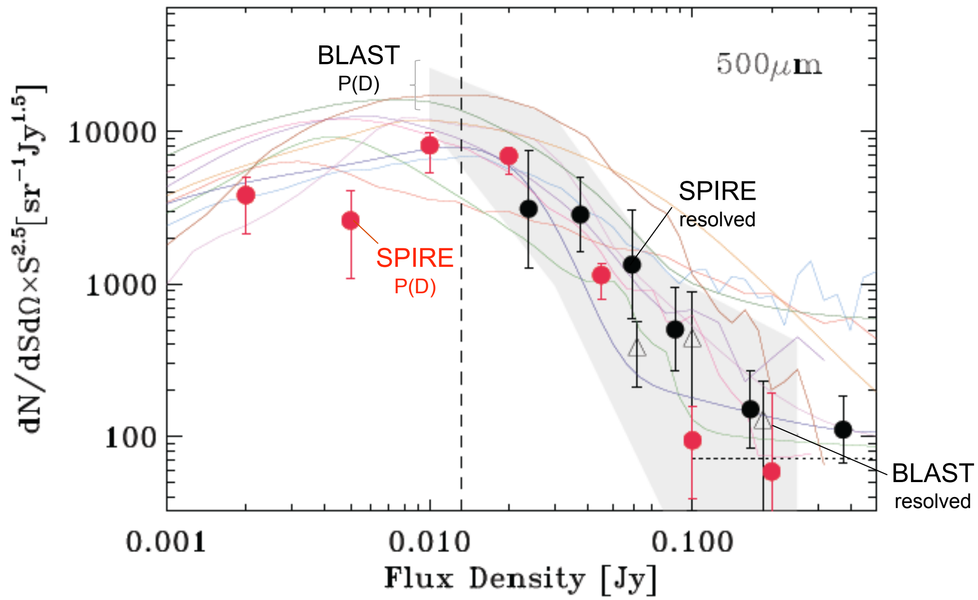


Glenn et al. 2010 MNRAS

SPIRE Source Counts

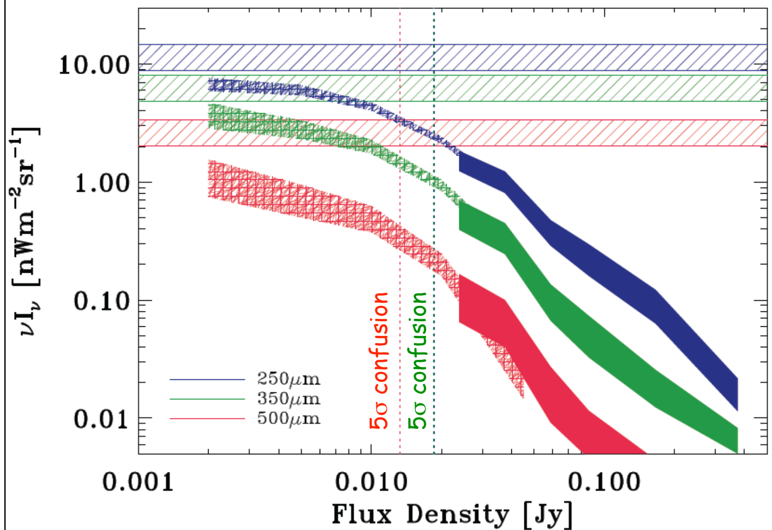


SPIRE Source Counts



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

Resolving the FIR Background



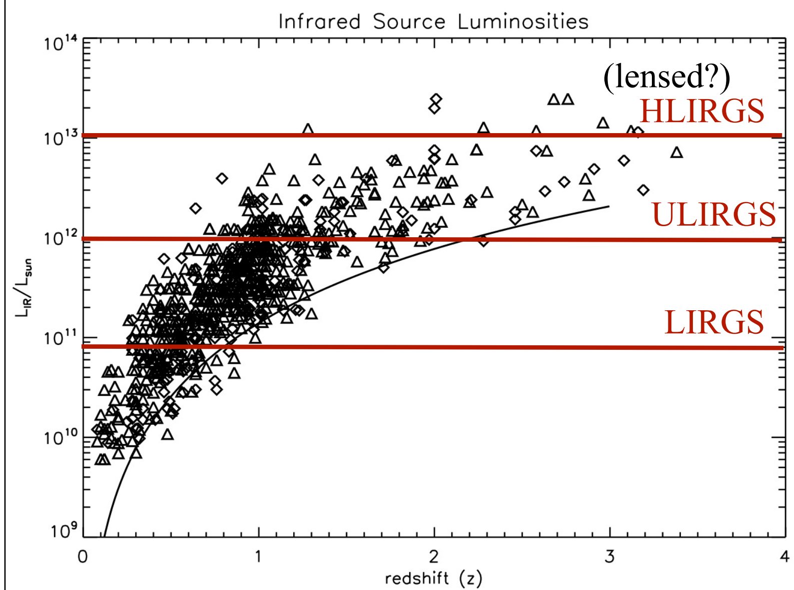
- **Source Counts**
  250, 350, 500 μm
  15%, 10%, 6%

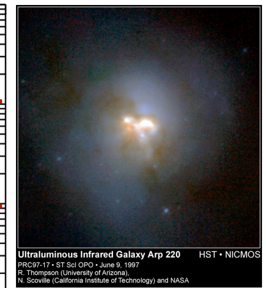
- **P(D)**
  250, 350, 500 μm
  65%, 60%, 45%

- **Stacking TBD**
  With BLAST:
  250, 350, 500 μm
  80%, 80%, 85%

<u>Of course</u>: The remainder are the most interesting sources!
E.g. z > 3 galaxy populations

What kind of luminosities?

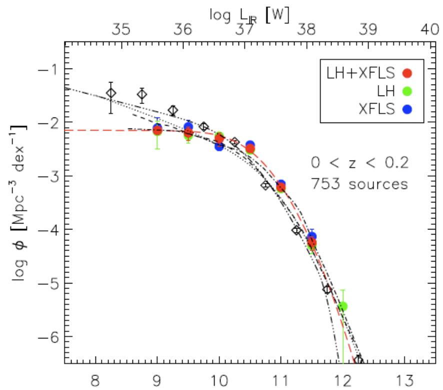




Are all starburst galaxies result of mergers?

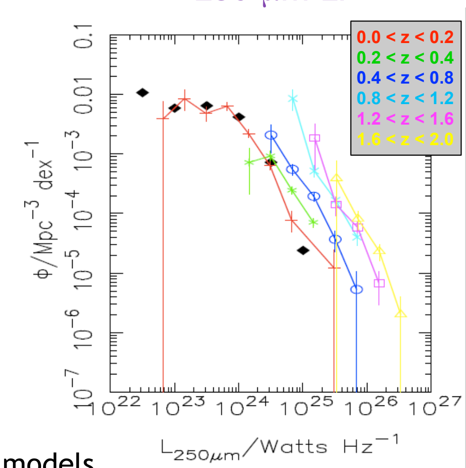
Strong Luminosity Evolution

Local Luminosity Function



Vaccari et al. (2010)

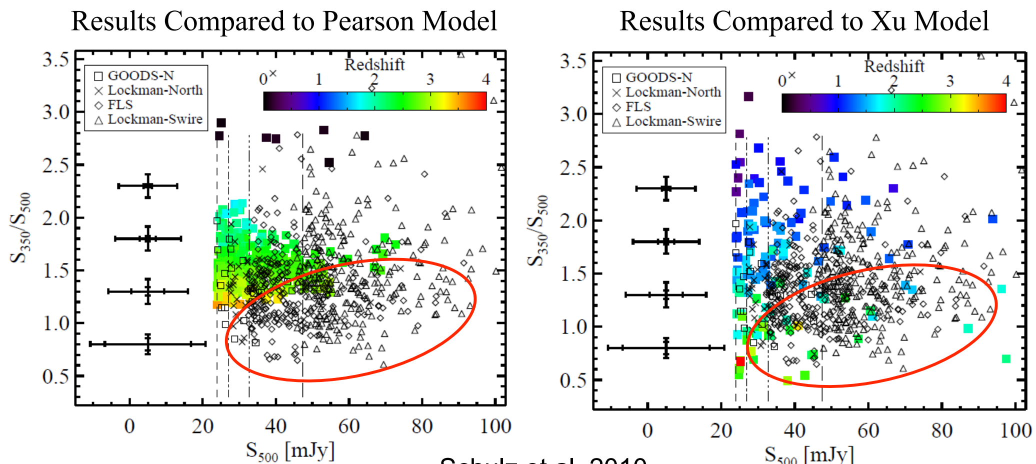
HerMES Rest-Frame 250 μm LF



Eales et al. (2010)

- Local sub-mm galaxy LF slightly above models
- Luminosity function increases out to z ~ 2
- Is it flattening out at z > 1?
- Next: better statistics from bigger samples

SPIRE Galaxy Colors



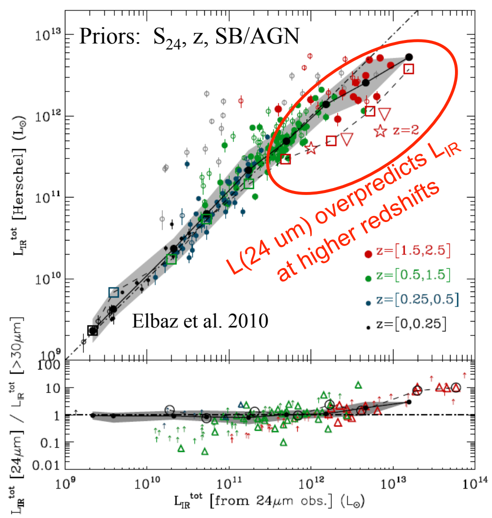
Schulz et al. 2010

Colors generally spread redder than models predict

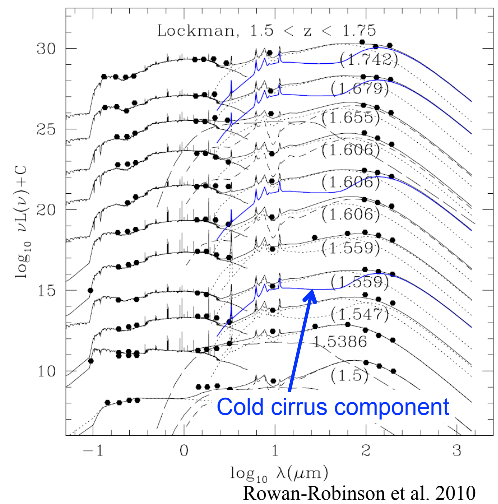
- colder dust and/or higher z populations?

How Well Do Galaxy Templates Work?

L_{IR} for Starbursts and AGNs

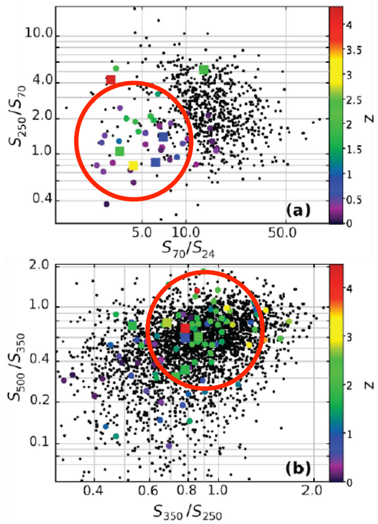


Multi-Wavelength SED Fits



- *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

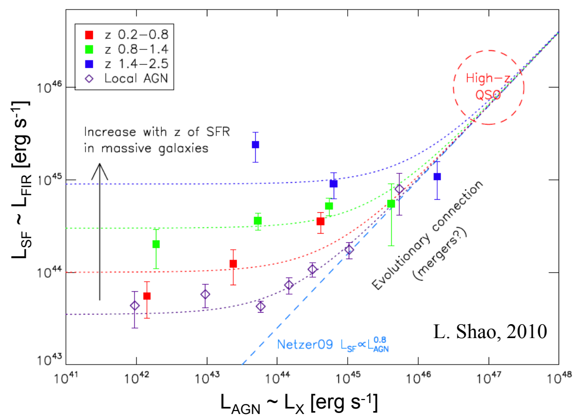


Distinct S_{70}/S_{24} colors, but not $S_{250}/S_{350}/S_{500}$

- FIR emission due to star formation

E. Hatziminaoglou, 2010

Two Modes of Host & AGN Evolution?



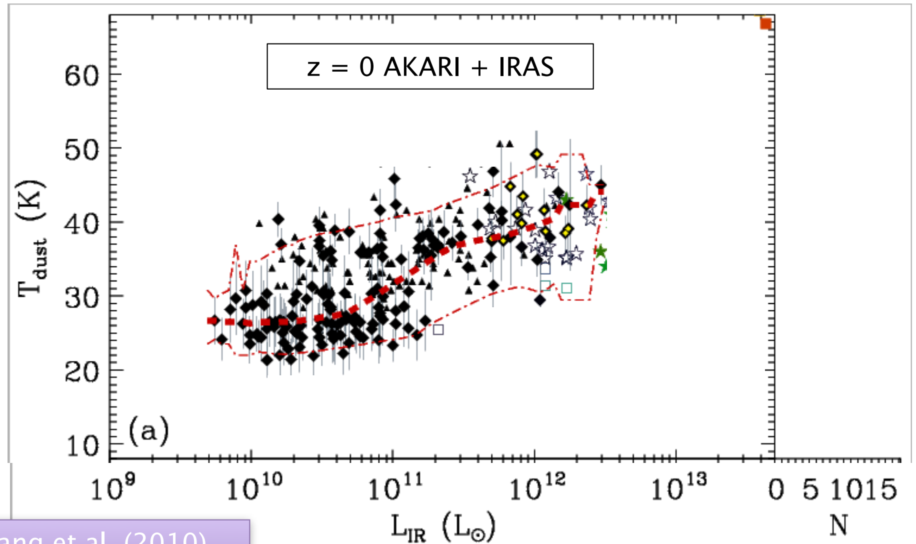
Low L_{AGN}: Increasing L_{SF} w/ z

- Follows behavior of FIR galaxies
- SF unrelated to AGN?

High L_{AGN}: Related to L_{SF}

- Trend is weaker
- Luminosities coupled by mergers?

Dust temperature distribution



Hwang et al. (2010)
Amblard et al. (2010)
Chapman et al. (2010)
Magdis et al. (2010)

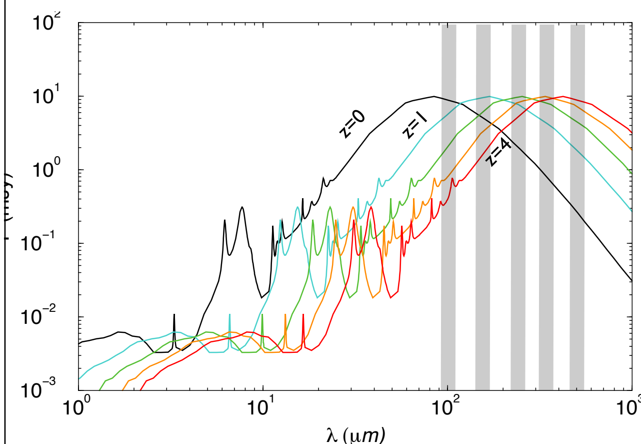
- lack of strong evolution of L_{IR}–T_{dust}
- mildly colder (U)LIRGs by ~2–5 K
- envelope extends to colder SMGs

-What about normal galaxies

Redshift distribution of SPIRE Sources?

Result from 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



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

Naive expectation based on sub-mm SED

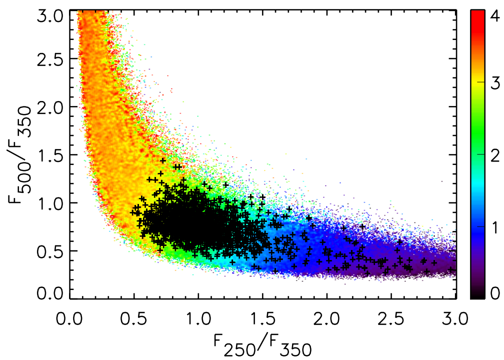
$S_{250} > S_{350} > S_{500}$: z < 2

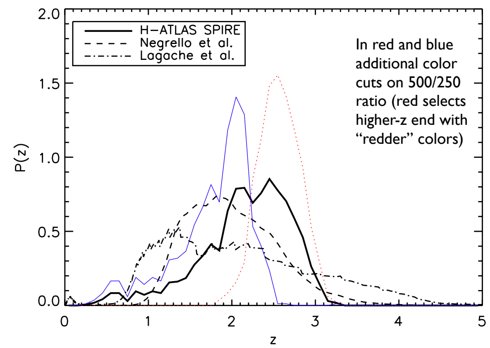
$S_{250} <\sim S_{350} > S_{500}$: z ~ 2 to 3

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

Redshift distribution of SPIRE Sources?

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?

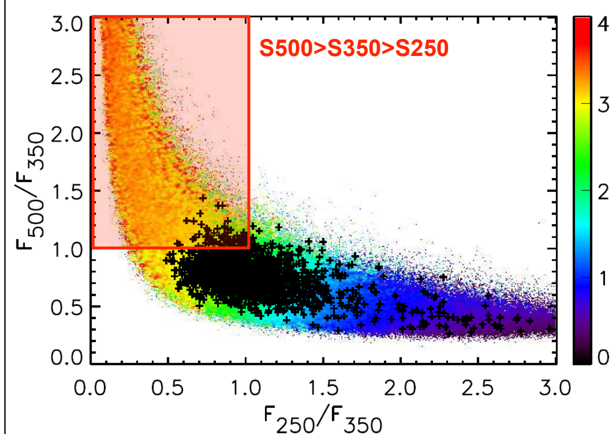
H-ATLAS:

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.

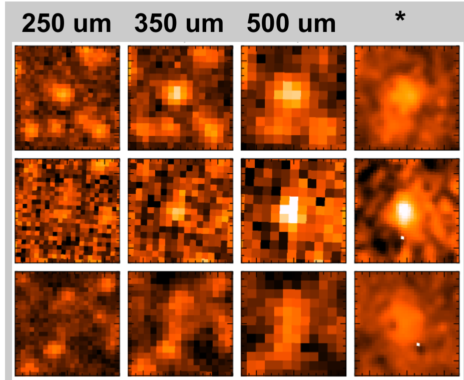
CO-line redshifts?

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

High Redshift Candidates?

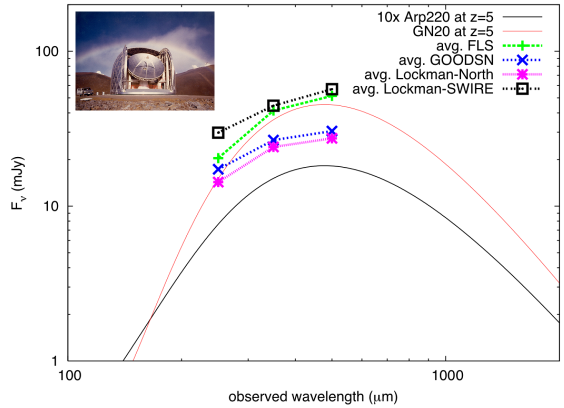
500 um peaked sources

Three examples:



*Confusion reduced S(500) – fS(250)

Average spectra of sources detected in 4 HerMES fields compared to templates:

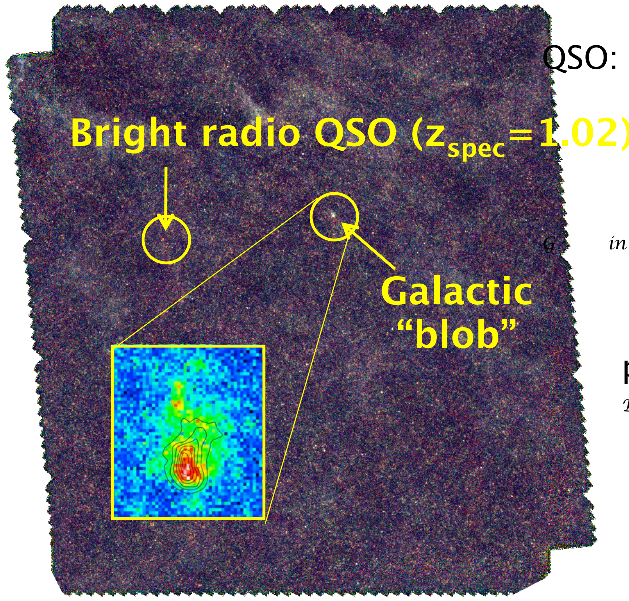


These could be:

~~*z = 1.5, T_{dust} = 20 K ULIRGs or*~~

z = 5, T_{dust} = 35 K HLIRGS or lensed

500 µm BRIGHTEST GALAXIES IN H-ATLAS SDP



QSO: $S_{250\mu m}$ = 159.6 mJy
$S_{350\mu m}$ = 193.8 mJy
$S_{500\mu m}$ = 265.8 mJy !
$S_{1.4GHz}$ = 571.7 mJy

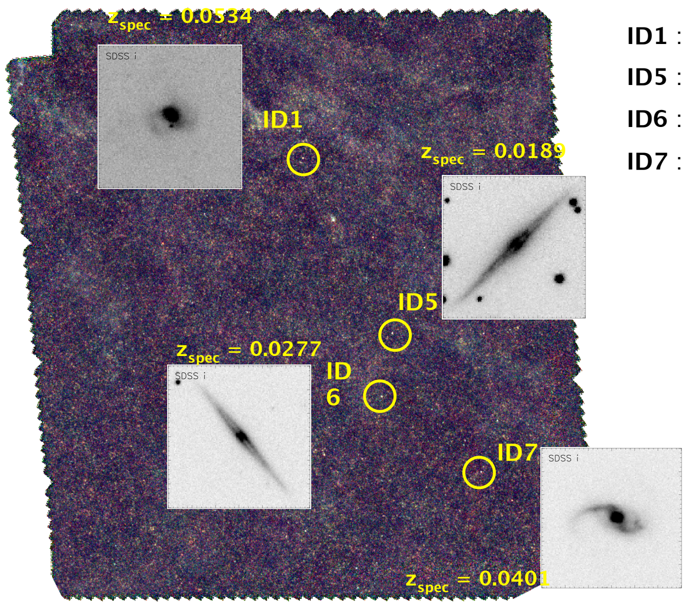
in WMAP point source catalog!

prediction: ~**0.1 deg**$^{-2}$

De Zotti et al. (2005)

Slides from
Mattia Negrello, H-ATLAS

500 μm BRIGHTEST GALAXIES IN H-ATLAS SDP



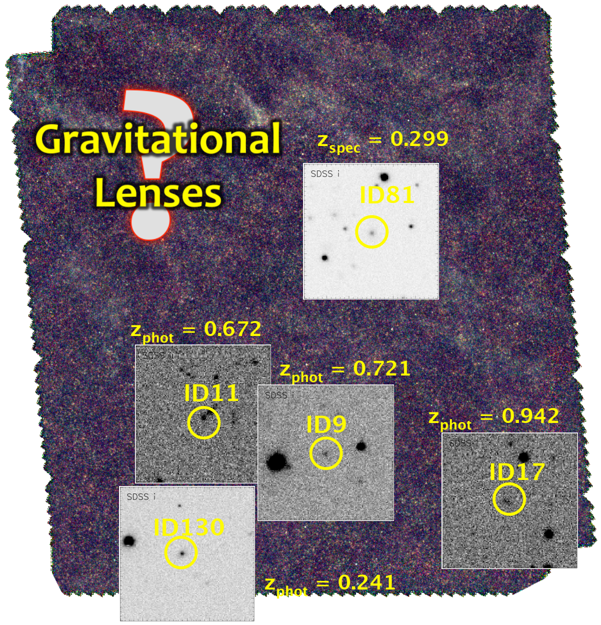
ID1 : $S_{500\mu m}$ = 177 ± 28 mJy

ID5 : $S_{500\mu m}$ = 122 ± 20 mJy

ID6 : $S_{500\mu m}$ = 112 ± 19 mJy

ID7 : $S_{500\mu m}$ = 104 ± 18 mJy

500 µm BRIGHTEST GALAXIES IN H-ATLAS SDP



ID9 : $S_{500\mu m}$ = 175 ± 28 mJy

ID11 : $S_{500\mu m}$ = 238 ± 37 mJy

ID17 : $S_{500\mu m}$ = 220 ± 34 mJy

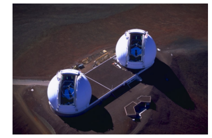
ID81 : $S_{500\mu m}$ = 166 ± 27 mJy

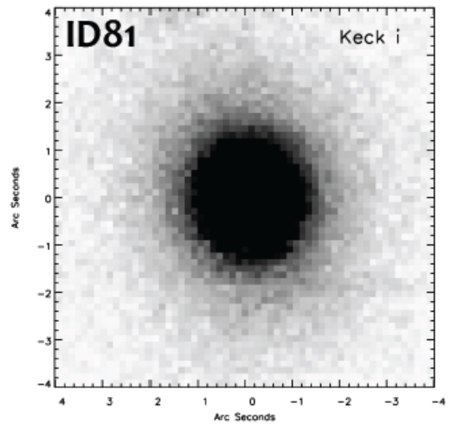
ID130 : $S_{500\mu m}$ = 108 ± 18 mJy

optical counterparts
$z_{phot/spec} < 1.0$

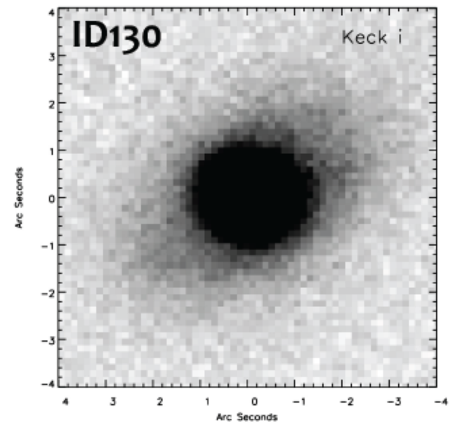
Lensing Candidates ID81 & ID130

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





z=0.299

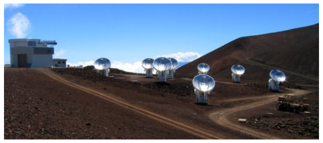


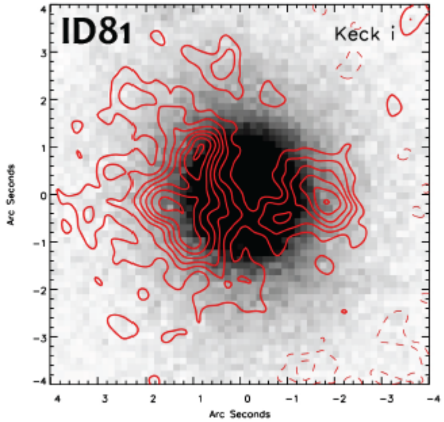
z=0.223

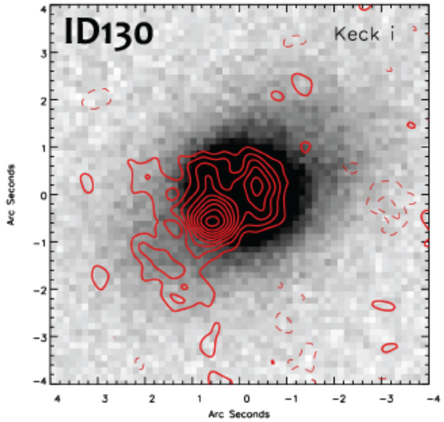
Sam Kim

Lensing Candidates ID81 & ID130

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



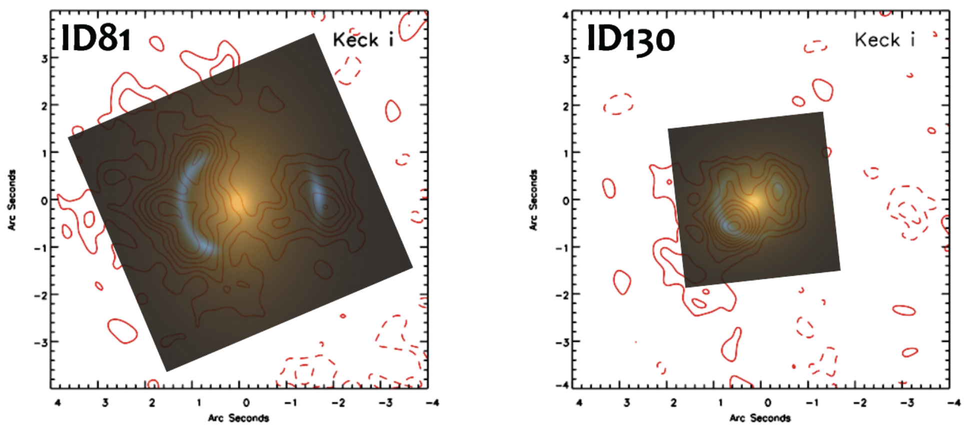




CREDITS: Mark Gurwell (CfA)

Lensing Candidates ID81 & ID130

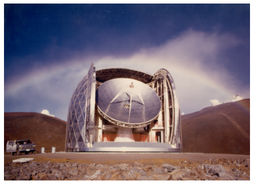
+ Lensing Model to SMA data

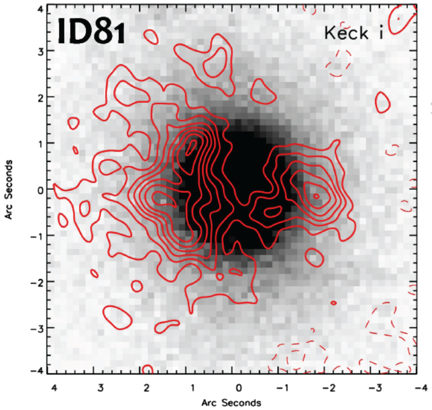


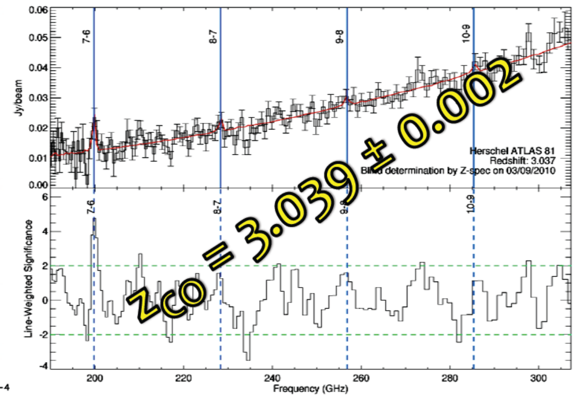
from http://www.slacs.org

First Herschel CO Redshift: ID81

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



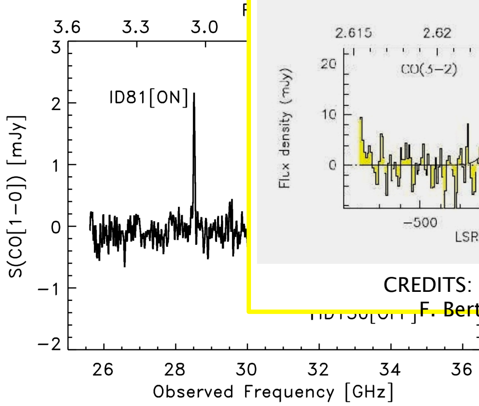




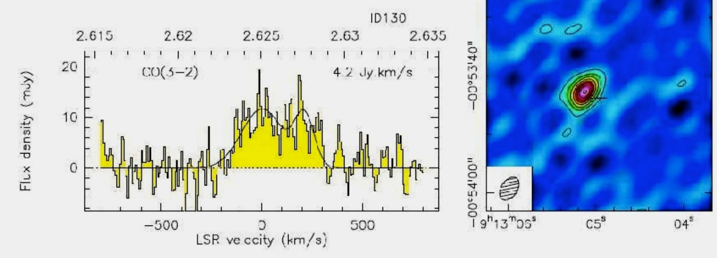
CREDITS: CSO/z-spec team

GRAVITATIONAL LENS CANDIDATES ID130

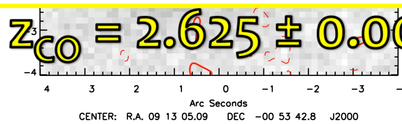
CO(1-0) redshift from GBT/Zpectrometer



confirmed by **PdBI**



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



$z_{CO} = 2.625 \pm 0.001$

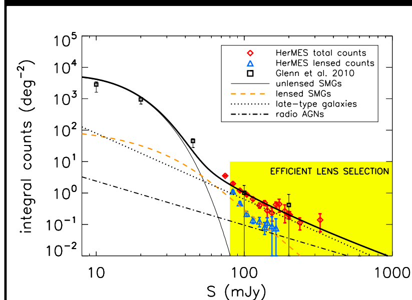
CREDITS: D. Frayer, A. Harris, A. Baker, R. Maddalena et al.

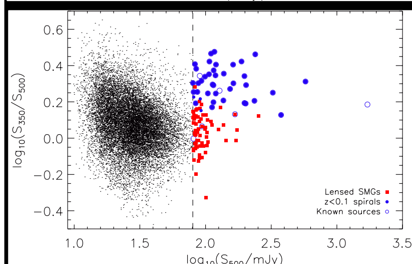
Strong lensing Studies with Herschel-SPIRE

(a) 0.5 million dusty galaxies, with 0.3 million at z~2, 3,000 at z>4, ~100 at z >5. Follow-up targets for ALMA, SPICA etc.

(b) 500 strongly lensed bright sources by the end of 2012: *a goldmine for cosmology!* we have 150 now already with 200 sq. deg of data.

Negrello et al. Science, 2010
(Nov 5th issue)



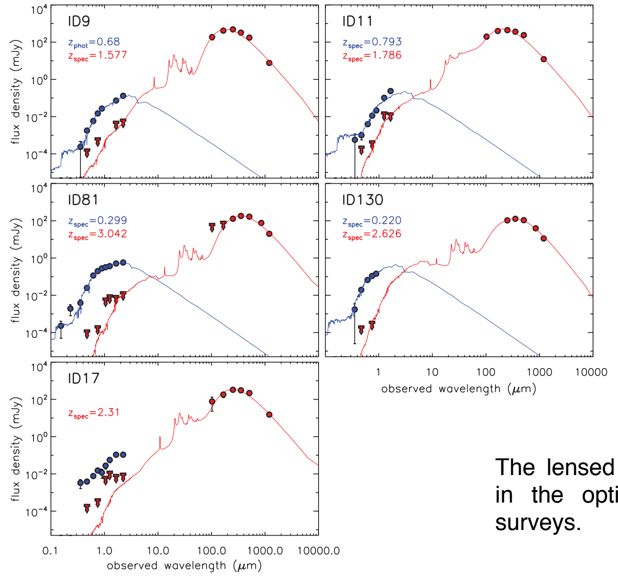


RESEARCH ARTICLES

The Detection of a Population of Submillimeter-Bright, Strongly Lensed Galaxies

Mattia Negrello,[1*] R. Hopwood,[1] G. De Zotti,[2,3] A. Cooray,[4] A. Verma,[5] J. Bock,[6,7] D. T. Frayer,[8] M. A. Gurwell,[9] A. Omont,[10] R. Neri,[11] H. Dannerbauer,[12] L. L. Leeuw,[13,14] E. Barton,[4] J. Cooke,[4,7] S. Kim,[4] E. da Cunha,[15] G. Rodighiero,[16] P. Cox,[11] D. G. Bonfield,[17] M. J. Jarvis,[17] S. Serjeant,[1] R. J. Ivison,[18,19] S. Dye,[20] I. Aretxaga,[21] D. H. Hughes,[21] E. Ibar,[18] F. Bertoldi,[22] I. Valtchanov,[23] S. Eales,[20] L. Dunne,[24] S. P. Driver,[25] R. Auld,[20] S. Buttiglione,[2] A. Cava,[26,27] C. A. Grady,[28,29] D. L. Clements,[30] A. Dariush,[20] J. Fritz,[31] D. Hill,[25] J. B. Hornbeck,[32] L. Kelvin,[25] G. Lagache,[33,34] M. Lopez-Caniego,[35] J. Gonzalez-Nuevo,[3] S. Maddox,[24] E. Pascale,[20] M. Pohlen,[20] E. E. Rigby,[24] A. Robotham,[25] C. Simpson,[36] D. J. B. Smith,[24] P. Temi,[37] M. A. Thompson,[17] B. E. Woodgate,[38] D. G. York,[39] J. E. Aguirre,[40] A. Beelen,[34] A. Blain,[7] A. J. Baker,[41] M. Birkinshaw,[42] R. Blundell,[9] C. M. Bradford,[6,7] D. Burgarella,[43] L. Danese,[3] J. S. Dunlop,[18] S. Fleuren,[44] J. Glenn,[45] A. I. Harris,[46] J. Kamenetzky,[45] R. E. Lupu,[40] R. J. Maddalena,[8] B. F. Madore,[47] P. R. Maloney,[45] H. Matsuhara,[48] M. J. Michaowski,[19] E. J. Murphy,[49] B. J. Naylor,[6] H. Nguyen,[6] C. Popescu,[50] S. Rawlings,[5] D. Rigopoulou,[5,51] D. Scott,[52] K. S. Scott,[40] M. Seibert,[47] I. Smail,[53] R. J. Tuffs,[54] J. D. Vieira,[7] P. P. van der Werf,[19,55] J. Zmuidzinas[6,7]

Sub-mm galaxy lensing



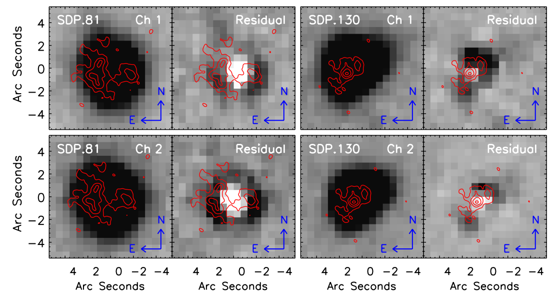
The lensed galaxies are not bright in the optical. Missed in optical surveys.

HERMES

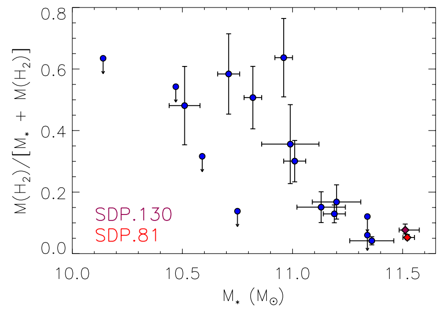
Proposed distortion of number counts by Blain 1996.
More detail on these from ATLAS still coming

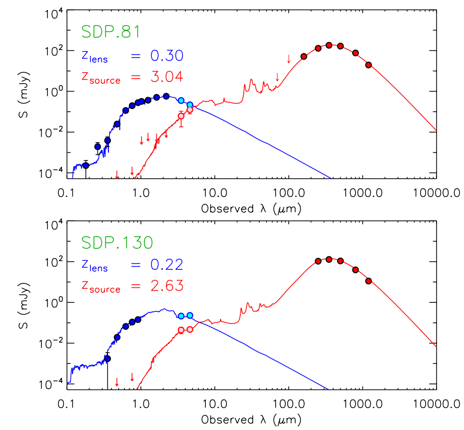
ATLAS First Gravitational Lenses

Background galaxies seen in Spitzer



(1100 seconds integrations/pixel)





log L_{dust} = 12.7 ± 0.05
log M_{dust} = 8.9 ± 0.03 (Herschel/MAMBO/SMA SED)
log M_{stars} = 11.7 ± 0.3 (Spitzer SED)
log M_{gas} = 10.1 ± 0.5 (CO line spectra)
log SFR = 2.5 ± 0.1
Av = 4.4 ± 0.6
Gas fraction = (5-8)%

Ross Hopwood, Cooray et al ApJL 2011

~0.9 candidates deg^{-2} in HerMES fields

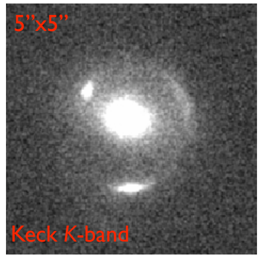
Wardlow et al. HerMES slides

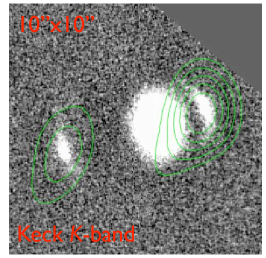
Field	RA[a]	Dec[a]	Area (deg^2)	Number of candidates	Number density (deg^{-2})
ADFS	$04^h43^m29^s$	$-53°51'09''$	8.5	8	0.9 ± 0.3
Bootes -NDWFS	$14^h32^m45^s$	$+34°10'10''$	11.3	11	1.0 ± 0.3
CDFS-SWIRE	$03^h32^m05^s$	$-28°16'35''$	12.2	8	0.6 ± 0.2
COSMOS	$10^h00^m28^s$	$+02°12'55''$	2.1	1	0.5 ± 0.5
EGS	$14^h20^m19^s$	$+52°48'56''$	3.1	1	0.3 ± 0.3
ELAIS-N1	$16^h10^m09^s$	$+54°18'50''$	3.7	2	0.5 ± 0.4
ELAIS-S1	$00^h35^m03^s$	-43°34'42''	8.6	5	0.6 ± 0.3
GOODS-N	$12^h36^m55^s$	$+62°14'19''$	0.6	0	< 1.6
Lockman-SWIRE	$10^h48^m00^s$	$+58°09'02''$	18.1	19	1.0 ± 0.2
Spitzer FLS	$17^h15^m52^s$	$+59°23'15''$	7.3	8	1.1 ± 0.4
XMM	$02^h20^m36^s$	$-04°31'27''$	21.6	24	1.1 ± 0.2
Total	···	···	97.1	87	0.90 ± 0.10

Coordinates and followup of ~90 lensed sources in
Julie Wardlow (UCI postdoc) et al. (2011 in prep)

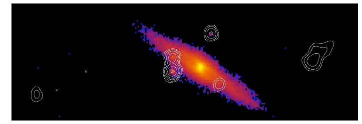
HERMES

An assortment of candidates

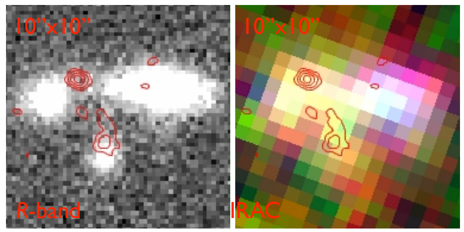


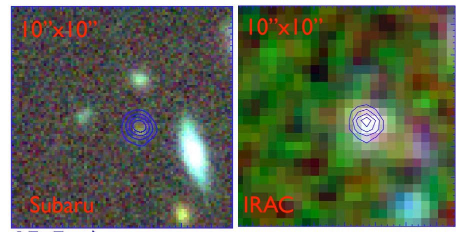


10"x5"



Keck *K*-band + EVLA 7 GHz



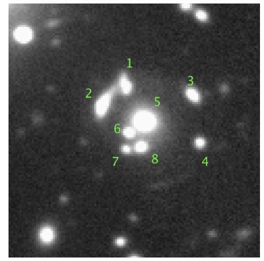


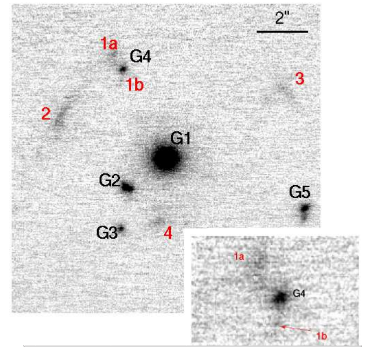
SXDF1100.001; Ikarashi et al. 2011

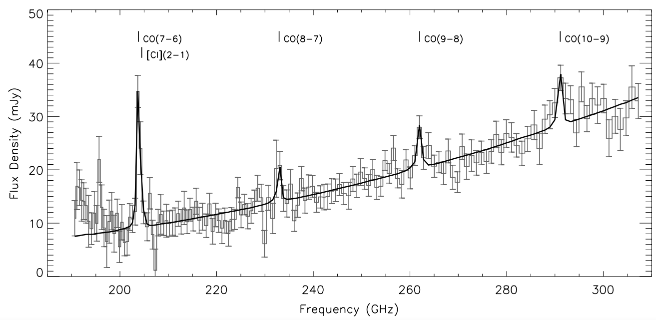
Example: Lockman01

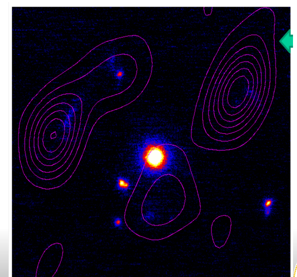
see Conley et al. 2011, Scott et al. 2011, Gavazzi et al. 2011, Riechers et al. 2011

- S_{500}~250mJy
- z_{SMG}=2.9; z_{G1}=0.6
- μ~11





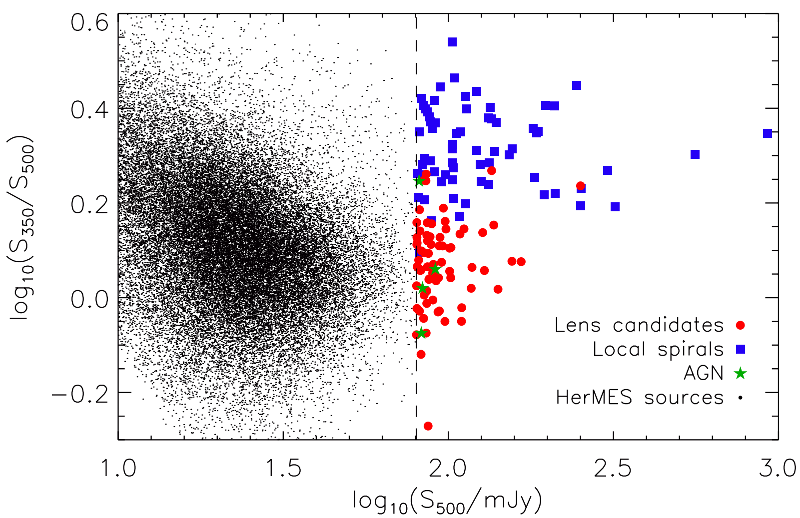




HERMES

lens code = sl_fit

Lensed galaxies are usually red in the submm

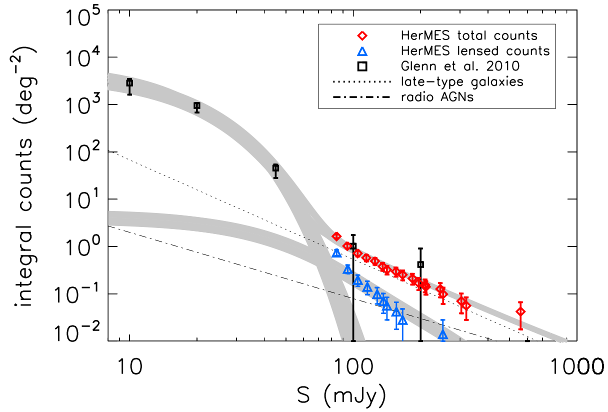


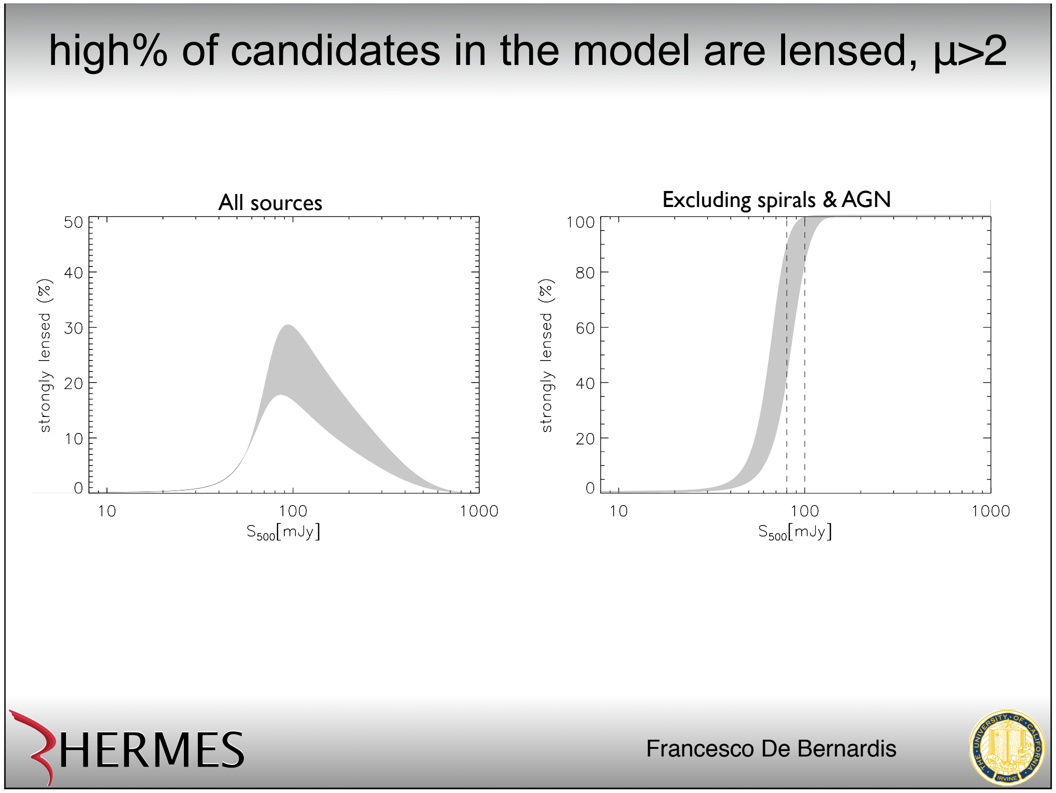
HERMES

of 4 bluer candidates 3 are real: lock01 and 2 shown on prev page

Modelling galaxy-galaxy lensing

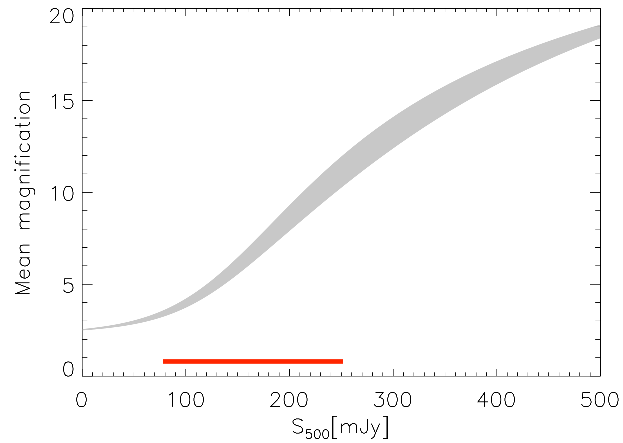
- Consider NFW & SIS density profiles & lens "intrinsic" N(>S)
- "Intrinsic" N(>S) from Schechter function fit
- Parameters constrained by requiring fit to observed N(>S)
- μ>2 for "strong" lensing





Blending ~5-10%

Average magnification in the model is ~5

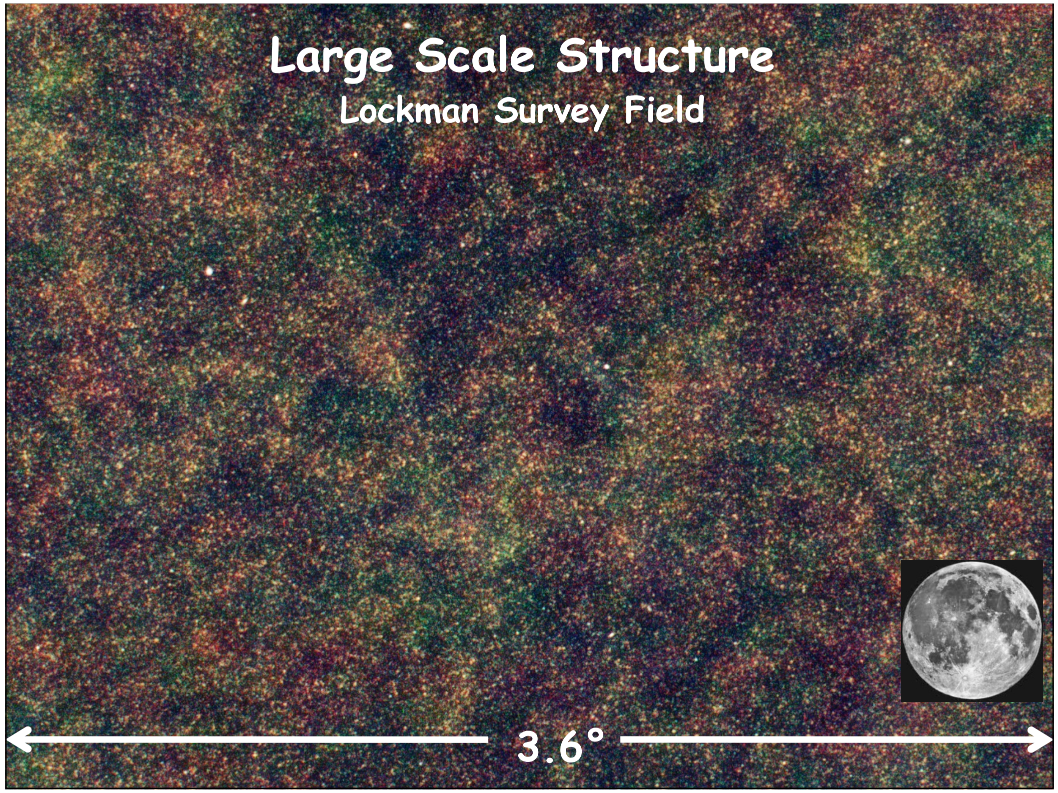


=> Most SMG galaxy-galaxy lenses are intrinsically "normal" SMGs

HERMES

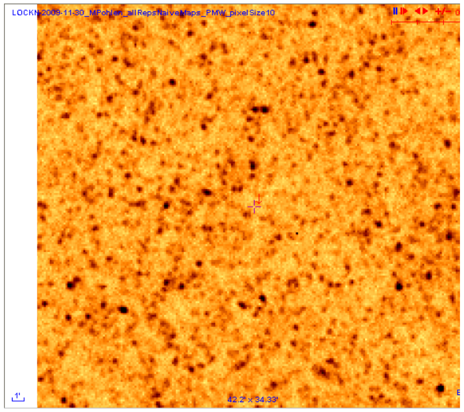
Francesco De Bernardis

But Ian CO plot shows ~10 by cf FWHM L'CO
Ref Bothwell in prep, Harris in prep.

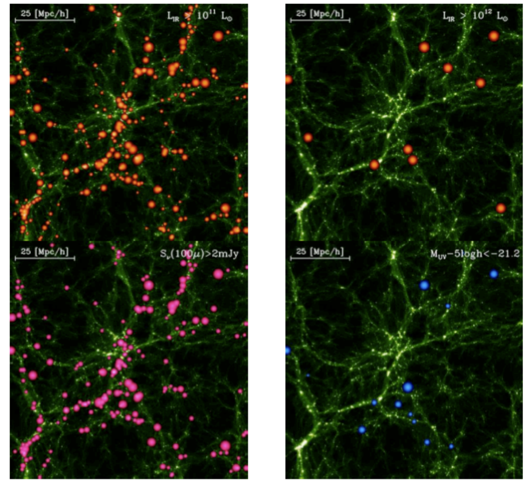


Large Scale Structure
Lockman Survey Field
3.6°

Where are the galaxies?



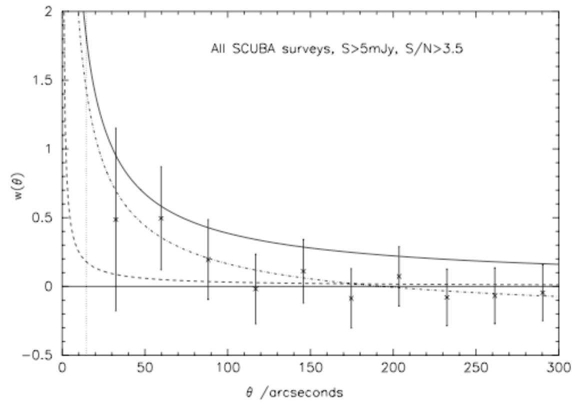
Lockman North SPIRE 350 μm



Lacey et al. arXiv:
0909.1567v2

Ultimately test specific predictions of clustering properties of galaxies

Pre-Herschel:



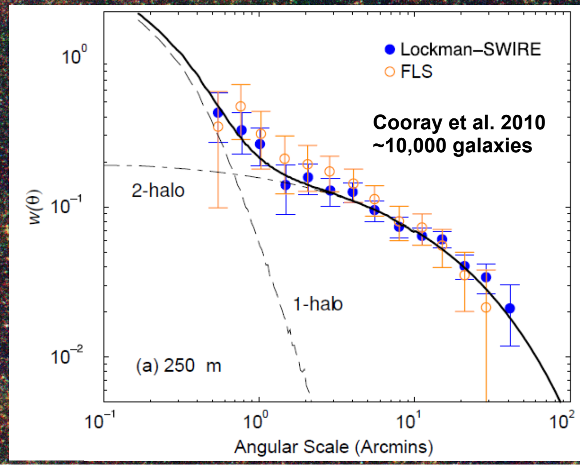
~3.5σ detection

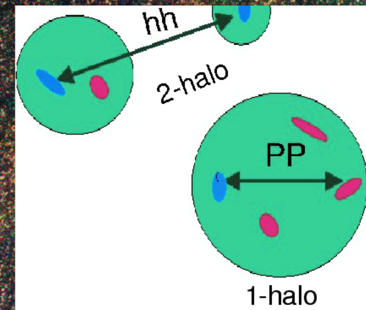
S. E. Scott, J. S. Dunlop and S. Serjeant (2006)

N.B. Previously sub-mm clustering with SCUBA ~73 sources

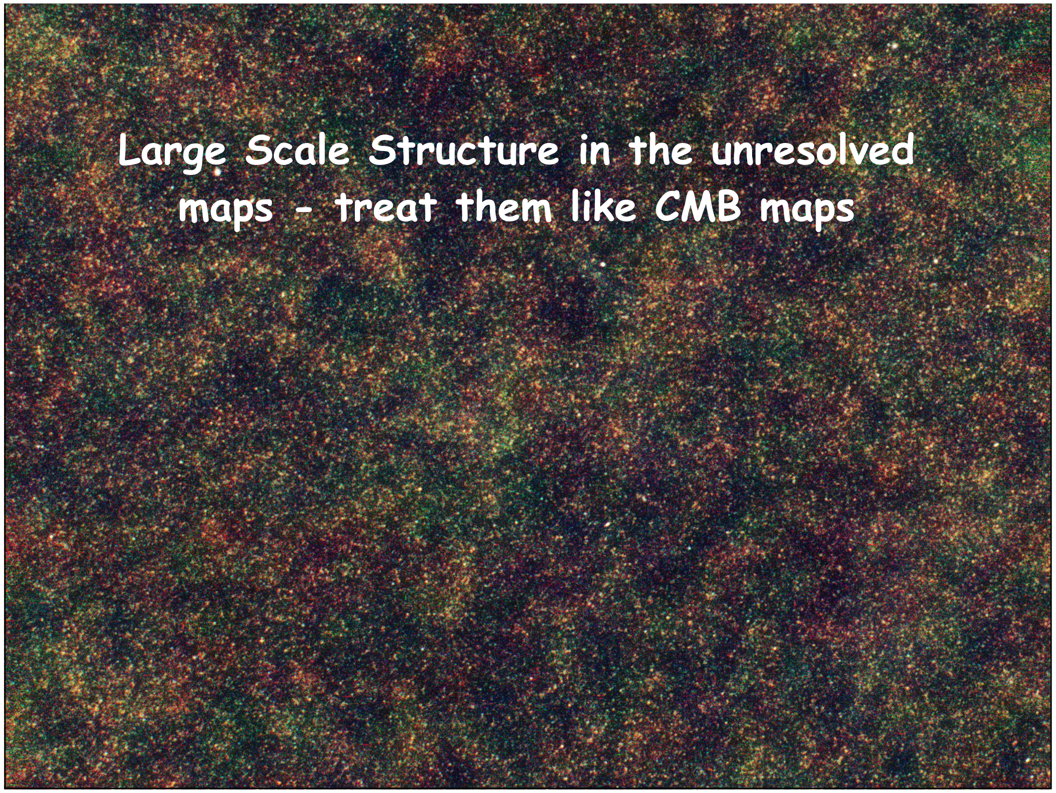
Large Scale Structure

Angular Correlation of Detected Galaxies

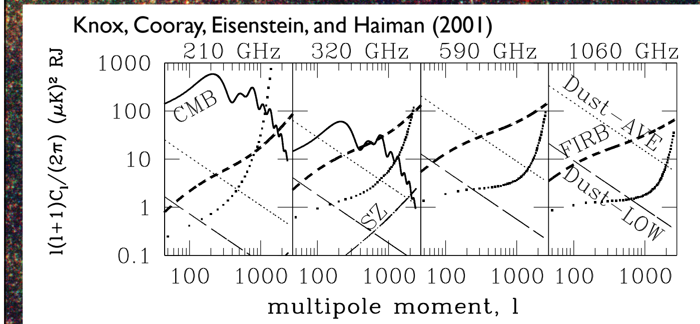


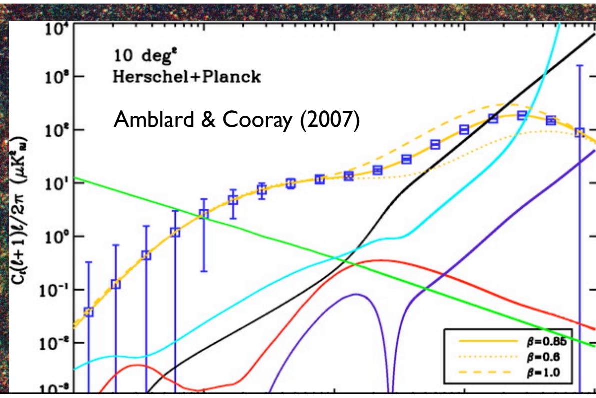


- Spatial clustering of bright SMGs compared to halo model
- Halo needed to host a S_{250} > 30 mJy FIR galaxy: M = $10^{12.6}$ M_{solar}
- ~15% appear as satellites in more massive halos M ~ $10^{13.1}$ M_{solar}
- Population statistics consistent with so-called "dust obscured galaxies"

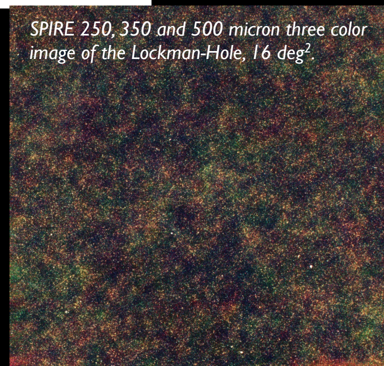

Large Scale Structure in the unresolved maps - treat them like CMB maps

2001-2007 era of predictions

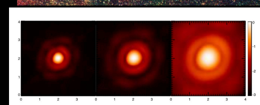




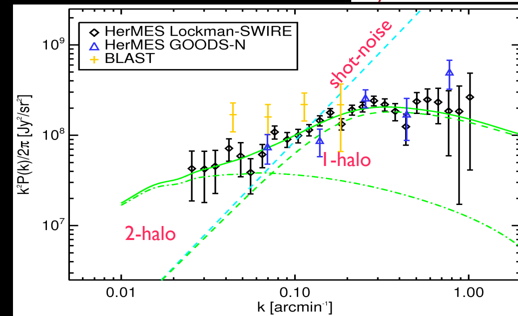
CIB fluctuations with Herschel-SPIRE

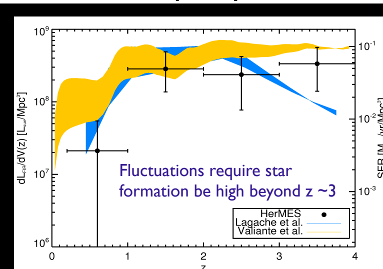


SPIRE 250, 350 and 500 micron three color image of the Lockman-Hole, 16 deg^2.



4'x4' Maps of Neptune made with 700 scans of SPIRE used for the PSF measurement

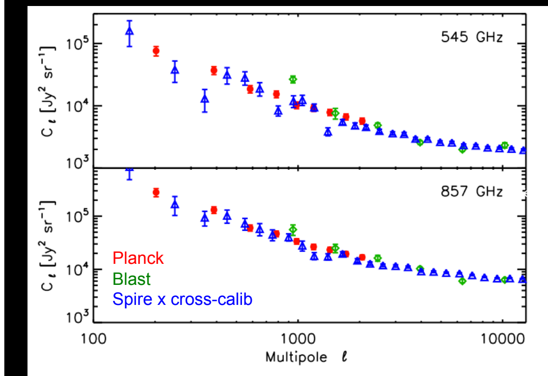


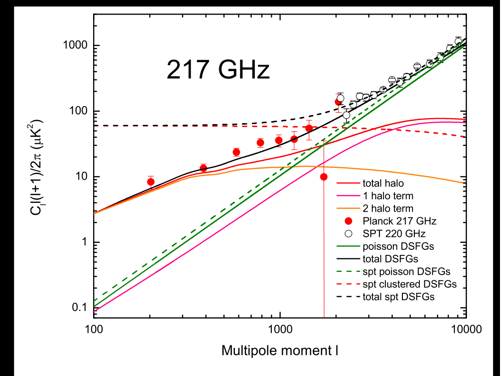


- Unresolved CIB fluctuations capture the spatial clustering of all sub-mm galaxies.
- Angular power spectrum of the CIB reveals that the minimum halo mass of sub-mm galaxies is about 3 x 10^{11} M_{sun}
- This minimum mass scale for sub-mm galaxies corresponds to the most efficient dark matter mass scale for star-formation in the Universe.

Amblard, A., Cooray, A., Serra, P. et al. *Sub-millimetre Galaxies reside in Dark Matter Halos with mass greater than 3x10^{11} M_{sun},* Nature, March 24, 2011.

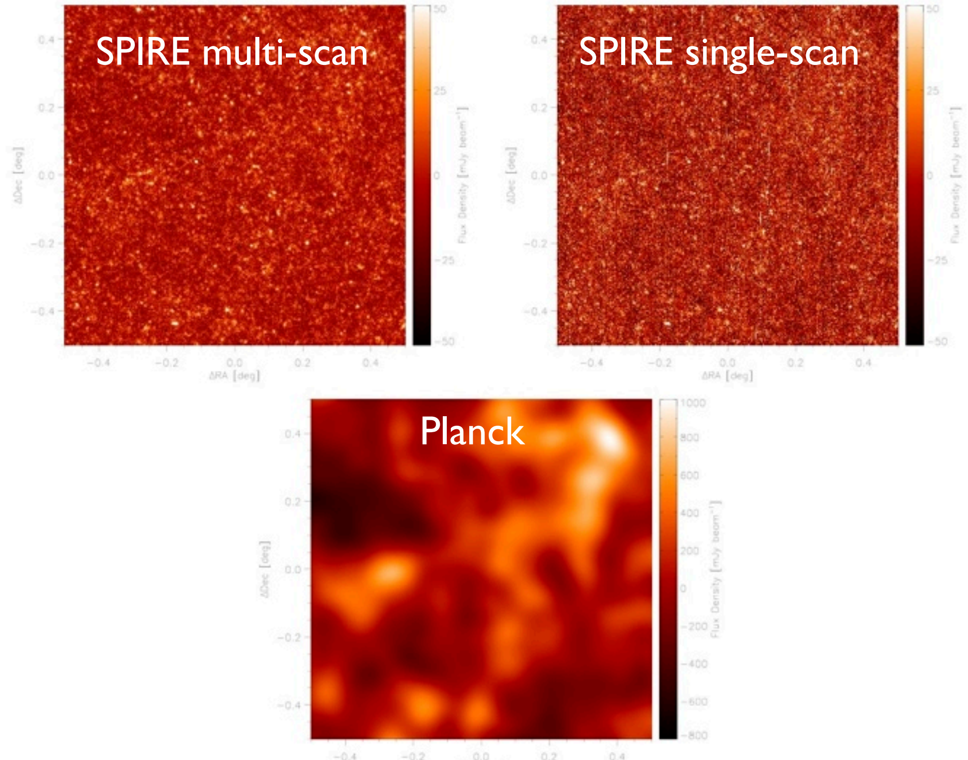
Comparison to Planck and others





Planck CIB in Lagache et al. 2010; joint Planck+Herschel in preparation

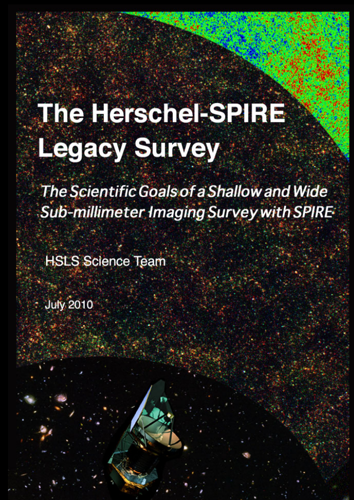
more measurements, applications (e.g., a search for lensing of the CIB) is going on now with papers over the next year.


SPIRE multi-scan
SPIRE single-scan
Planck

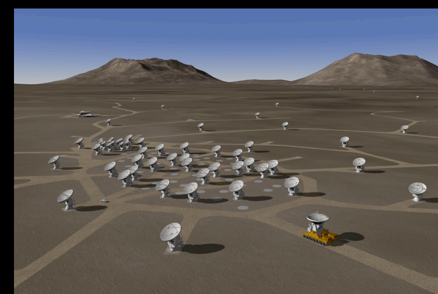
Herschel-SPIRE Legacy Survey (HSLS)

Version 2010: 4000 sq. degrees on the sky with SPIRE. *780 hours to complete, single scans in SPIRE fast-mode (60"/sec). ESA/HOTAC declined due to overall schedule constraints.*

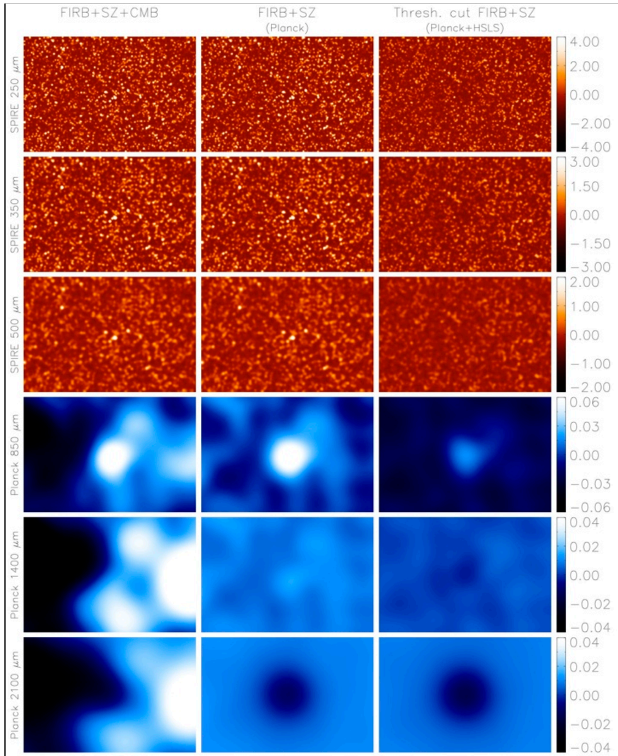
Version 2011: 1500 to 2000 sq. degrees to be proposed in September 2011. Unlikely to be contiguous! Final coverage depends on helium boil-off (January 2013 +/- 2 months)



The HSLS will find 1 to 2 million dusty galaxies,
~1000 strongly lensed bright sources easily identified
~1 million at z~2, 10,000 at z>4. Follow-up targets for ALMA, SPICA etc.
a goldmine for cosmology!



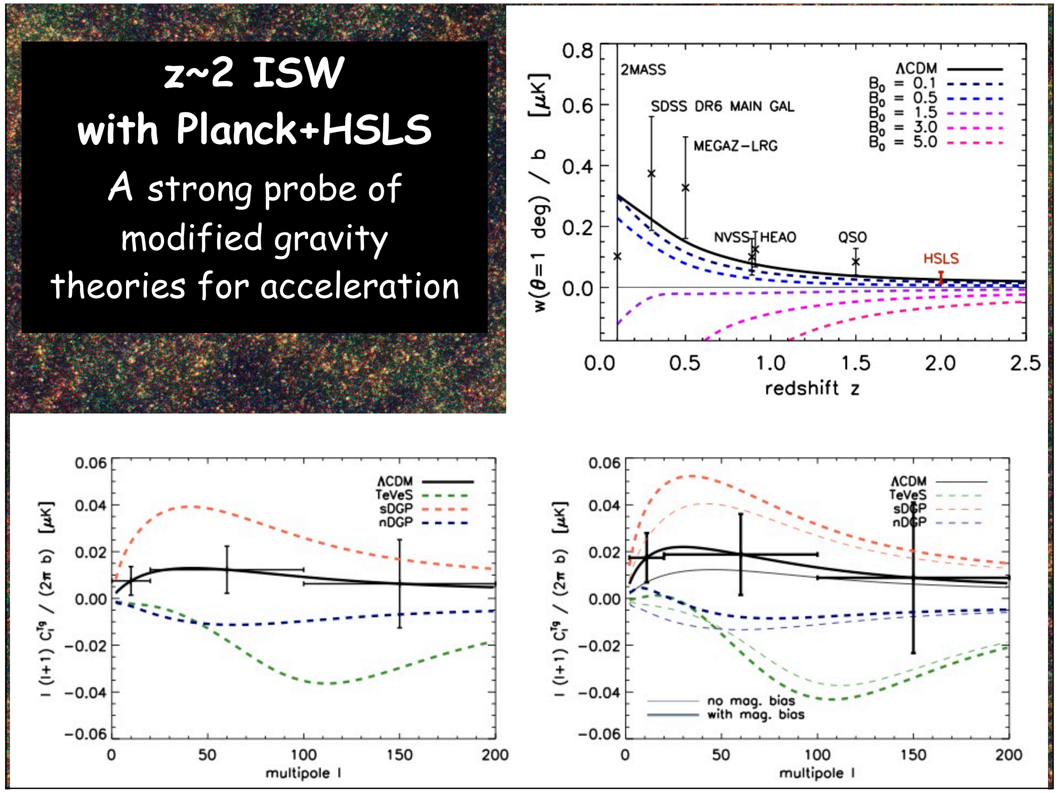
see the HSLS White Paper on the arxiv.

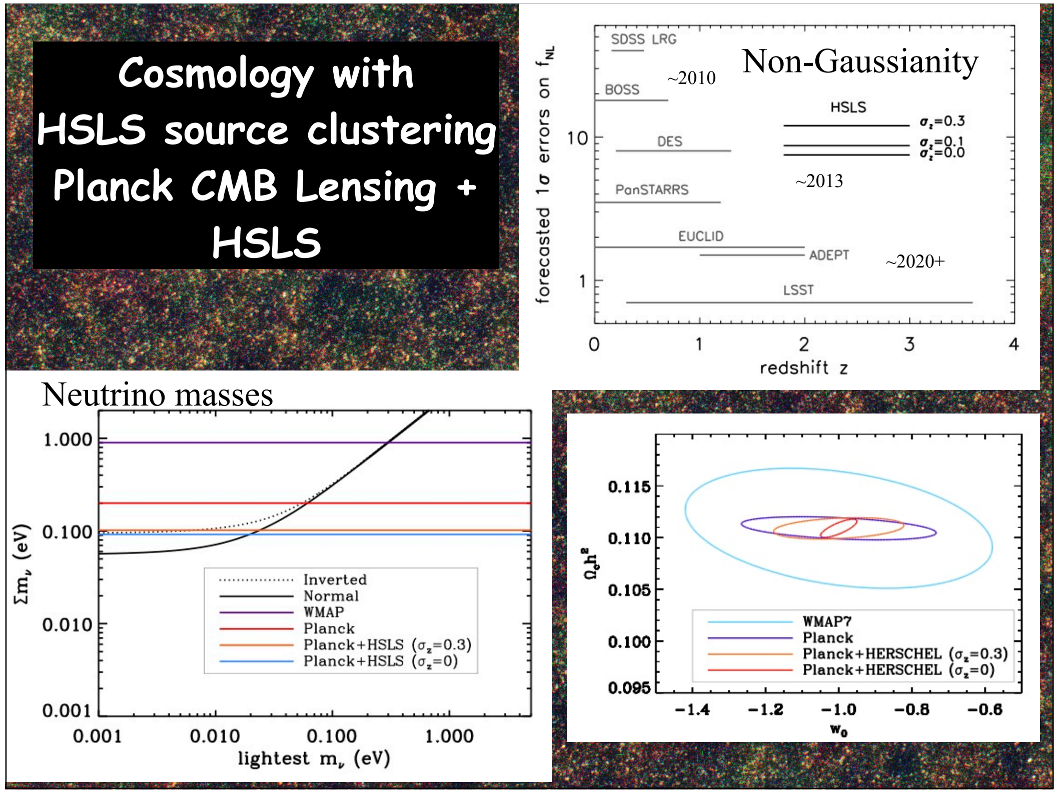


Cosmological Applications of HSLS sources and maps

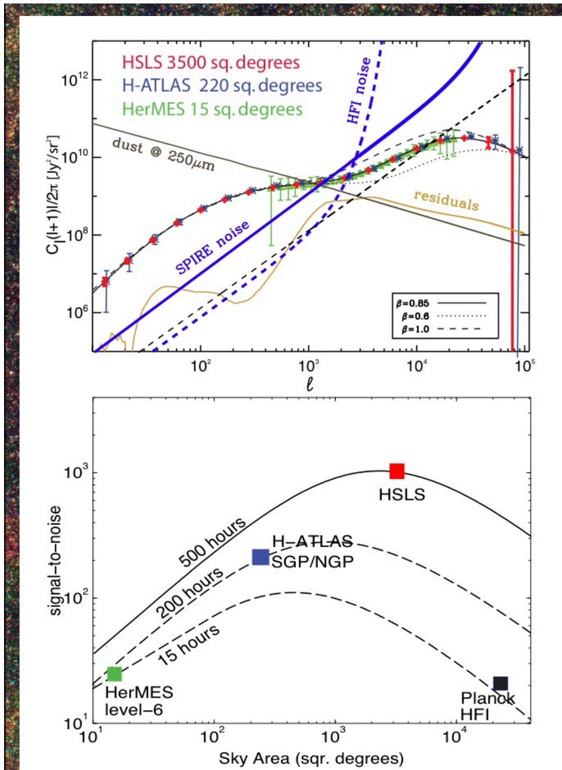
HSLS will "clean" Planck SZ clusters

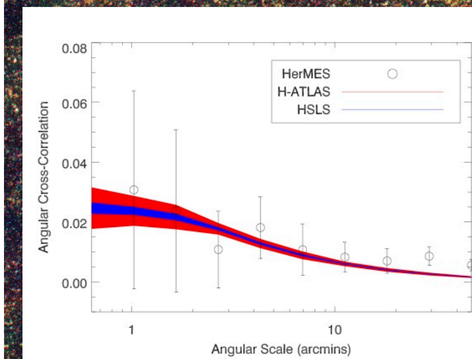
leading to peculiar velocities, gas temperature from relativistic corrections, more accurate cluster mass estimates.


z~2 ISW
with Planck+HSLS
A strong probe of
modified gravity
theories for acceleration
w(θ=1 deg) / b [μK]
redshift z
2MASS
SDSS DR6 MAIN GAL
MEGAZ-LRG
NVSS HEAO
QSO
HSLS
ΛCDM
B0 = 0.1
B0 = 0.5
B0 = 1.5
B0 = 3.0
B0 = 5.0
l (l+1) C_l^Tg / (2π b) [μK]
multipole l
ΛCDM
TeVeS
sDGP
nDGP
no mag. bias
with mag. bias

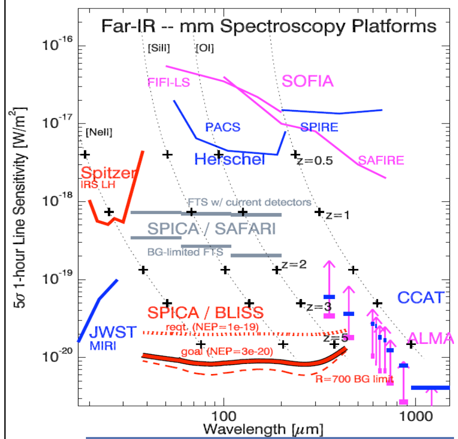

Cosmology with
HSLS source clustering
Planck CMB Lensing +
HSLS
Non-Gaussianity
forecasted 1σ errors on f_NL
redshift z
SDSS LRG
~2010
BOSS
HSLS
σ_z=0.3
σ_z=0.1
σ_z=0.0
DES
~2013
PanSTARRS
EUCLID
ADEPT
~2020+
LSST
Neutrino masses
Σm_ν (eV)
lightest m_ν (eV)
Inverted
Normal
WMAP
Planck
Planck+HSLS (σ_z=0.3)
Planck+HSLS (σ_z=0)
Ω_c h^2
w_0
WMAP7
Planck
Planck+HERSCHEL (σ_z=0.3)
Planck+HERSCHEL (σ_z=0)

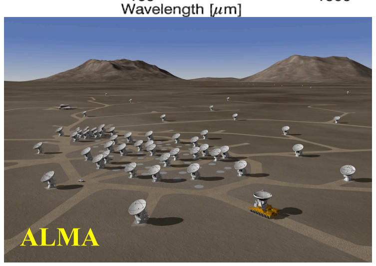
HSLS fluctuations and weak lensing magnification

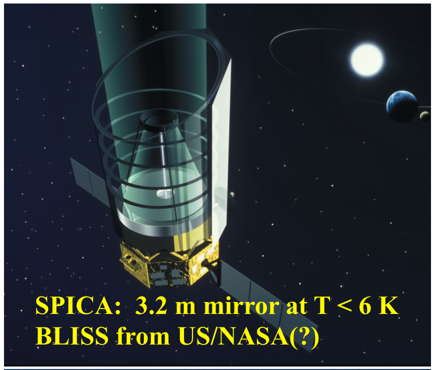




After Herschel?







Conclusions

Herschel has opened up the dusty universe in a new wavelength regime for the first time.

After waiting 10 years, we are finally buried in data

Large sample of lenses, mostly unexpected (what do we get out at the end?). First CIB fluctuations measured. More to come over the next two years.

follow progress at http://oshi.esa.int