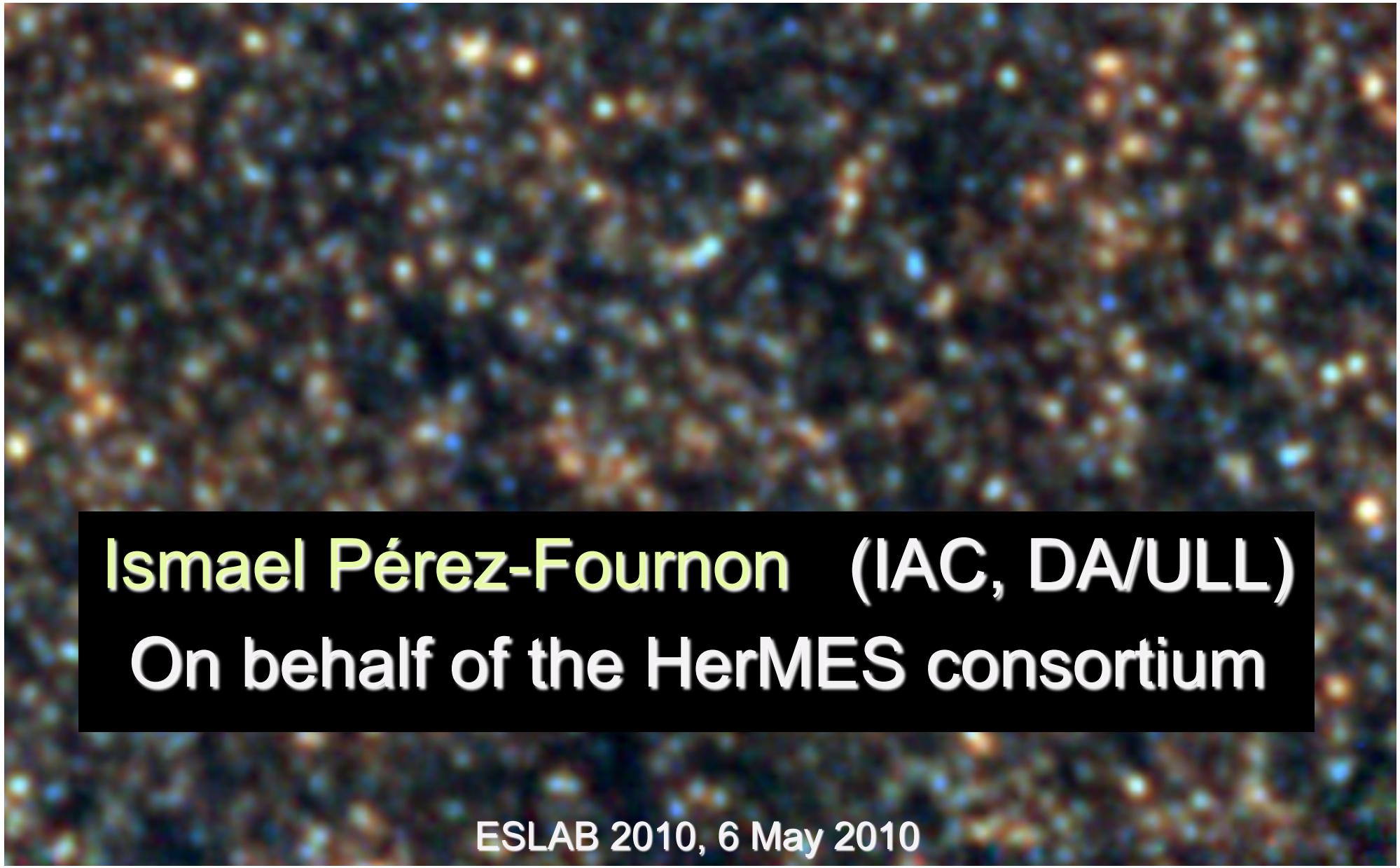
# The Herschel multi-Tiered Extragalactic Survey: the Nature of Herschel Galaxies (Colours, SEDs, high-z Candidates)



Ismael Pérez-Fournon (IAC, DA/ULL)
On behalf of the HerMES consortium

ESLAB 2010, 6 May 2010

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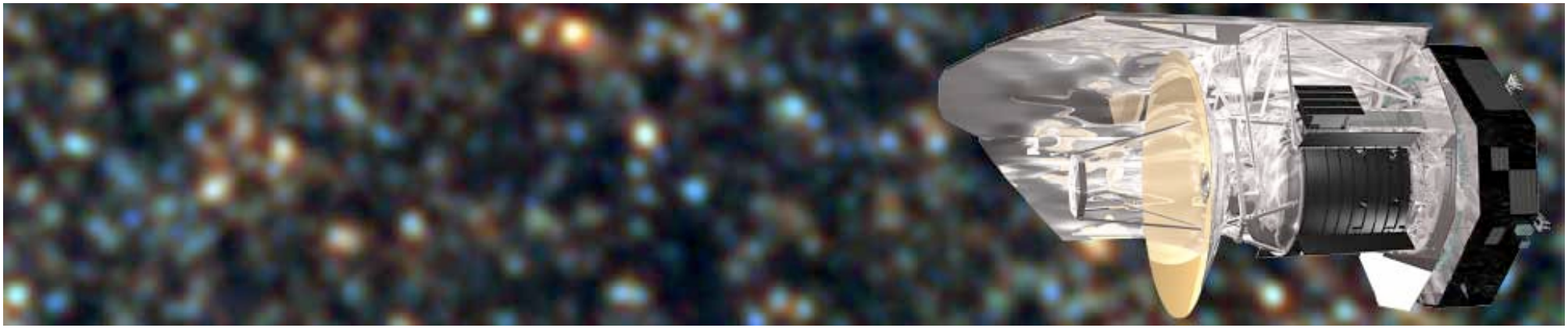
hermes.sussex.ac.uk



# HERSCHEL MULTI-TIERED EXTRAGALACTIC SURVEY

# The HERMES Team

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, Emanuele Daddi, 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, Sebastien 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, HienTrong Nguyen, Brian O'Halloran, Seb Oliver, Alain Omont, Frazer Owen, Mathew Page, Maurillo Pannella, Pasquale Panuzzo, Andreas Papageorgiou, Harsit Patel, Chris Pearson, Ismael PerezFournon, Michael Pohlen, Naseem Rangwala, Jason Rawlings, Gwen Raymond, Dimitra Rigopoulou, Laurie Riguccini, Davide Rizzo, Giulia Rodighiero, Isaac Roseboom, Michael Rowan-Robinson, Miguel SanchezPortal, 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, Laurent Vigroux, Lingyu Wang, Rupert Ward, Don Wiebe, Gillian Wright, Kevin Xu, Michael Zemcov

Faculty and Researchers PostDocs Students

+ engineers, instrument/software, developers etc.

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# Outline

- HerMES main science goals and overview of the first results (see also talks by David Elbaz, Mat Page and Seb Oliver and the HerMES posters)
- HerMES fields and levels
- HerMES SDP observations
- Source extraction
- SPIRE colours
- Multi-wavelength colours
- Search for FIR galaxies at very high-z ($z > 4$)
- High-z populations (SMGs, LBGs, OFRGs, …)
- Low-, and intermediate-z populations: SEDs, Td, extinction properties
- Conclusions

# HerMES science goals

HerMES has being designed to chart the formation and evolution of infrared galaxies throughout cosmic history. It consists of a nested set of the best cosmological fields for FIR/ submm observations.

HerMES main science goals are to:

- measure the bolometric emission of infrared galaxies
- study the evolution of the luminosity function,
- measure their clustering properties, and
- probe populations of galaxies below the confusion limit through lensing and statistical techniques.

We make maximum use of ancillary surveys from radio to X-ray wavelengths to facilitate source extraction, redshift determination, rapidly identify unusual objects, and understand the relationships between thermal dust emission and other emission mechanisms.

HerMES is providing a rich data set legacy for the astronomical community to mine for years to come. The HerMES data products will be released through the HeDAM database in Marseille:

http://hedam.oamp.fr/HerMES

First data release: before the OT proposal deadline in July 2010.

# HerMES SDP papers
# A&A special issue and other journals

- 10 papers submitted for the A&A special issue

(two of them joint HerMES&PEP papers)

- Many more in preparation

- 16 posters presented at this conference

# Hermes: ESLAB 2010 posters

- **P1.47** HerMES, the Herschel Multi-tiered Extragalactic Survey: FIR Properties of known AGN ***Hatziminaoglou, E.*** *& HerMES*
- **P1.49** Deep Galaxy Number Counts: A Fluctuation Analysis of SPIRE Science Demonstration Phase Observations ***Glenn, J.*** *& HerMES*
- **P1.51** Spectral Energy Distributions, Luminosities, & Star-Formation Rates in GOODS-North Galaxies ***Brisbin, D.*** *& HerMES*
- **P1.52** HerMES the Herschel multi-tiered Extragalactic Survey: The Herschel View of Star Formation ***Buat, V.*** *& HerMES*
- **P1.53** HerMES, the Herschel Multi-Tiered Extragalactic Survey: A Comparison of Mid and Far-Infrared Star Formation Indicators using Herschel and Spitzer IRS ***Castro-Rodríguez, N.*** *& HerMES*
- **P1.61** Wide Field Extragalactic Surveys at 100 and 160 μm from HerMES: Number Counts and Contribution of PACS Sources to the SPIRE Population ***Aussel, H.*** *& HerMES*
- **P1.63** HerMES Observation of SMG ***Chanial, P.*** *& HerMES*
- **P1.65** HerMES, the Herschel Multi-Tiered Extragalactic Survey: Candidate High-Redshift Galaxies discovered with SPIRE ***Dowell, C.*** *& HerMES*

- **P2.47** HerMES the Herschel Multi-tiered Extragalactic Survey: Aggregate FIR Properties of 3.6 micron, 24 micron andRadio-Selected Galaxies ***Vieira, J.*** *& HerMES*
- **P2.49** HerMES, the Herschel Multi-Tiered Extragalactic Survey: The Far-Infrared Properties of Type-2 Quasi-Stellar Objects ***Stevens, J.*** *& HerMES*
- **P2.55** PACS/SPIRE Properties of IRAC Selected Star-Bursts at z~2 ***Magdis, G.E.*** *& HerMES*
- **P2.56** HerMES, the Herschel Multi-tiered Extragalactic Survey: Star Formation in Powerful Radio and X-ray AGN ***Seymour, N.*** *& HerMES*
- **P2.59** HerMES the Herschel Multi-tiered Extragalactic Survey: Dust and Star Formation around Distant X-Ray selected AGN. ***Page, M.*** *& HerMES*
- **P2.63** The FIR/SMM Local Luminosity Density : The HerMES Local Luminosity Function at 100-500 micron ***Vaccari, M.*** *& HerMES*
- **P2.65** The Submillimeter Colors of Herschel/SPIRE-Detected Galaxies ***Schulz, B.*** *& HerMES*
- **P2.67** The SPIRE Confusion Limit ***Nguyen, T.*** *& HerMES*

# HERMES The largest project on Herschel (850 hours)

Clusters

Level1 0.11 □°

Level2 0.36 □°

Level3 1.25 □°

Level4 ~4 □°

Level5 ~30 □°

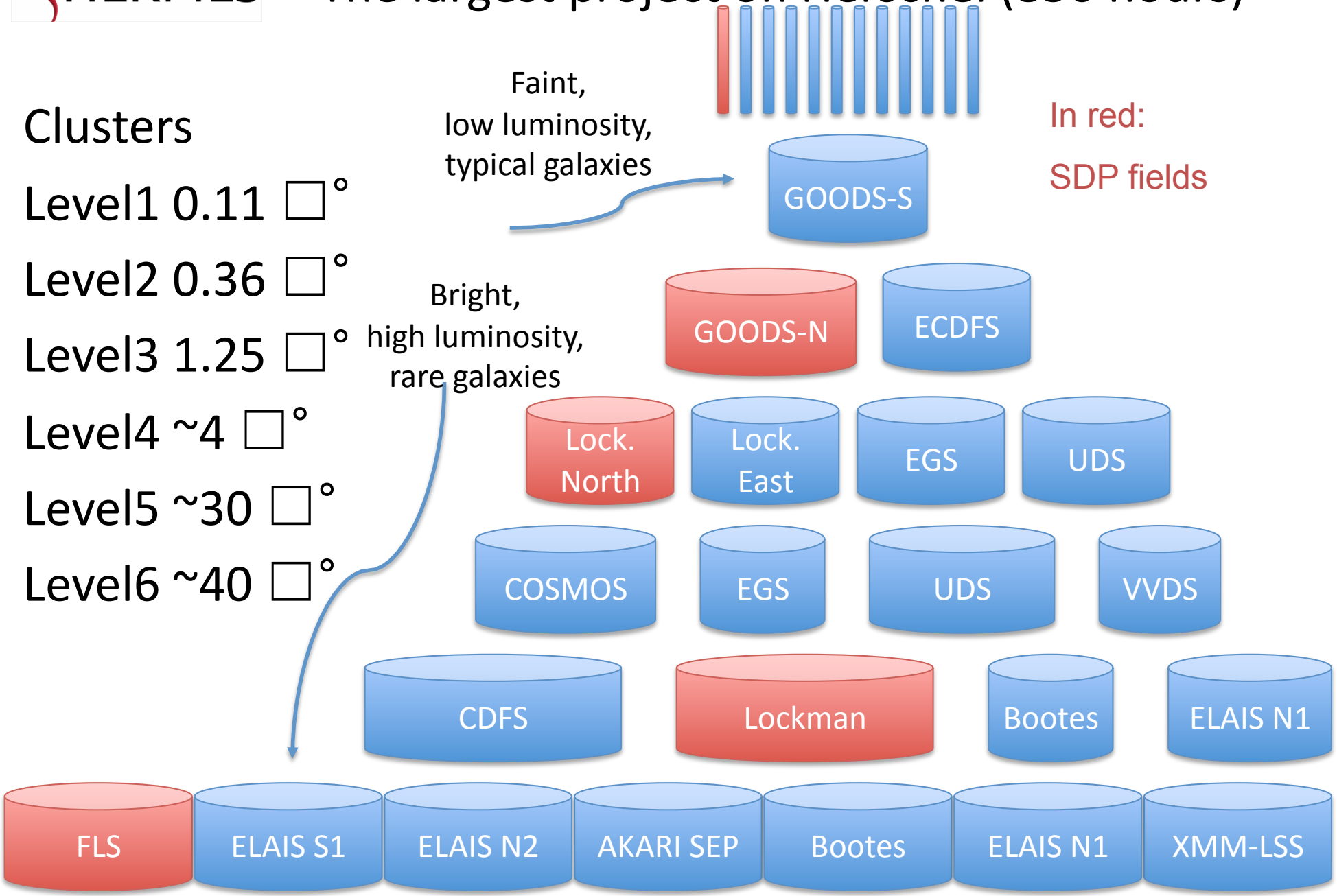
Level6 ~40 □°

Faint,
low luminosity,
typical galaxies

Bright,
high luminosity,
rare galaxies

In red:

SDP fields



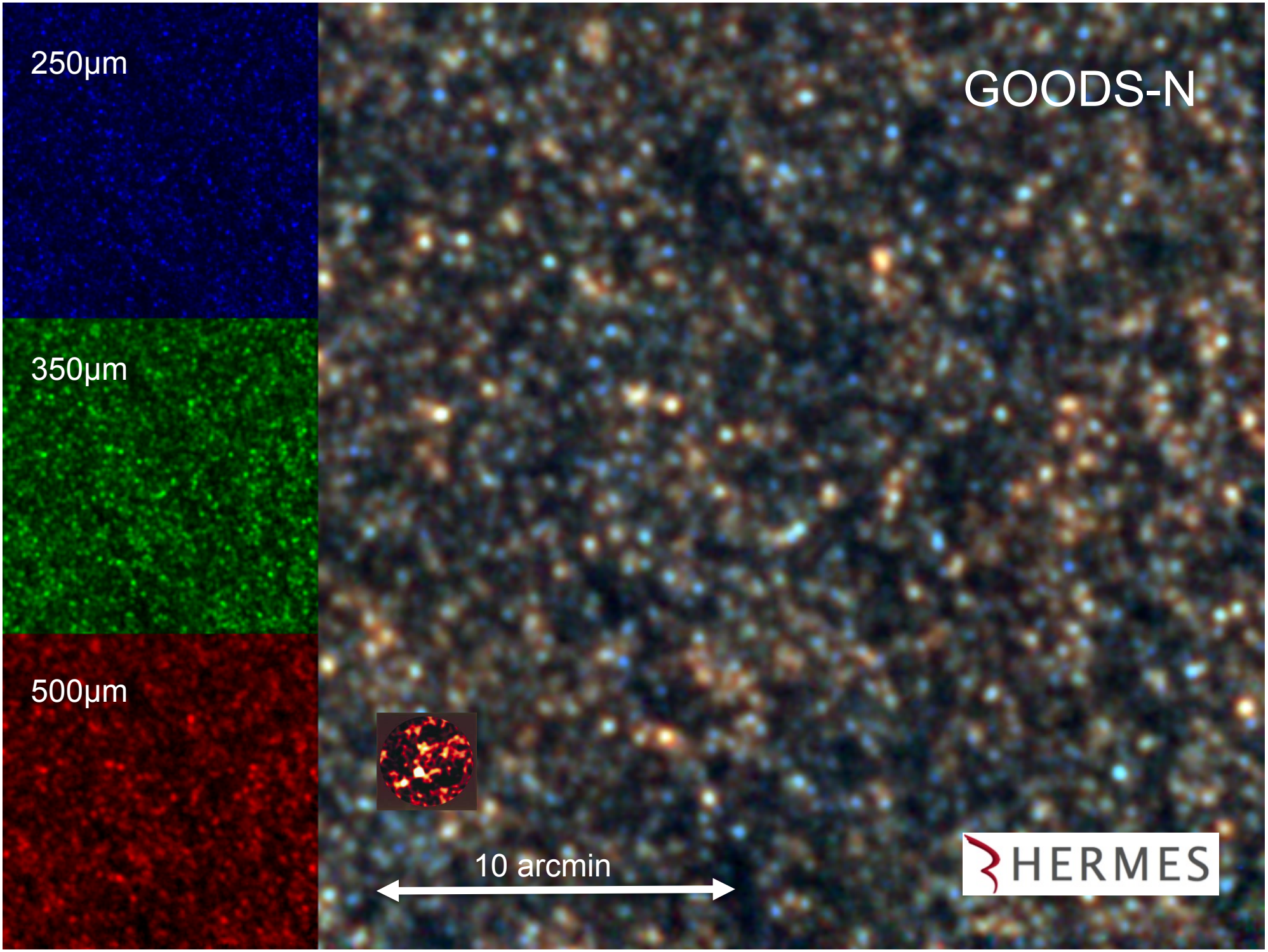
# HERMES Science Demonstration Observations

| | | |
|---|---|---|
| • Abell 2218 | 9’ × 9’ | SPIRE |
| • GOODS-N | 30’ × 30’ | SPIRE |
| • Lockman-North | 35’ × 35’ | PACS & SPIRE |
| • FLS | 2.6° × 2.3° | PACS & SPIRE |
| • Lockman-SWIRE | 3.6° × 3.6° | SPIRE |

27,113 sources

Flux (250μm) > 20mJy

about 60 hours, 7% of our final time (850 hours)


250μm
350μm
500μm
GOODS-N
10 arcmin
HERMES

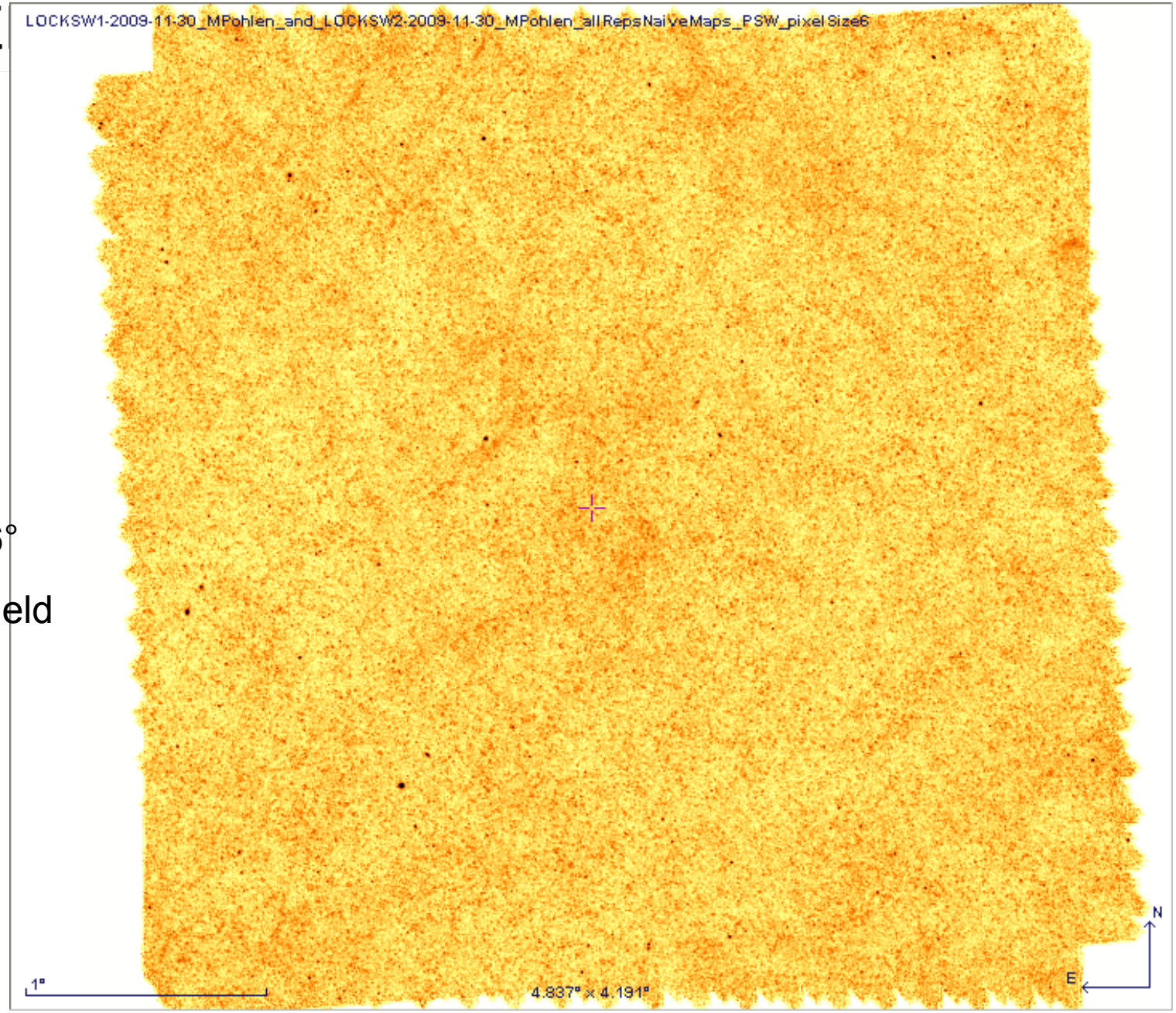
Lockman SWIRE

SPIRE 250μm

3.6° × 3.6°

Shallow field

(level 6)



SPIRE

250 μm image and detected objects (5-σ) in the joint SWIRE-HerMES area

250μm

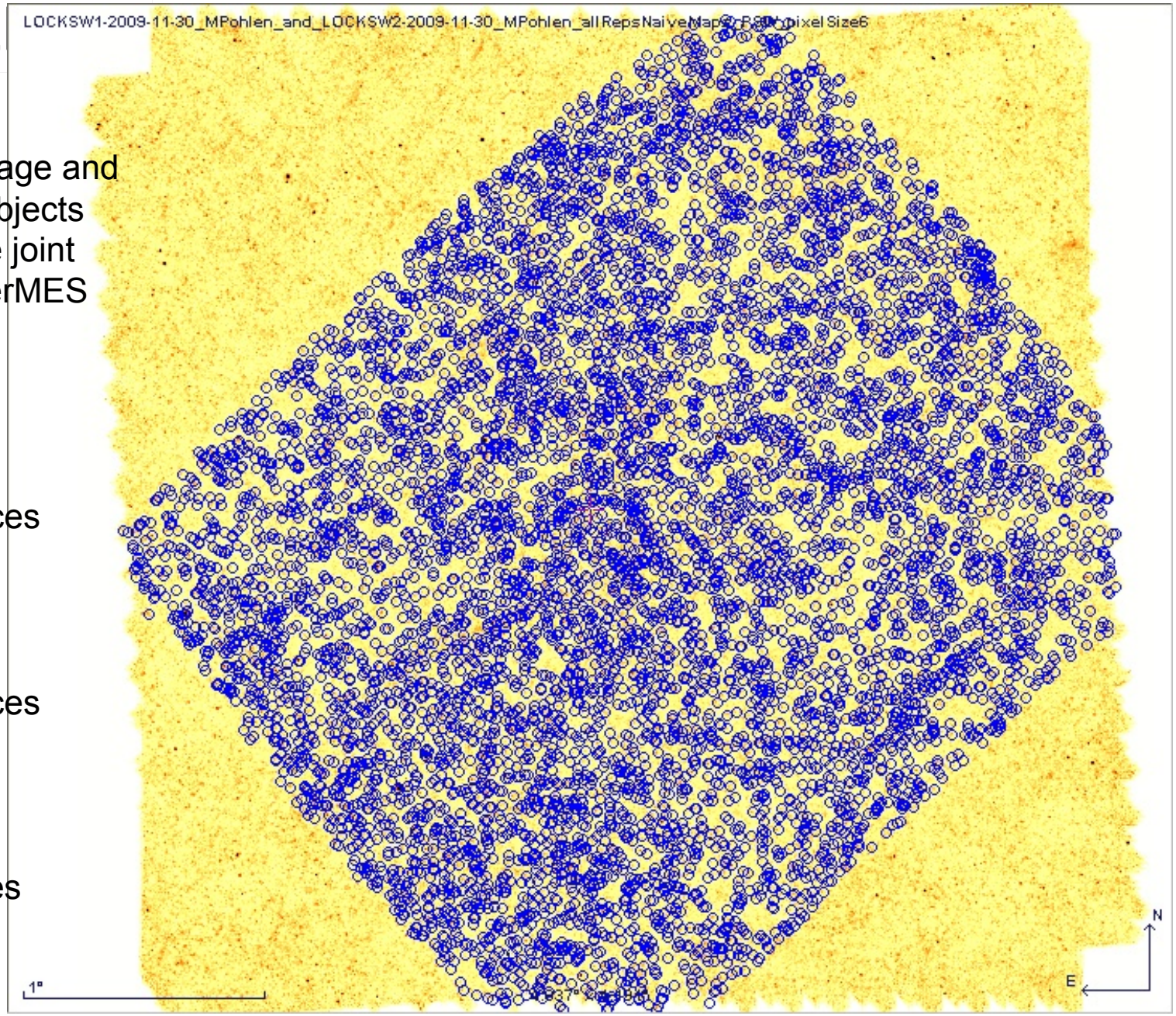
7772 sources

350μm

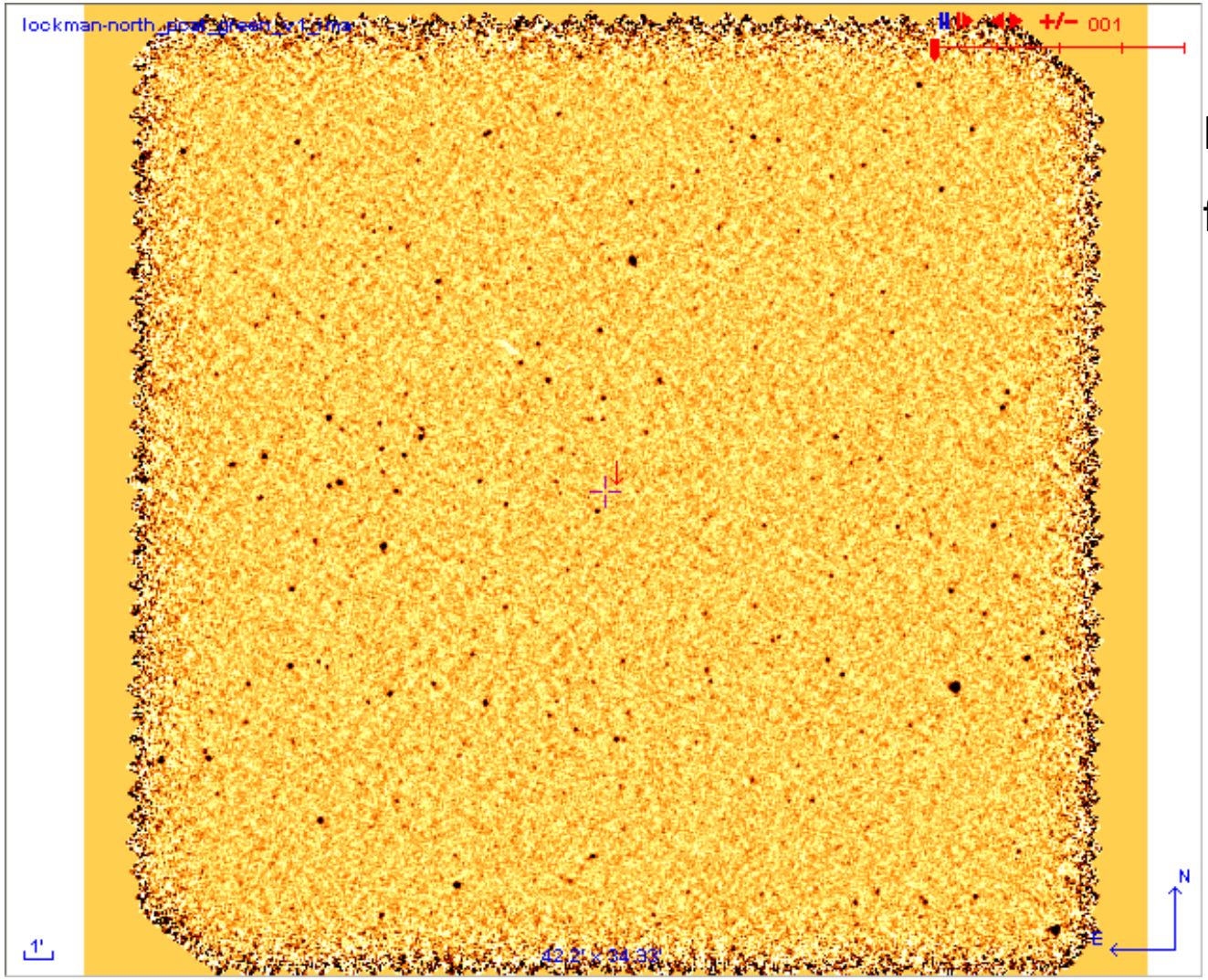
3808 sources

500μm

421 sources



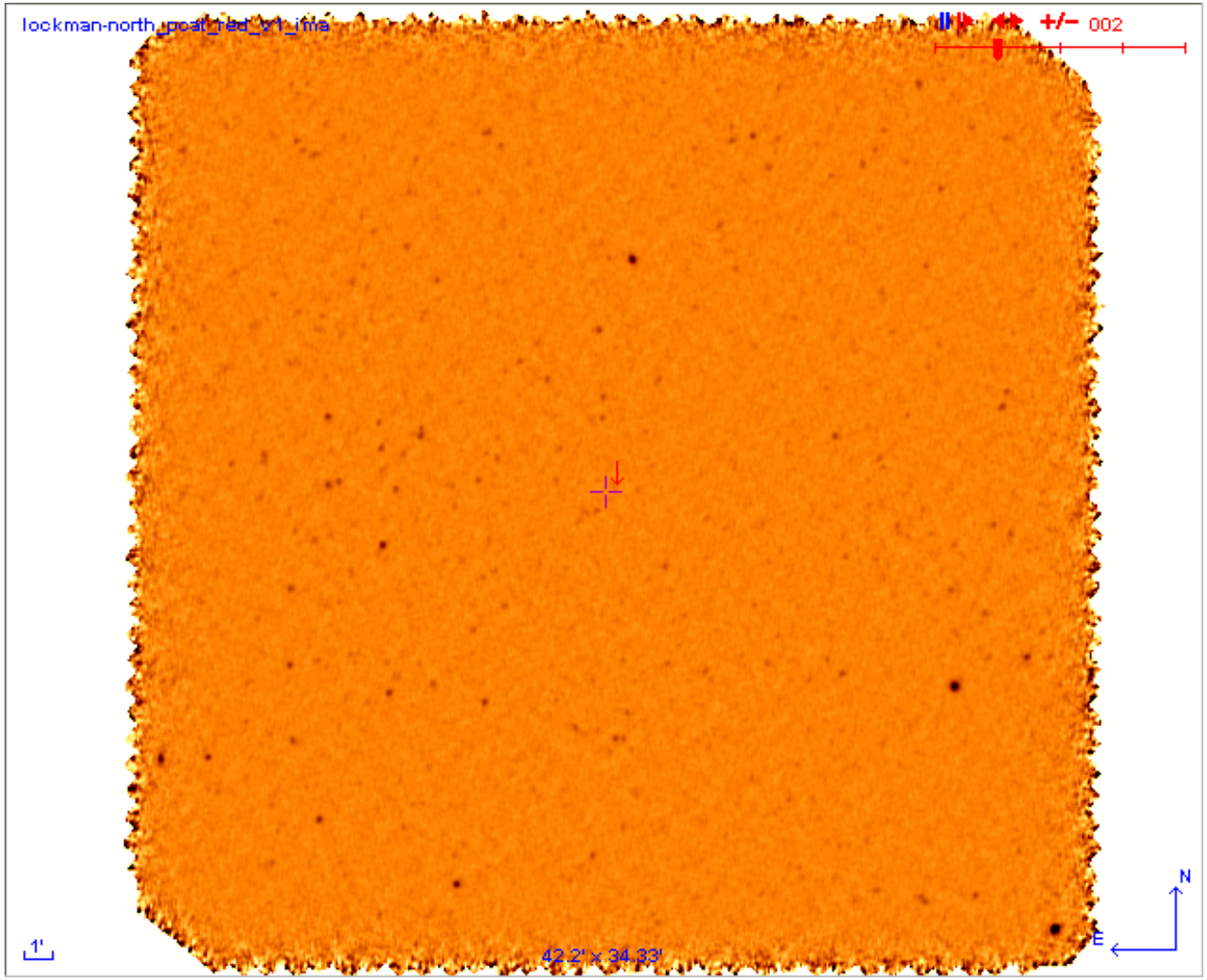
# Lockman North PACS 100 µm



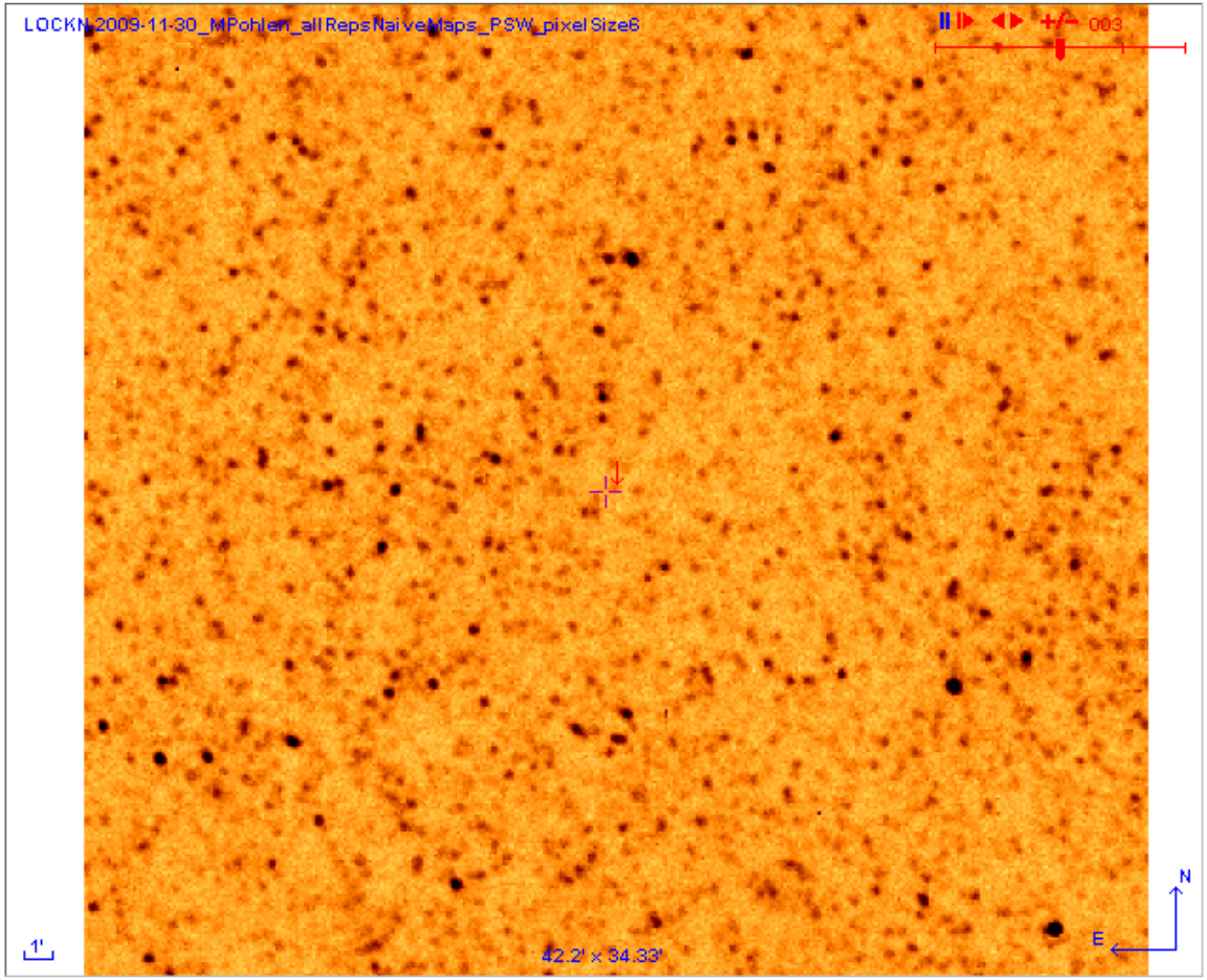

Medium-depth field (level 3)

Ultra-deep radio data available in this field

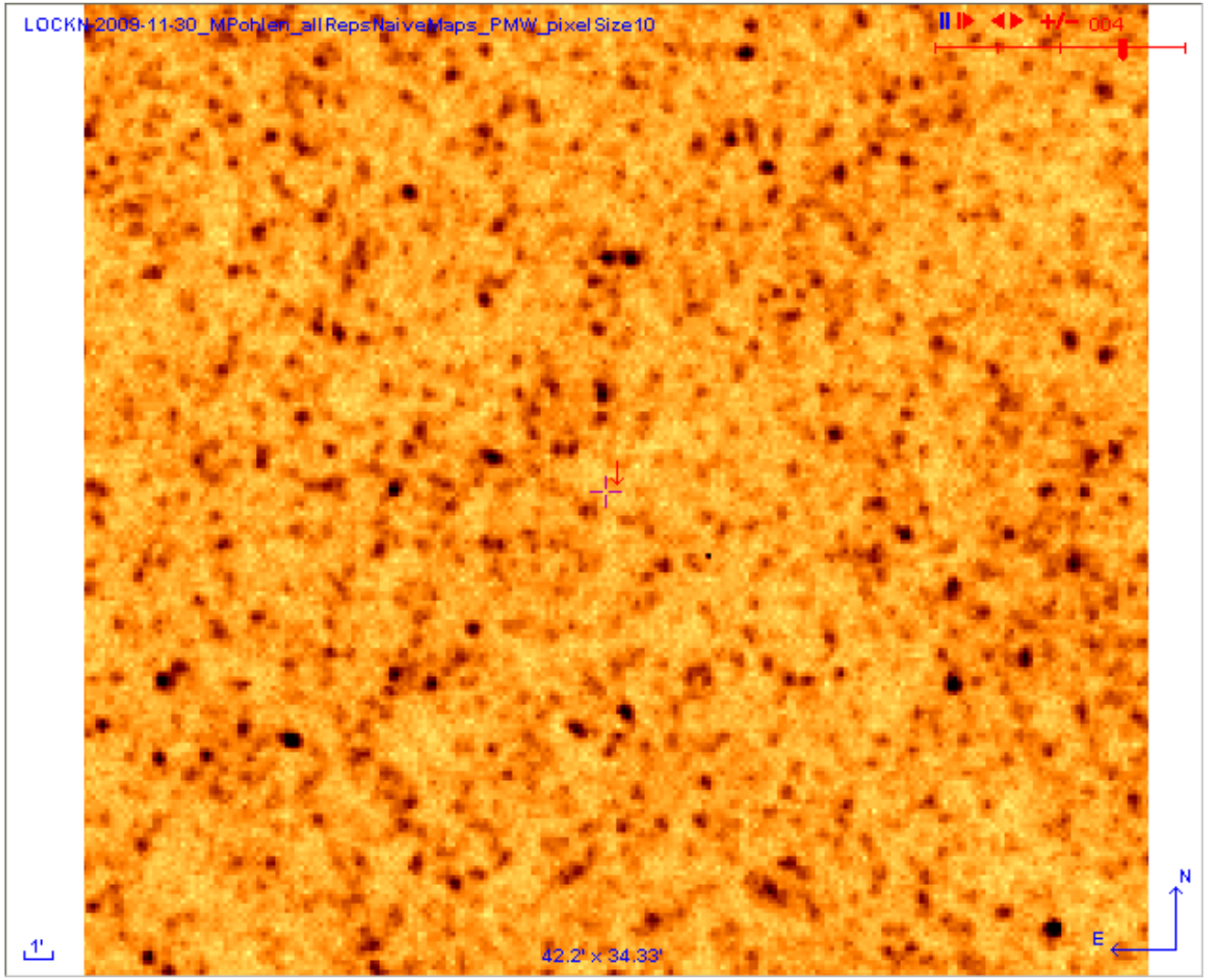
# Lockman North PACS 160 µm



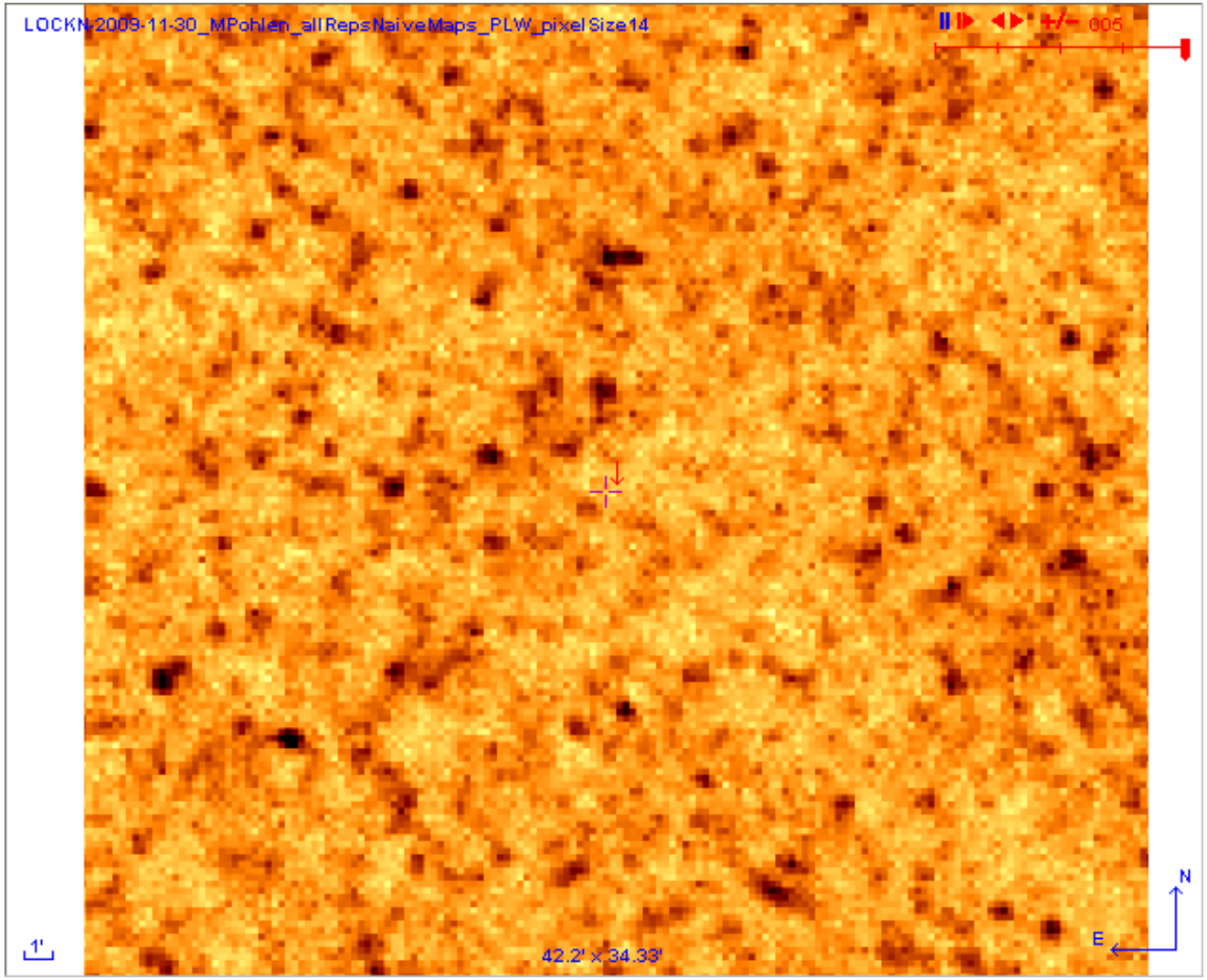
# Lockman North SPIRE 250 µm



# Lockman North SPIRE 350 µm



# Lockman North SPIRE 500 µm



# Source extraction

Two methods:

- Blind extraction

  Smith et al. 2010

- Extraction using priors (mainly Spitzer 24 µm fluxes and positions)

  Roseboom et al. 2010

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# Source extraction (XID)
# Roseboom et al. 2010

- The SPIRE fluxes of 24 μm sources are estimated using a linear inversion method which finds the best fit set of fluxes considering the 24 μm source positions and the SPIRE maps. Similar methods have been used previously on Spitzer and BLAST data (Magnelli et al. 2009; Bethermin et al. 2010; Chapin et al. 2010).
- Testing was performed on two simulated datasets by taking the mock catalogues of Fernandez-Conde et al. (2008) and producing maps which match the observed properties (i.e. noise, PRF) of our HDF-N (deep) and LH-SWIRE (shallow) data.
- Comparisons are performed between our XID method and two existing techniques; the ubiquitous p-statistic coupled with Sussextractor derived source catalogues, and a more simple map based approach based on Bethermin et al. (2010).
- At 250 μm the HerMES XID method is seen to outperform the others in terms of both completeness and flux accuracy for all fluxes. In the longer wavelength bands (350 μm and 500 μm), our method offers the best flux accuracy, although at the expense of significant incompleteness.

**While our method requires 24 μm detections, we estimate that in our deepest fields we are missing at most 15% of the faint SPIRE population with extreme 250/24 μm flux ratios.**

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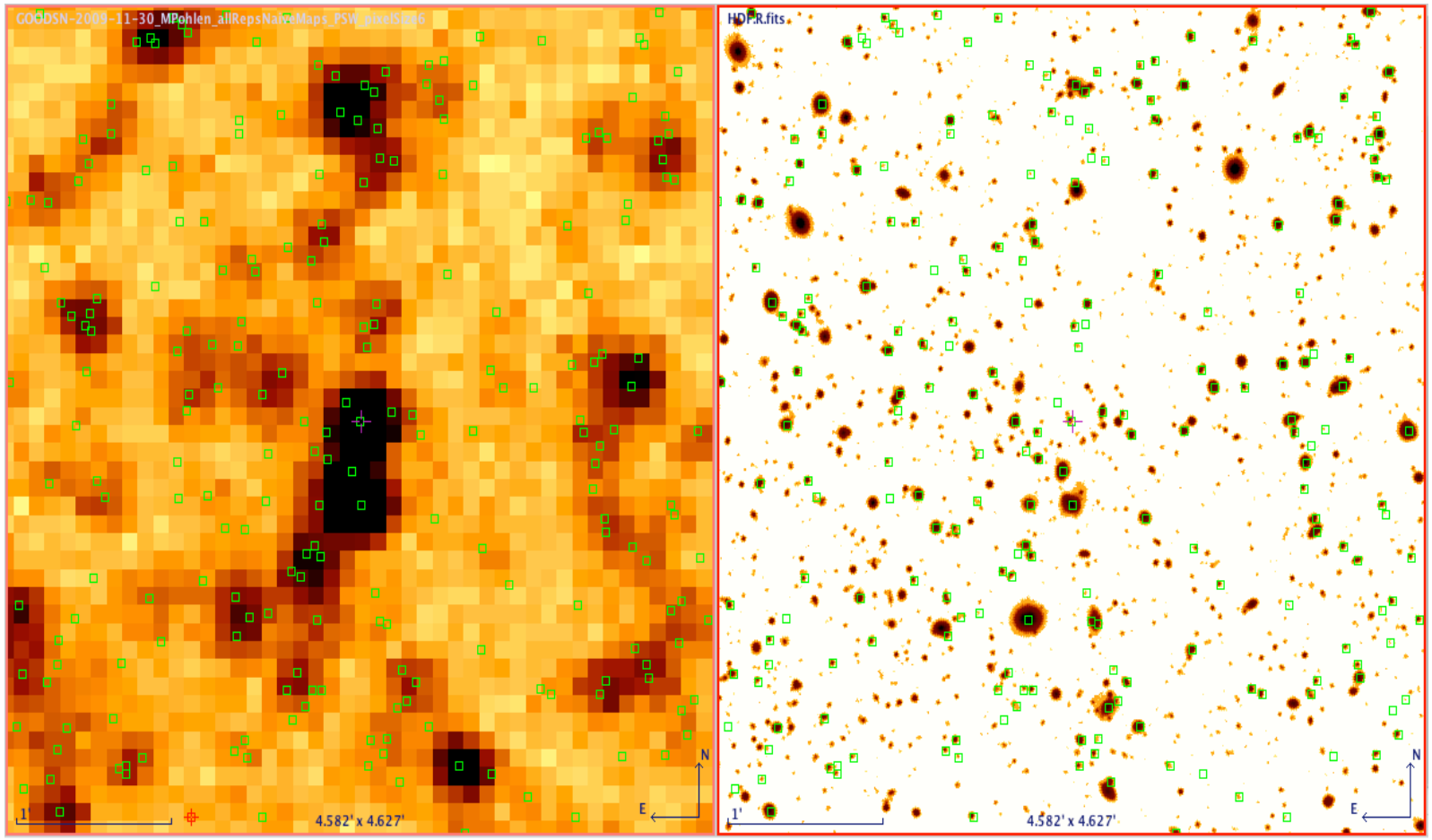
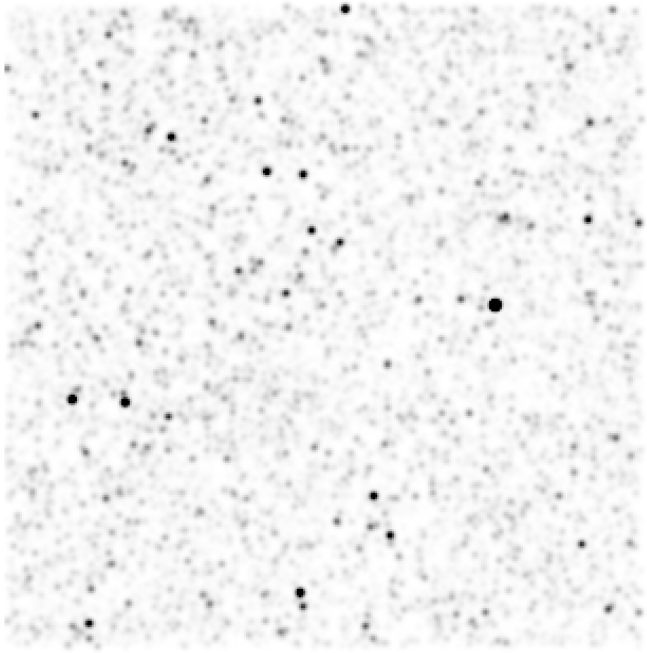
# Source extraction (XID)
# Roseboom et al. 2010



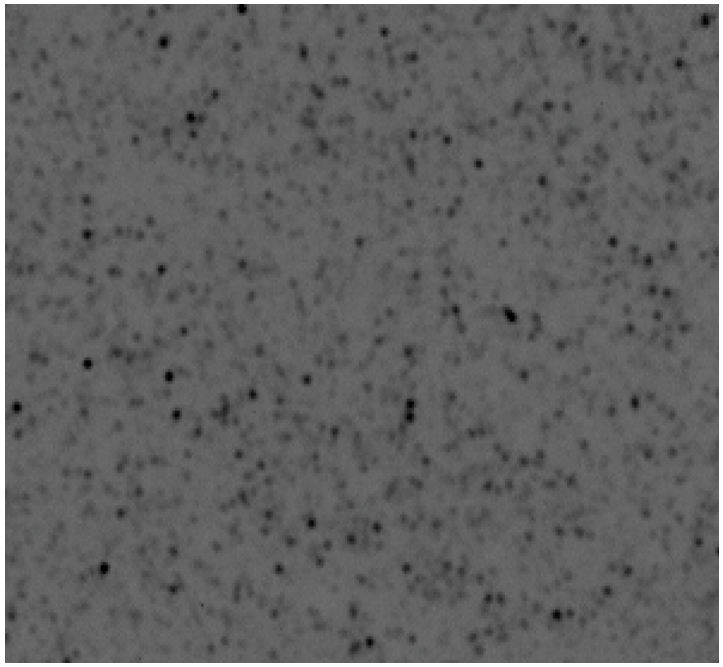

GOODS-N SPIRE 250 μm image (left), R-band optical (right). Green squares are Spitzer MIPS 24 μm sources. It is clear that even if we consider only 24 μm sources there are still ~1 src/beam. The strong correspondence between SPIRE 250 μm and 24 μm can be seen in the left image.

# Source extraction: simulations

The reliability of this method of source extraction has been evaluated using simulations. See detailed results on completeness and flux errors in Roseboom et al 2010.



250 μm simulated map



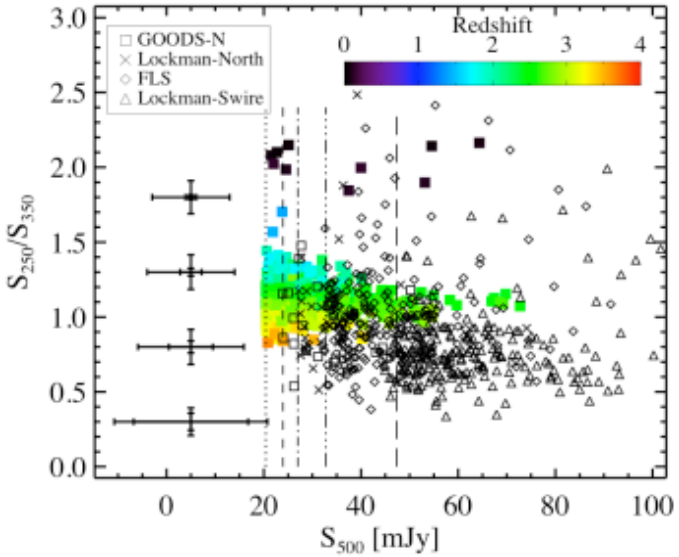
GOODS-N
SPIRE 250 μm

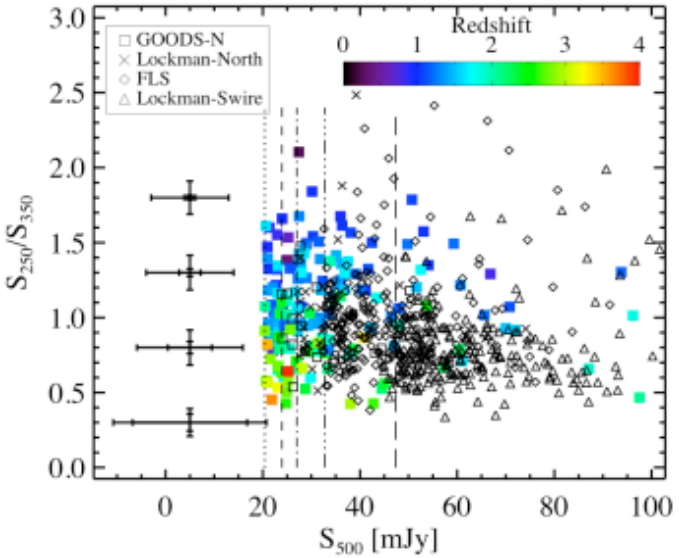
# SPIRE colours
# Schulz et al. 2010 & P2.65

- The observations in colour-colour space are in agreement with redshift tracks of contemporary models and the bulk of sources cover a range of 1<z<3.5 somewhat depending on the model used.
- The observations in colour-flux space show a population of red sources towards higher fluxes that is not well represented by model catalogues. This population is most likely a blend of closer objects with a strong cold dust component and distant lensed objects.

Mock catalog:

Pearson et al. 2007




Mock catalog:

Xu et al. 2007

Measured S250/S350 colour versus 500 μm flux distributions for the SPIRE sources (black symbols) in comparison with mock catalogues of Pearson et al. (2007) to the left and Xu et al. (2001) on the right. The large error crosses on the left represent average 1-sigma total uncertainties dominated by extragalactic confusion and the smaller tick marks show instrumental noise only, which is negligible for GOODS-N and Lockman-N.

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# Multi-wavelength colours
# Pérez-Fournon et al. 2010

- Large dispersion in most colour-z diagrams

  (due to the large separation in wavelength and different SED types)

- Small dispersion in colour-z in particular bands

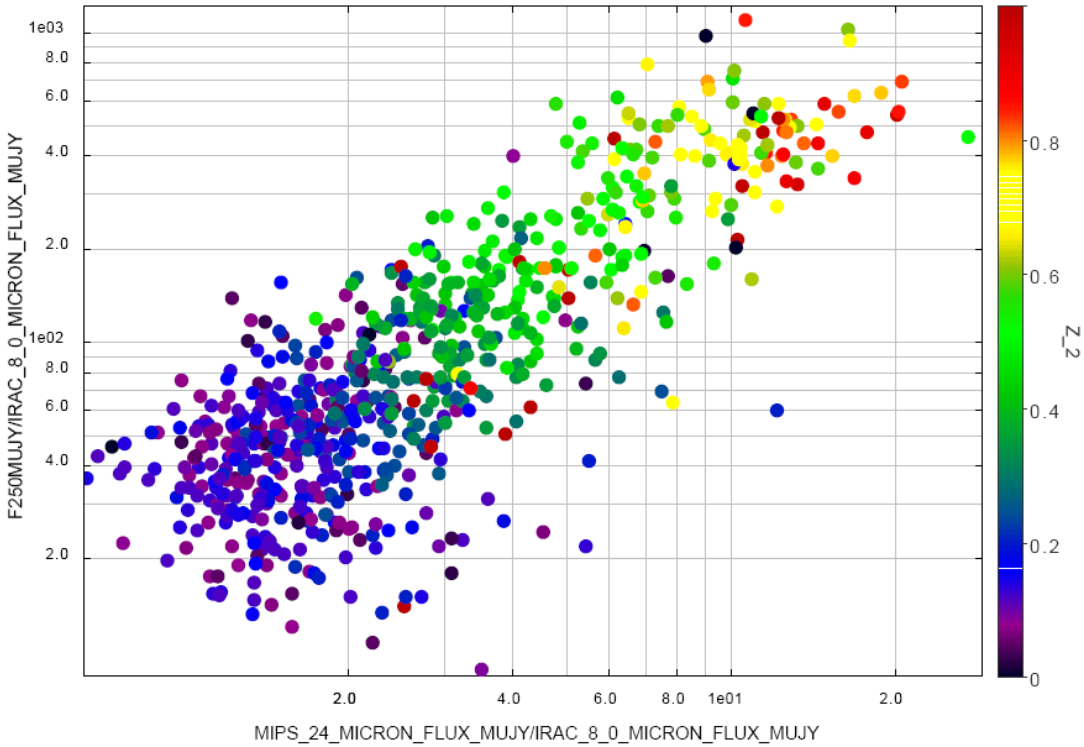
- Clear gradients with z in some colours (good redshift indicators)

# Multi-wavelength colours
# Pérez-Fournon et al. 2010

flux (SPIRE 250 μm) / flux (IRAC 8.0 μm) vs flux (MIPS 24 μm) / flux (IRAC 8.0 μm)

Sample:

z < 1 SPIRE sources in Lockman SWIRE with spectroscopic redshifts from the MMT/Hectospec survey of Huang et al. 2010




SPIRE 250 μm, Spitzer MIPS 24 μm, Spitzer IRAC 8.0 μm provide good redshift information of SPIRE sources at z < 0.8 (the bulk of the SPIRE sources in shallow surveys)

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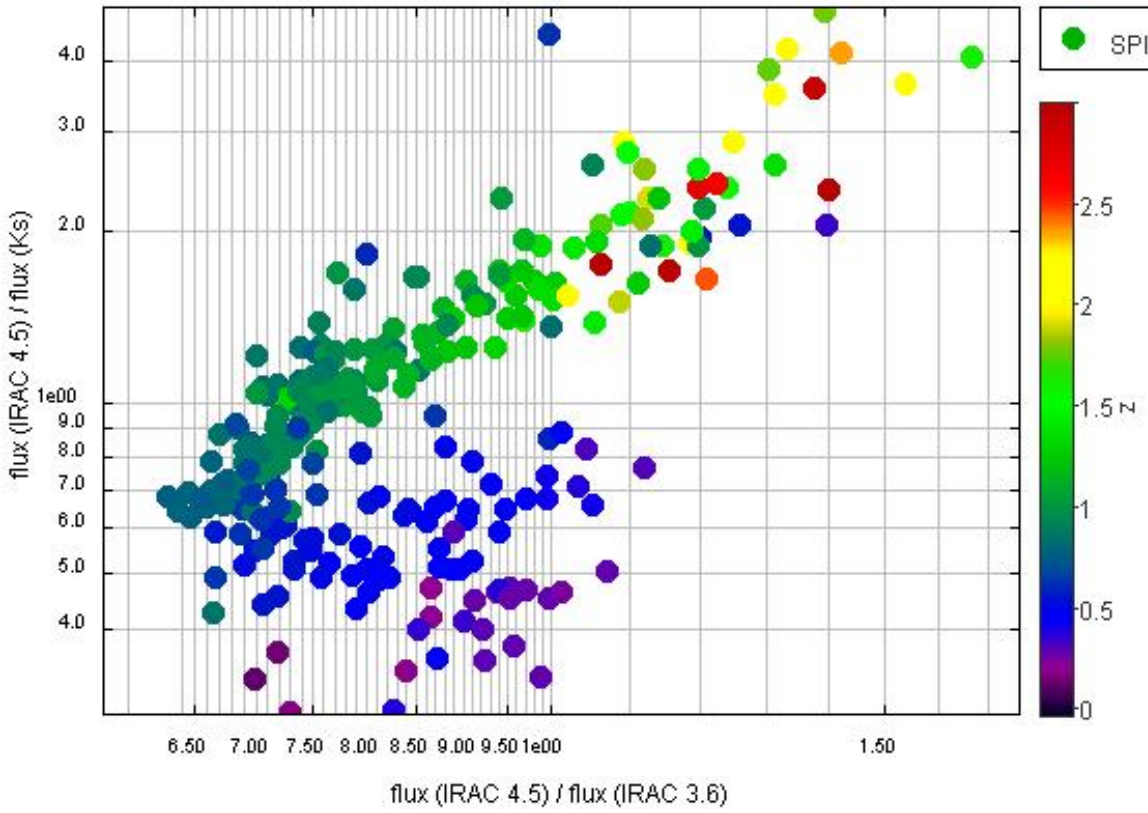
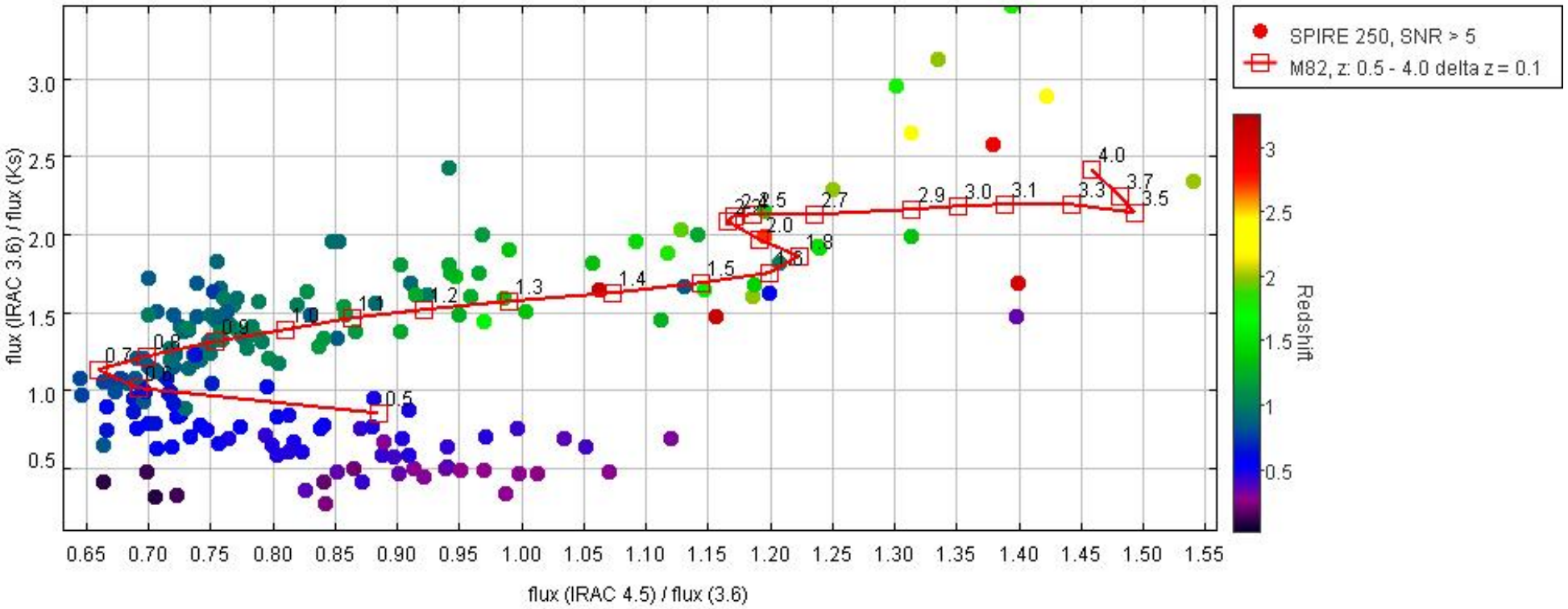
# Multi-wavelength colours
# Pérez-Fournon et al. 2010

flux (IRAC 4.5 μm) / flux (Ks) vs flux (IRAC 4.5 μm) / flux (3.6 μm)




Low dispersion of the colours of SPIRE sources in these bands

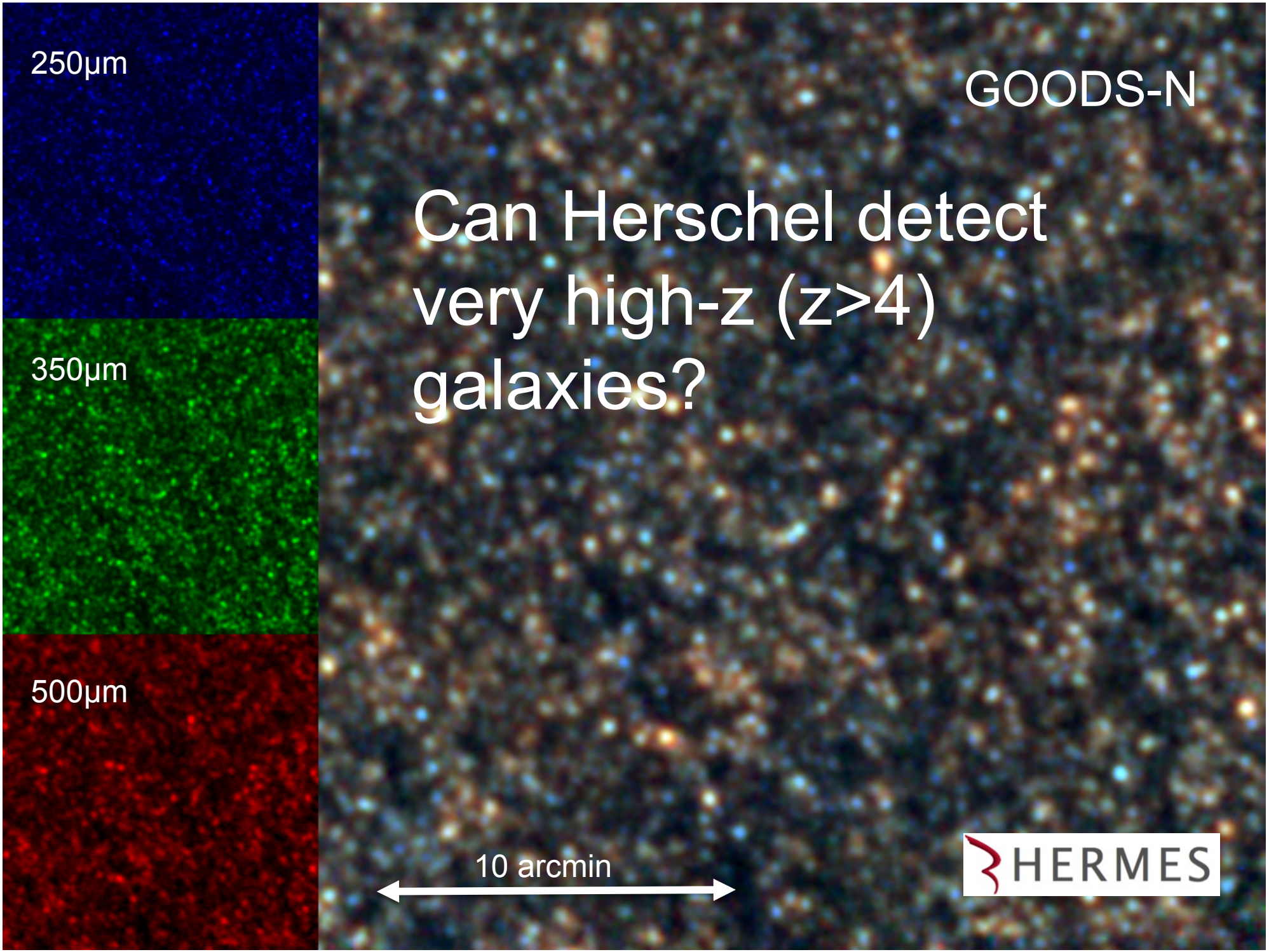
# Multi-wavelength colours
# Pérez-Fournon et al. 2010



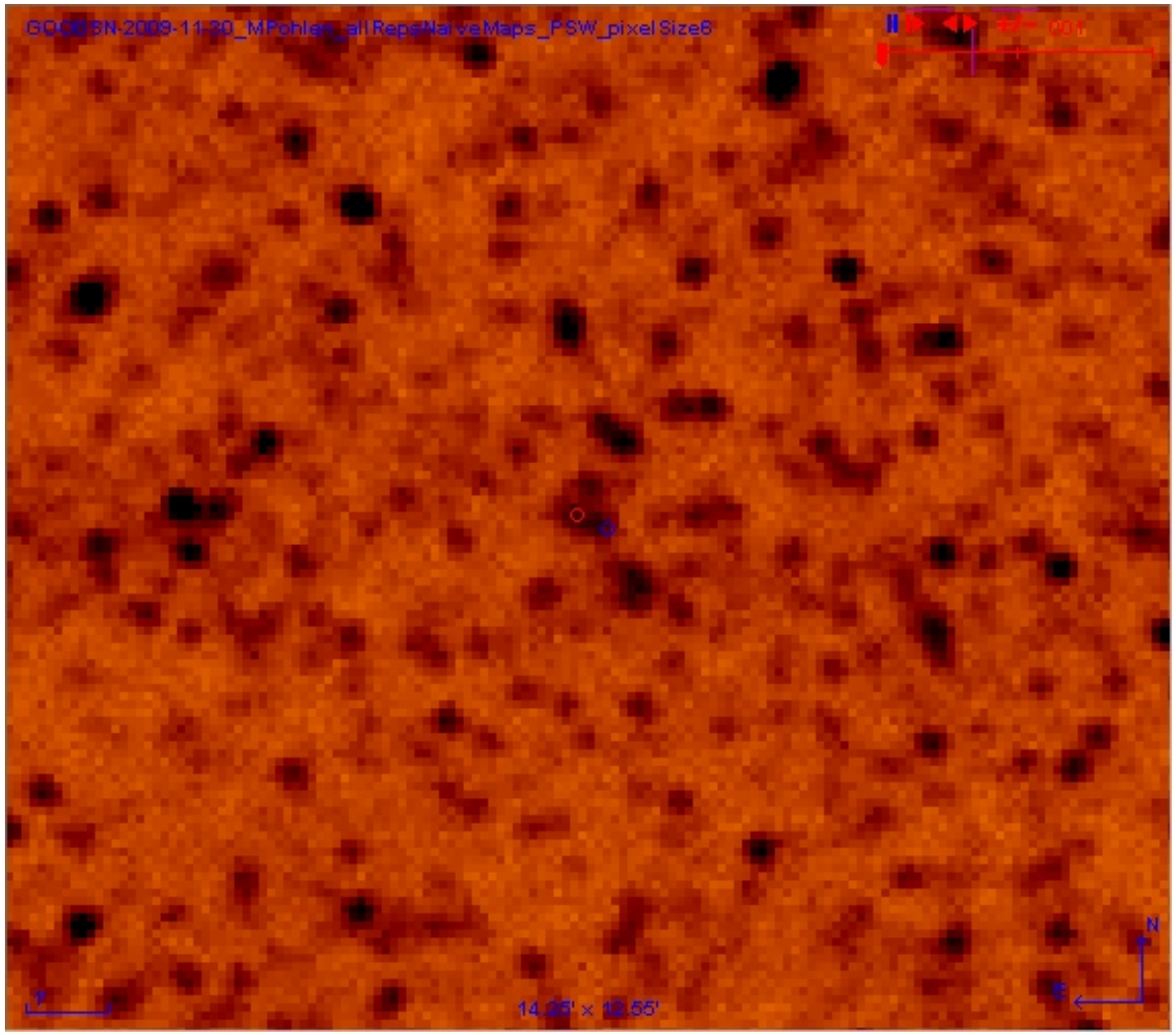

K, 3.6 μm, & 4.5 μm: good redshift indicators for SPIRE sources at 0.8 < z < 1.6

Good prospects for sample selections for near-IR spectroscopic follow-up

Good sinergy with Spitzer warm surveys (SERVS and SEDs) and ground-based near-IR surveys (UKIRT, VISTA, …)


250μm
350μm
500μm
GOODS-N
Can Herschel detect very high-z (z>4) galaxies?
10 arcmin
HERMES

# GOODS N, 2 SMGs at z = 4.05, 250 µm



GN 20
and
GN 20.2a

Daddi+09
Z = 4.05
protocluster

The SPIRE properties of SMGs in the HerMES SDP fields are discussed in Chanial et al. 2010 & P1.63

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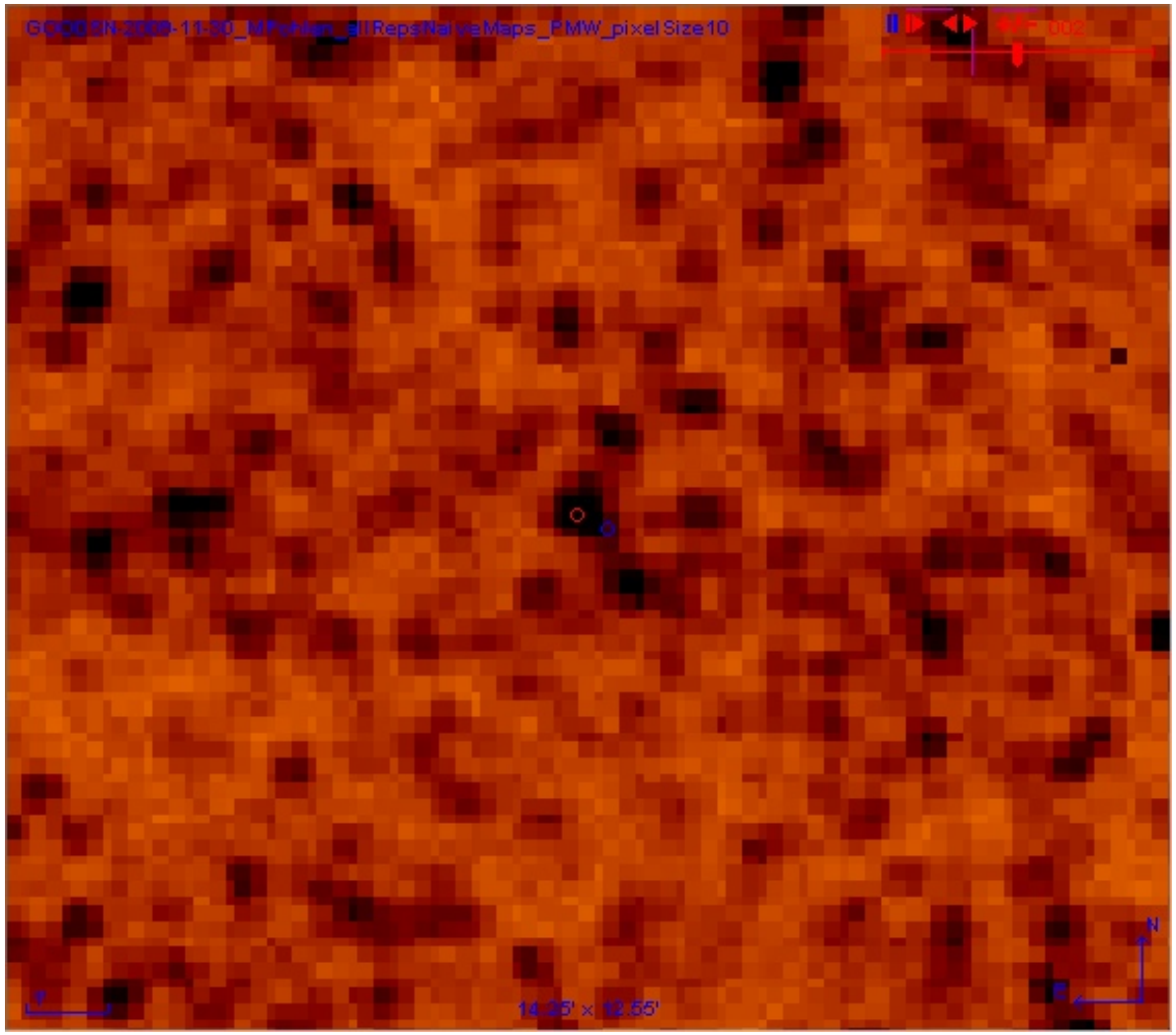
# GOODS N, 2 SMGs at z = 4.05, 350 µm



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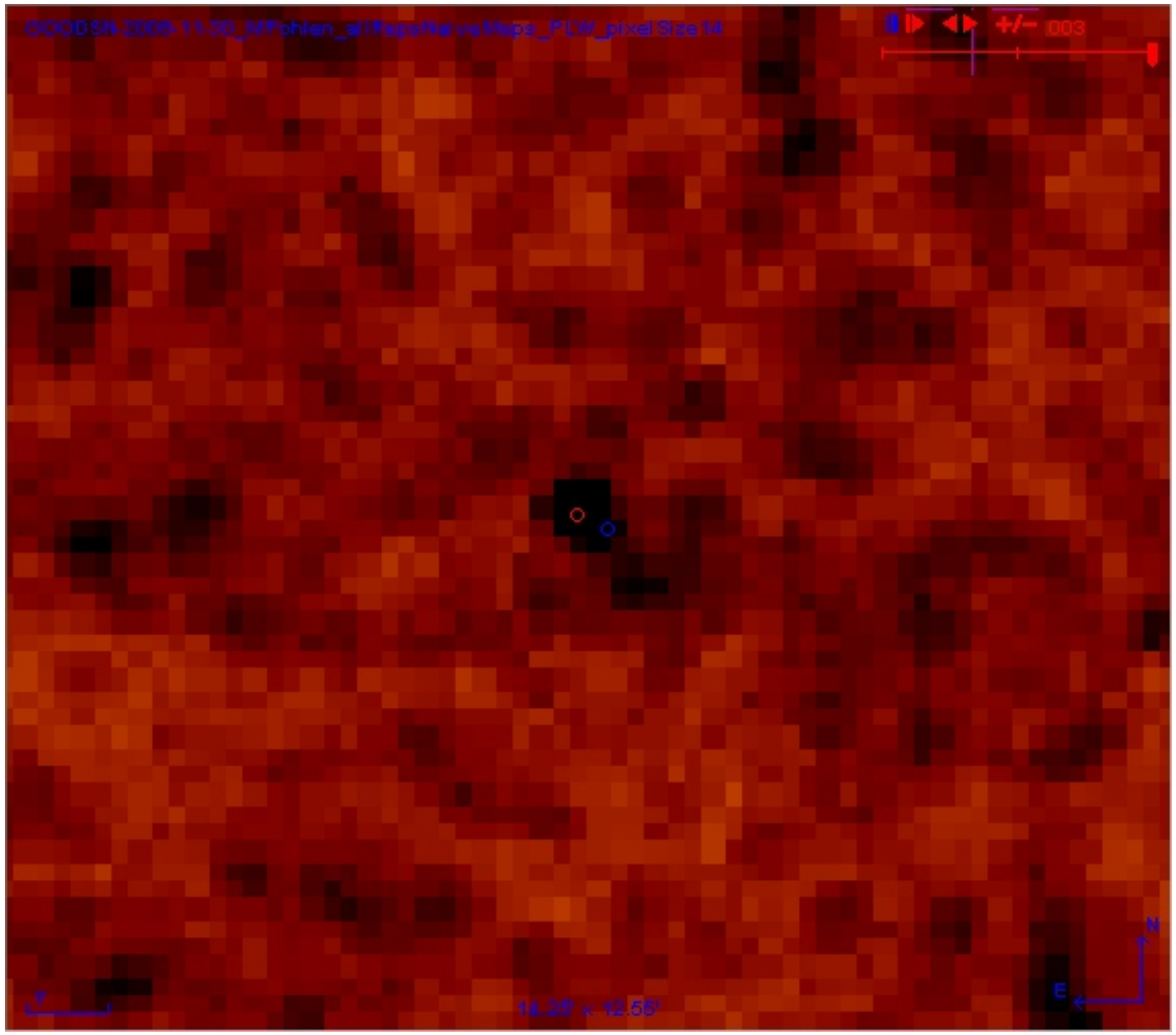
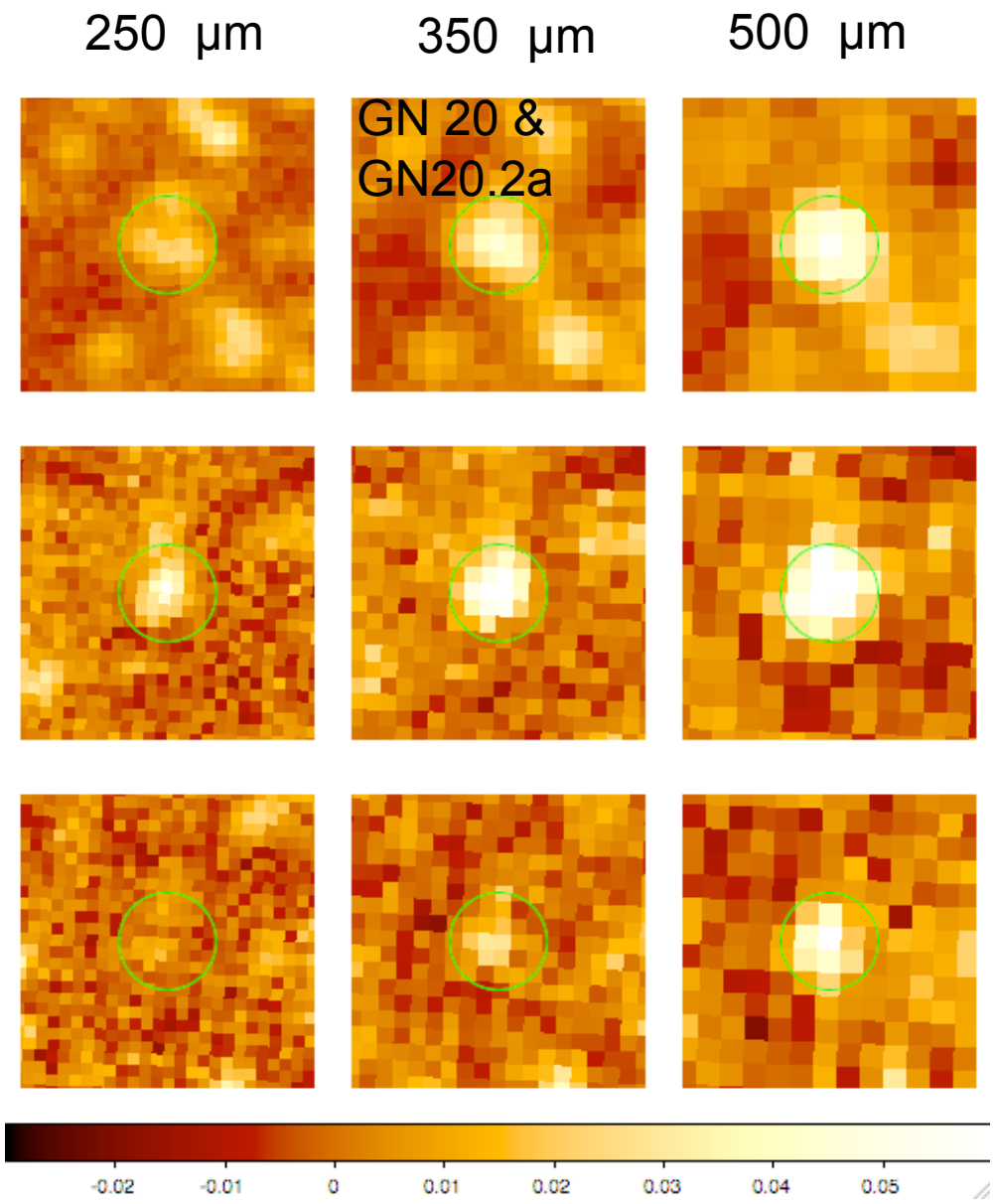
# GOODS N, 2 SMGs at z = 4.05, 500 µm



# Very high-z candidates
# Dowell et al. 2010 & P1.65

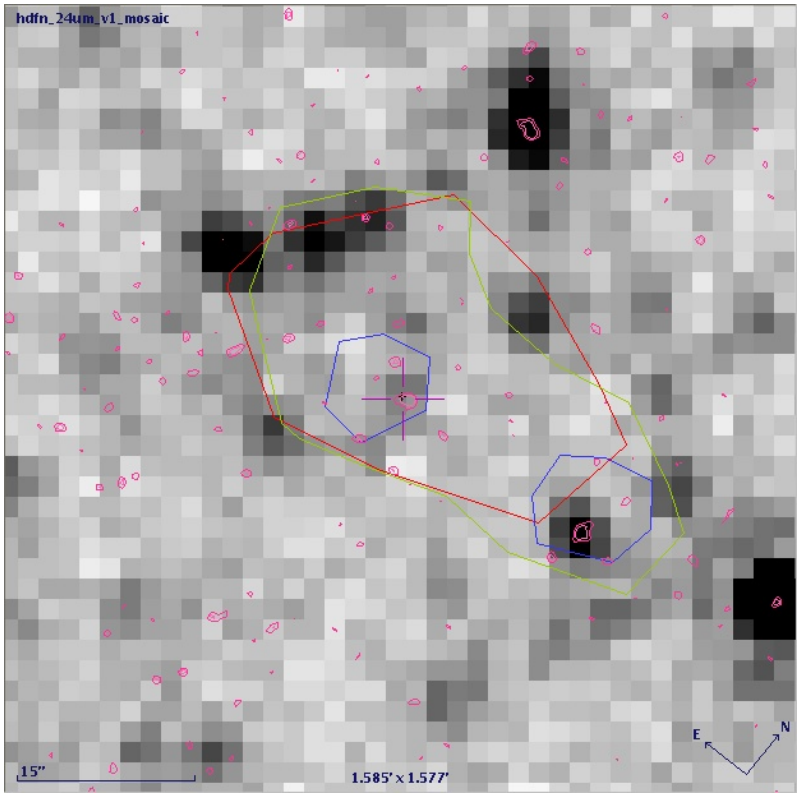


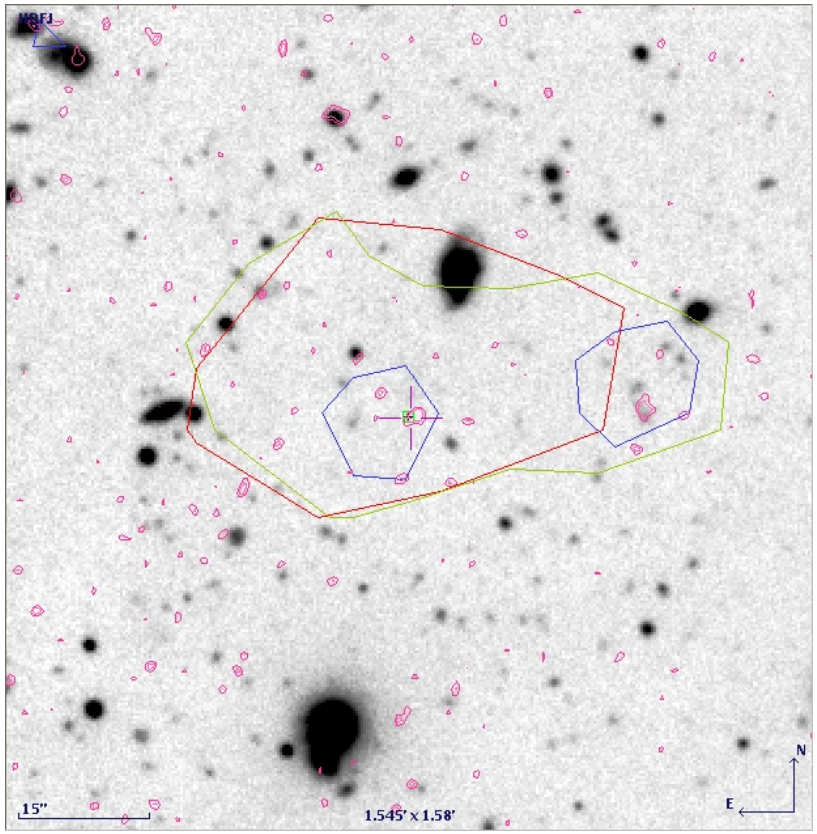

- In hopes of getting a glimpse of the top of the IR luminosity function at z > 4, SDP fields have been searched for galaxies which peak at ≈ 500 μm
- GN20 and GN20.2-a at z = 4.05 is a prototype (Pope et al. 2005; Daddi et al. 2009)
- Several dozen SPIRE sources in this new sample:
  - Some are like GN20 but brighter.
  - Some are redder.

# Sources with extreme colours (optical blank fields)

MIPS 24 μm image

I-band R > 25.6




Contours: SPIRE 250, 350 & 500 μm and radio (1.4 GHz)

Pérez-Fournon et al. 2010

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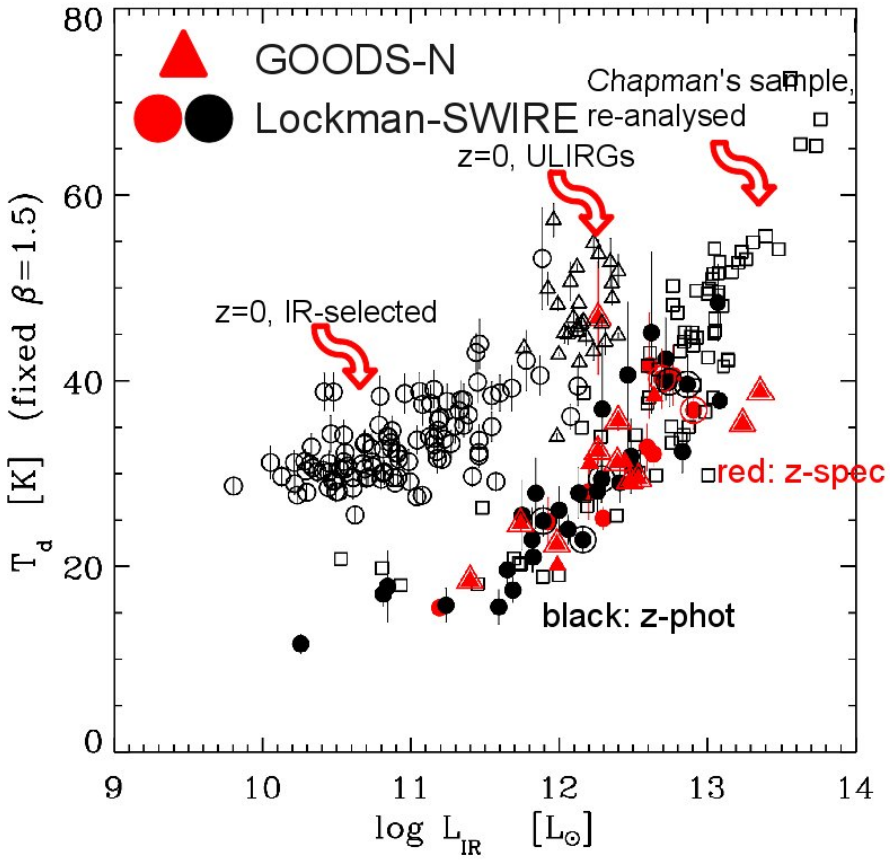
# Known high-z populations

- SMGs (Chanial et al. 2010 & P1.63)
- LBGs (Rigopoulou et al. 2010)
- OFRGs (Chapman et al. 2010)
- IRAC-selected z ~ 2 ULIRGS (Magdis et al. 2010, D. Elbaz talk, P2.55)
- QSOs (Hatziminaoglou et al. 2010, M. Page talk, P1.47)

# Submm galaxies
# Chanial et al. 2010 & P1.63




first direct measurement of LIR and Td for a large SMG sample.

➜ re-evaluate their contribution to the cosmic star formation rate densities

- SMG samples: SCUBA-detected sources

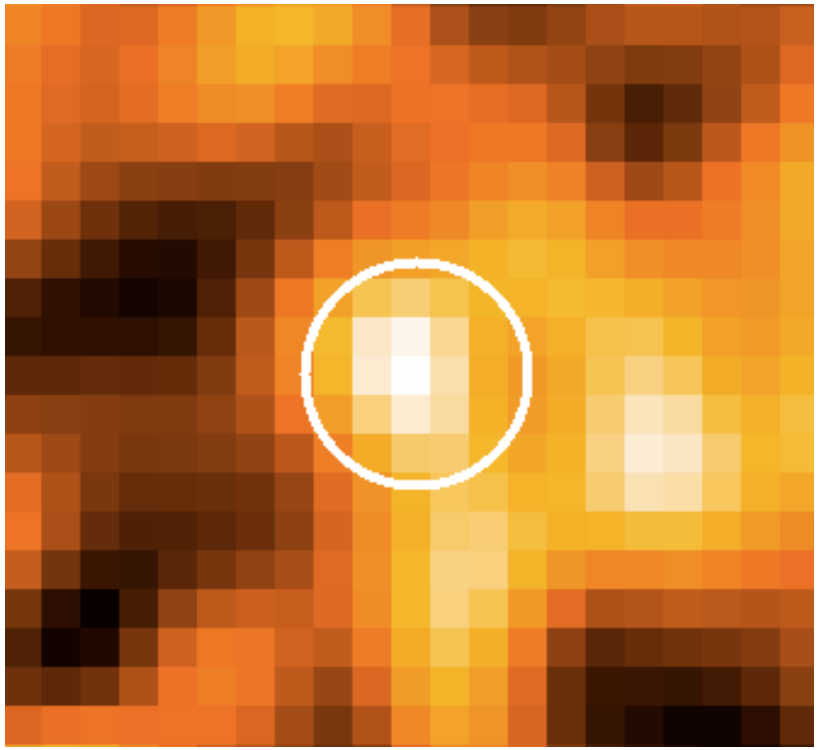
➜ GOODS-N (Pope et al. 2006)
➜ Lockman-SWIRE (Dye et al. 2008)

# Lyman Break Galaxies
# Rigopoulou et al. 2010

Stacked analysis carried out at the optical positions of all 9 LBGs in GOODS-N with Spitzer 24 μm detections.

A significant detection (4.5-σ )

With <S250>= 5.9+/-1.3 mJy



Stacked image of MIPS detected z~3 LBGs in HDF-N (Rigopoulou et al 2010)

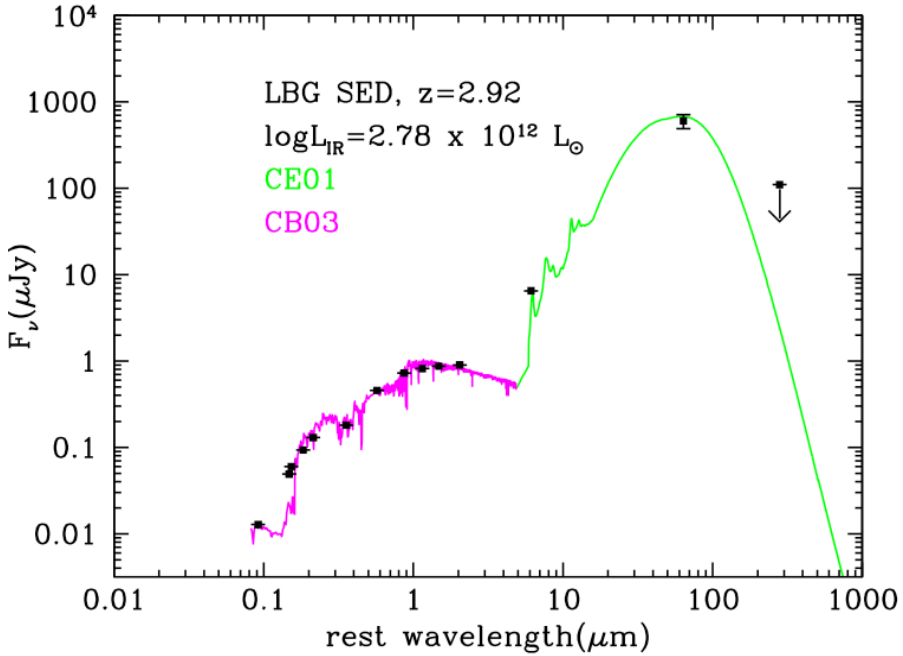
# Lyman Break Galaxies
# Rigopoulou et al. 2010

Average SED of z~3 LBGs including UV/ opt/mid/far IR data.

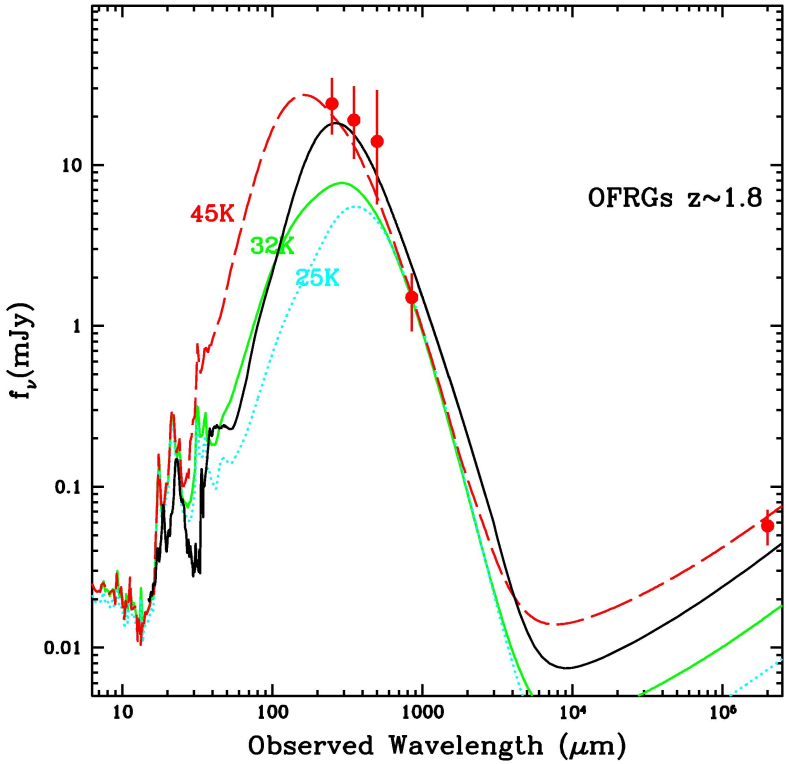
UV/optical fit with Bruzual & Charlot models.

Mid/far-IR fit with Chary & Elbaz templates.

$L_{IR}$ ~ 2.78 x 10 $^{12}$ $L_{\odot}$ which places z~3 LBGs in the ULIRG regime



# Optically faint Radio Galaxies
# Chapman et al. 2010




average props of OFRGs
in Lockman-East

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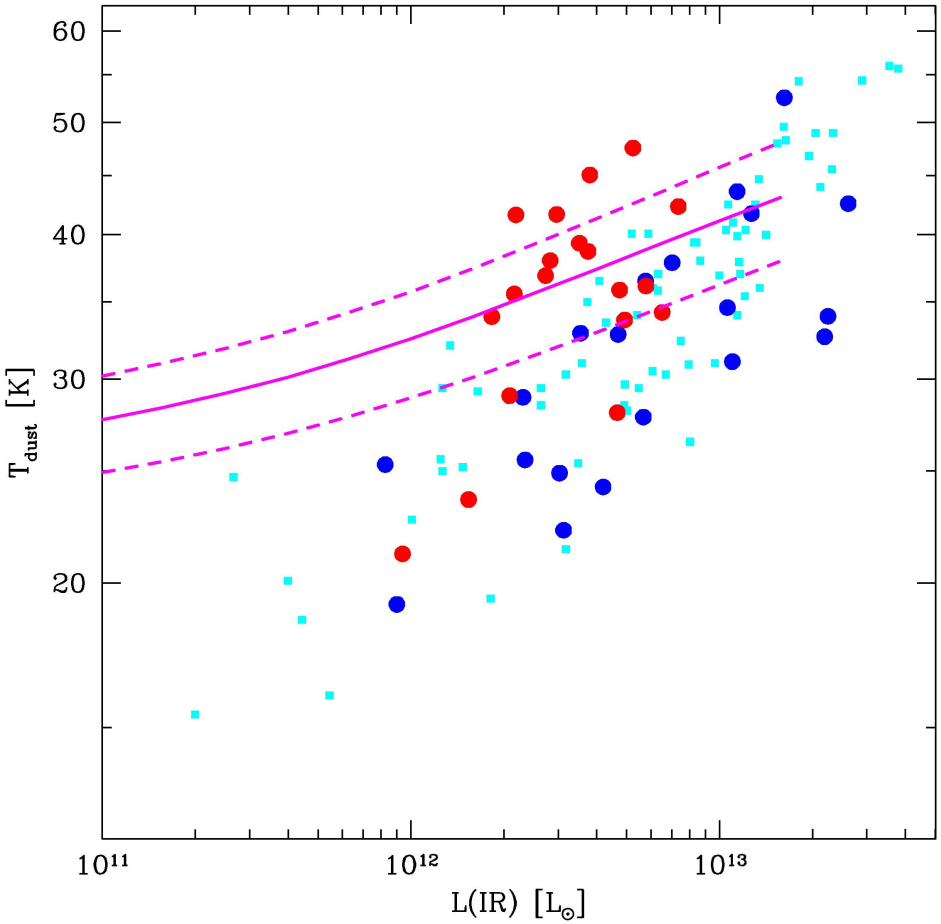


Td – L (IR) plane

Comparison of OFRG with SMGs in the same field, and Chapman+2005 SMGs.

Many submm-undetected OFRGs are far-IR luminous, and have <Td> hotter than typical submm-detected galaxies.

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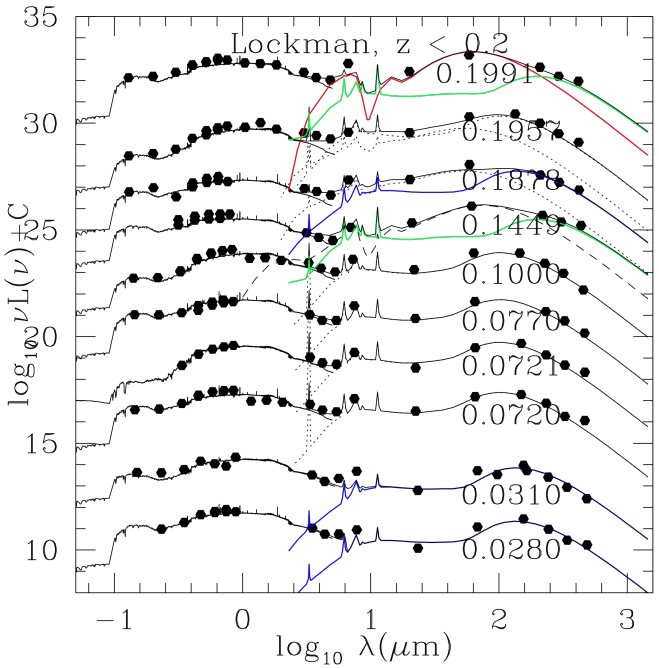
# Detailed SED studies, dust attenuation and UV SFR

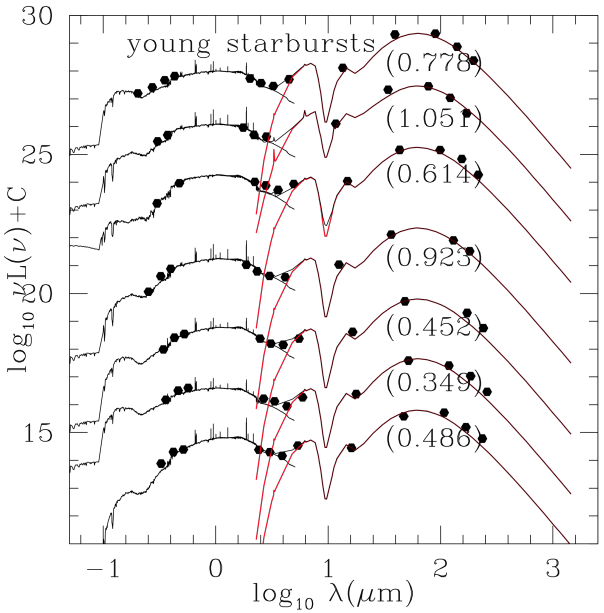
- Elbaz et al. 2010, D. Elbaz talk
- Rowan-Robinson et al. 2010
- Brisbin et al. 2010 & P1.51
- Buat et al. 2010 & P1.52

# Cold dust and young starbursts
## Rowan-Robinson et al. 2010

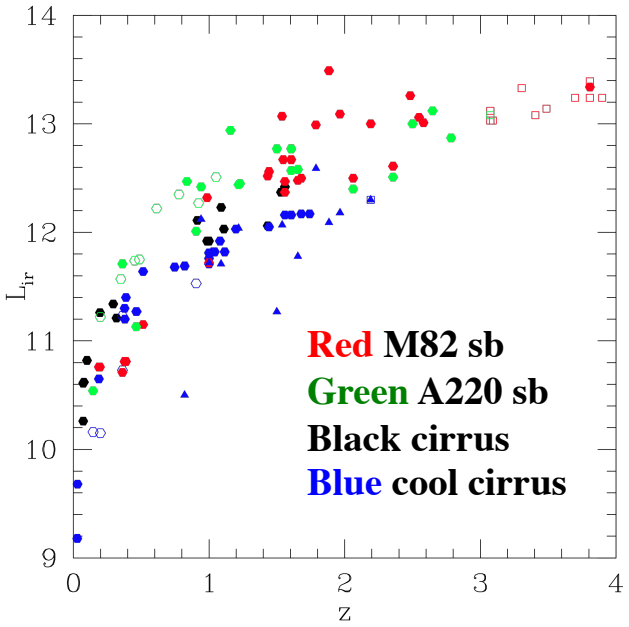



Rowan-Robinson et al. (2010, MN subm) models SEDs of 68 galaxies at 0<z<4 in Lockman, 5-σ at 250, 350, 500 μm

Cooler 'cirrus' components are needed: 15-20 K (blue curves), 10-13 K (green). Also young starburst component (red).

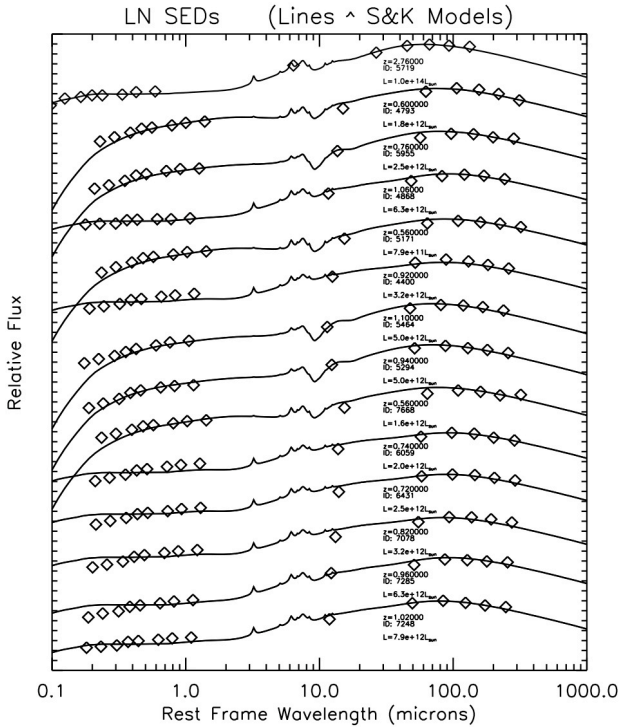


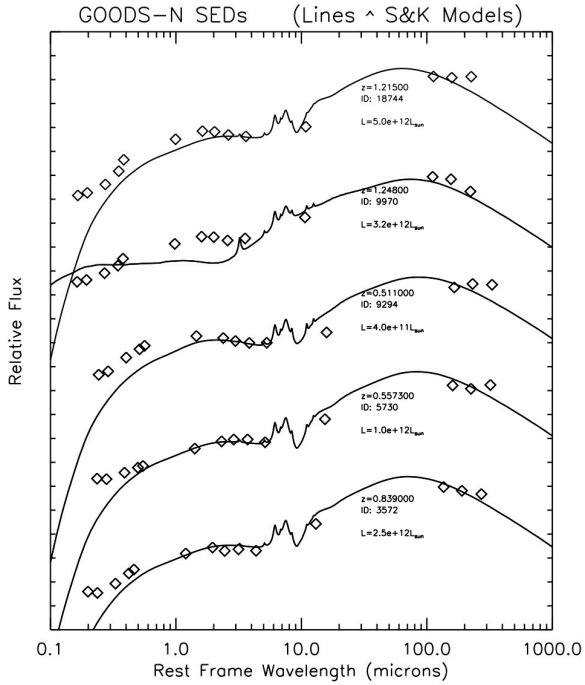

Cool dust found to z~2, L~$10^{12}$ $L_o$



# Spectral Energy Distributions, Luminosities, & Star-Formation Rates in GOODS-North Galaxies

## Brisbin et al. 2010 & P1.51




High redshift (z>0.5) source SEDs in Lockman North (left) and GOODS-N (right)

Sources with unambiguous flux densities at all three SPIRE bands (~20)

Sources fit with models by Siebenmorgen and Krügel (A&A 2007)

FIR excesses (GOODS-N sources 18744, 9294, 5730) hint at cool dust component

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# Conclusions

- Herschel is working exceptionally well
- Very high source detection rate with SPIRE (>27000 galaxies from SDP data only)
- Many HerMES SDP first results using Herschel and ancillary data, over a wide range in FIR luminosity, redshift, and galaxy types
- Very high-z FIR galaxies can be found with SPIRE (large number of $z > 4$ candidates)

**THANKS to the HSC, the instrument teams and the SPIRE and HerMES consortia!**