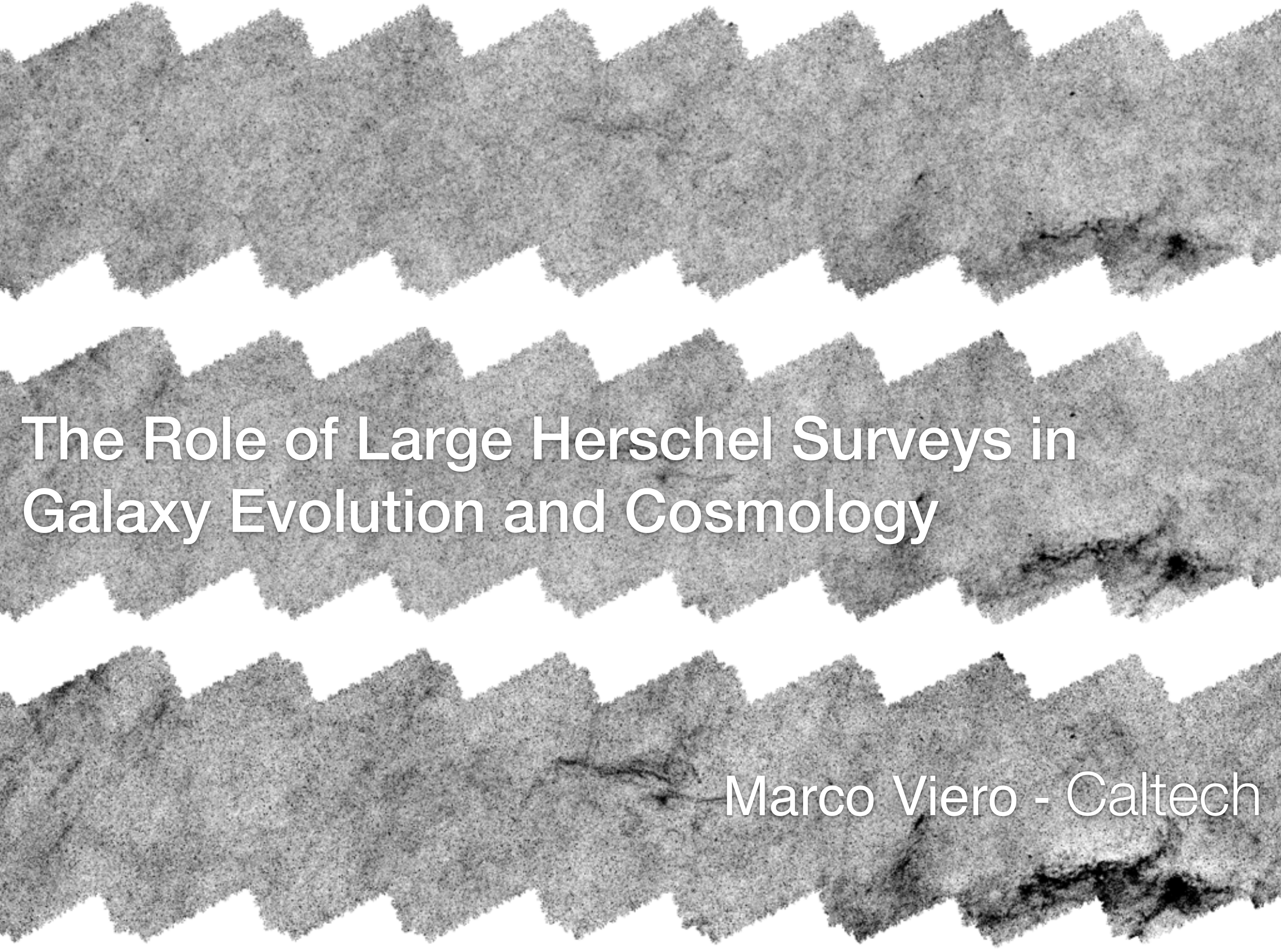
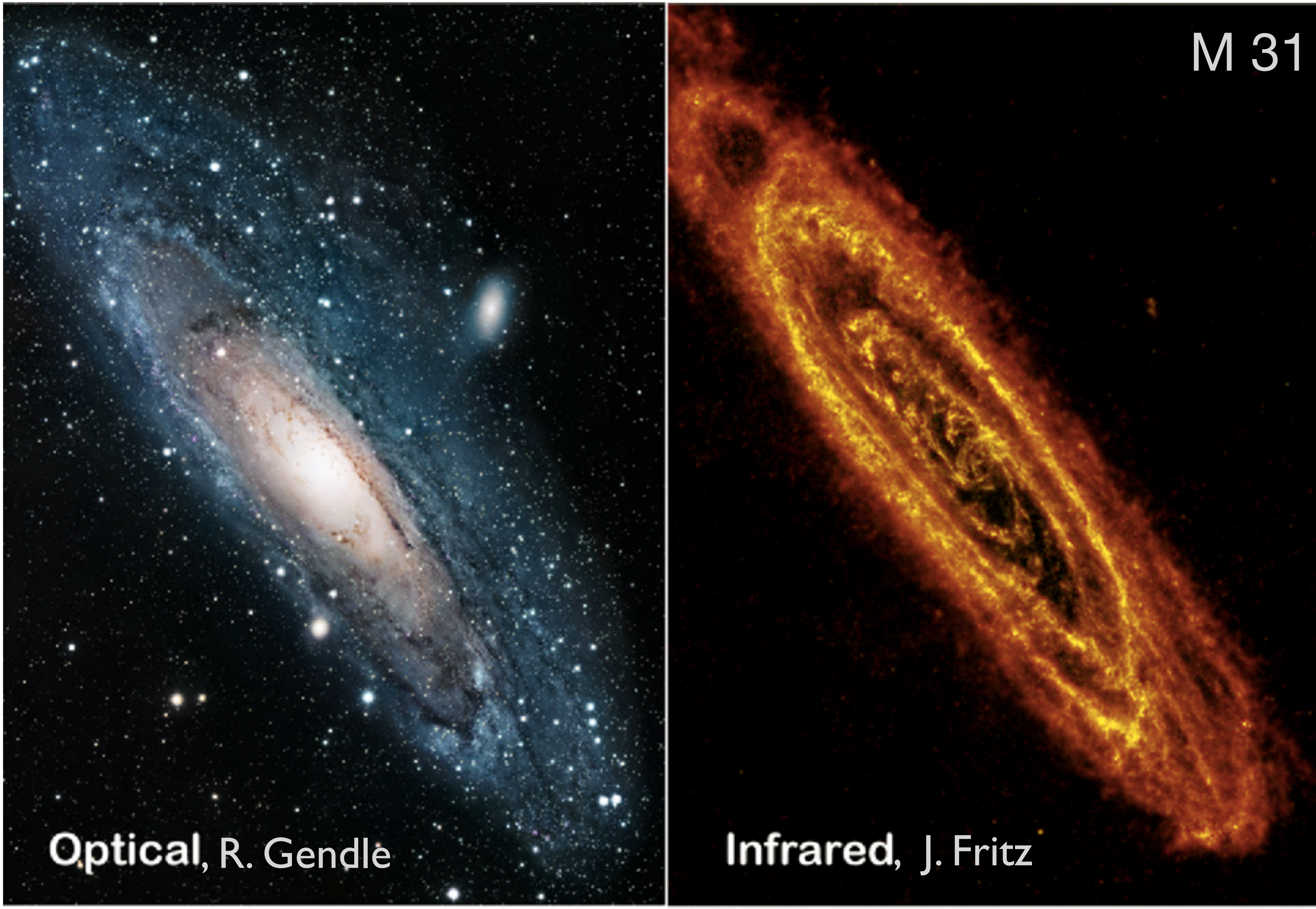


The Role of Large Herschel Surveys in Galaxy Evolution and Cosmology

Marco Viero - Caltech

Outline

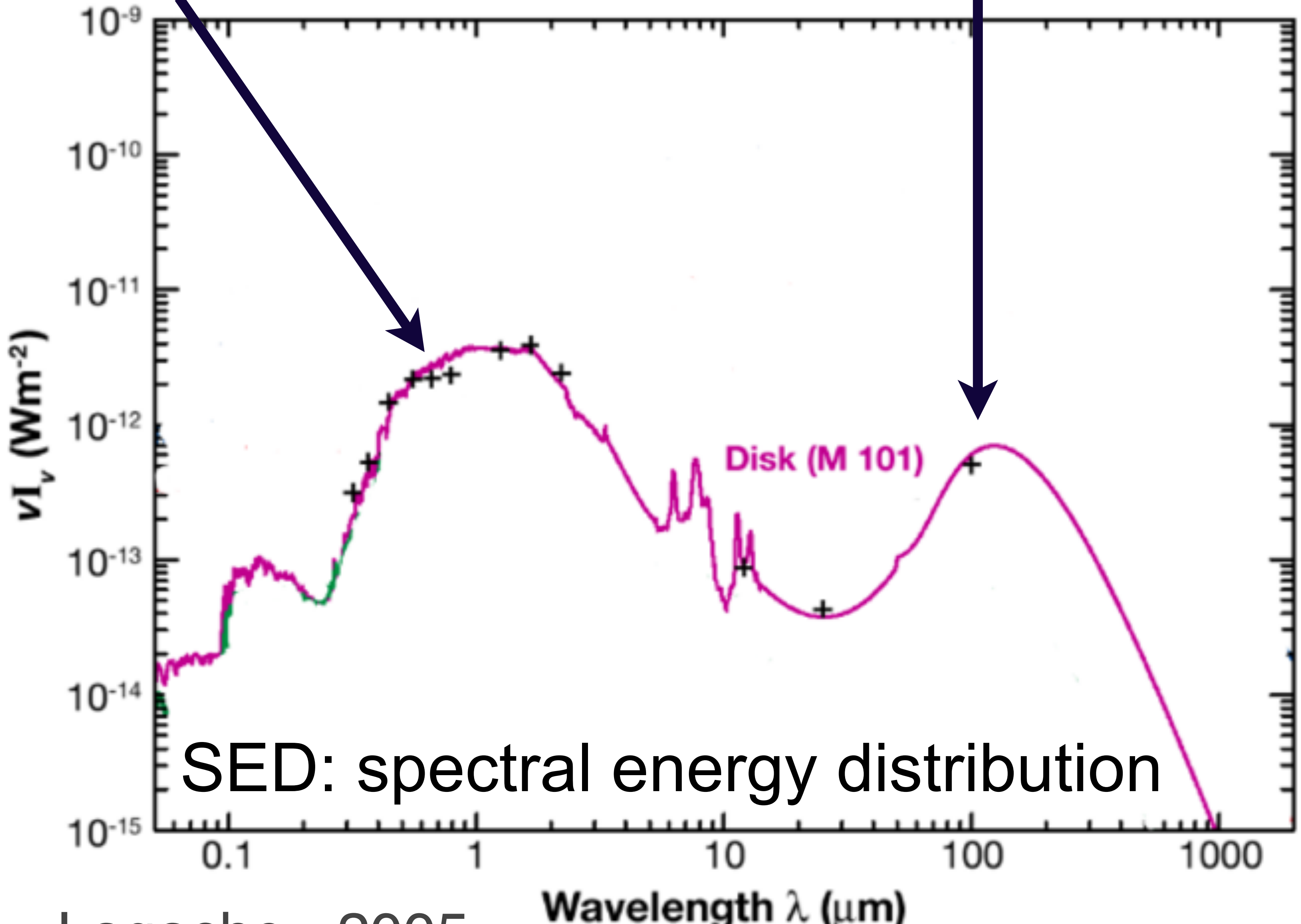
- Why the Cosmic Infrared Background (CIB)?
- Auto and cross-correlations of CIB as a tool to:
  - measure galaxy-galaxy clustering to determine the dark matter hosts of dusty star-forming galaxies
  - determine the connection between the Cosmic Optical and Infrared Backgrounds
  - cosmological applications
- The Future in Surveys



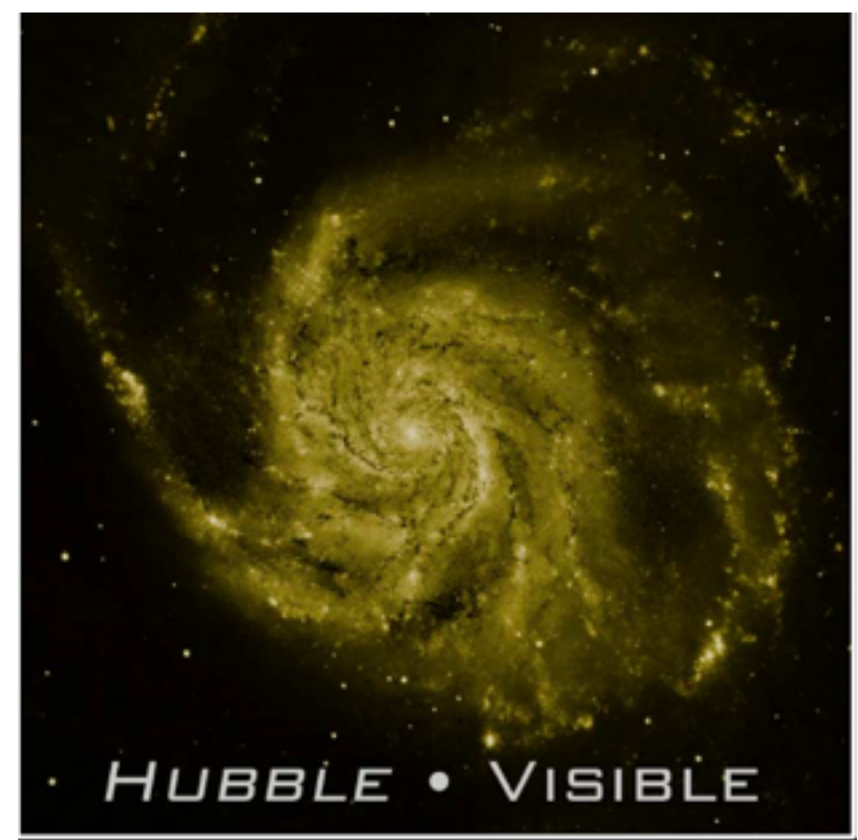
far-infrared/submillimeter:
dust warmed by stars

Dust re-emits in the FIR

Optical/UV Starlight absorbed by dust

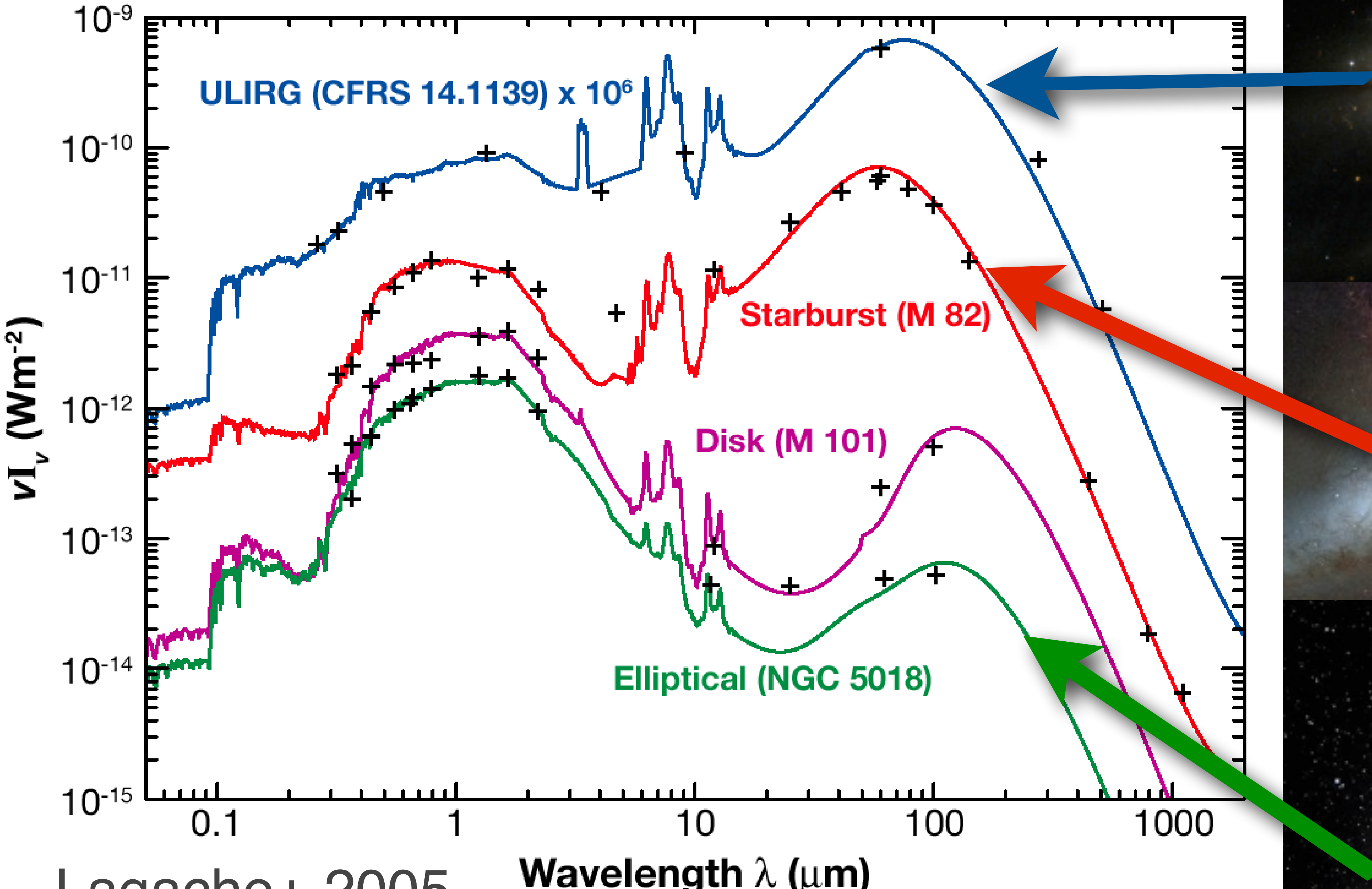


Lagache+ 2005



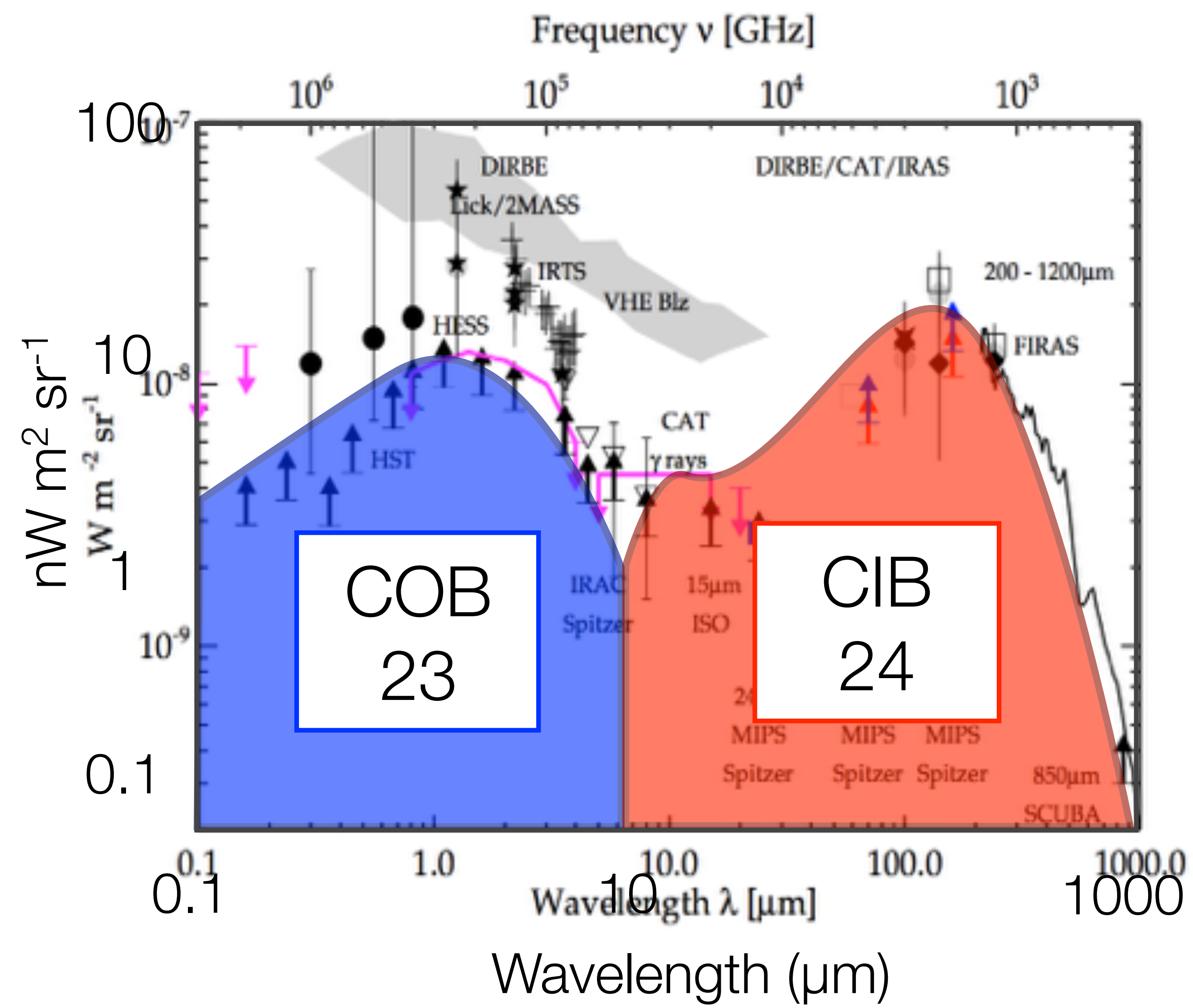
UV/Optical and FIR/submm SED

Dusty Star-Forming Galaxies (DSFGs)



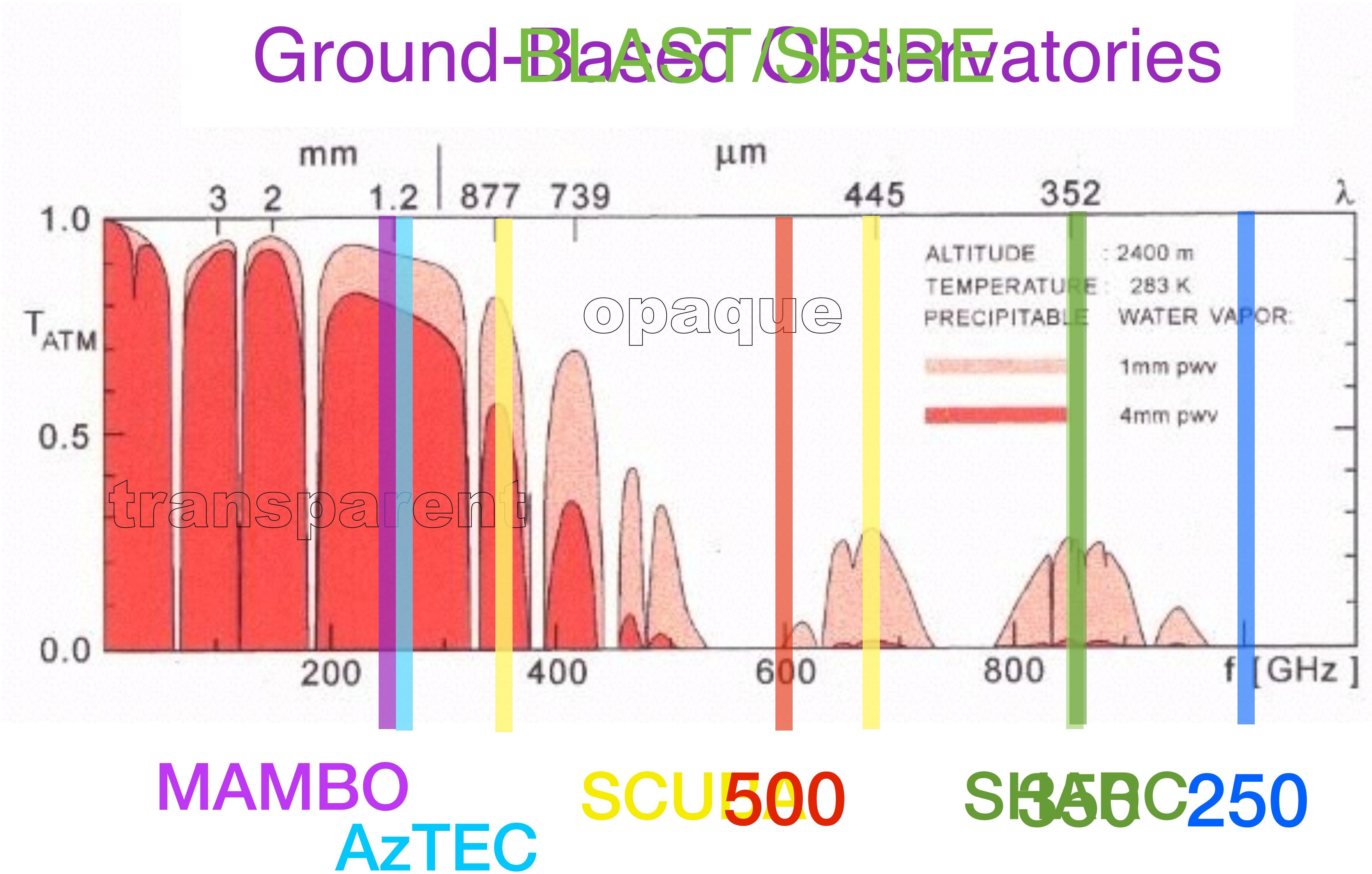
Lagache+ 2005

Optical and FIR SED



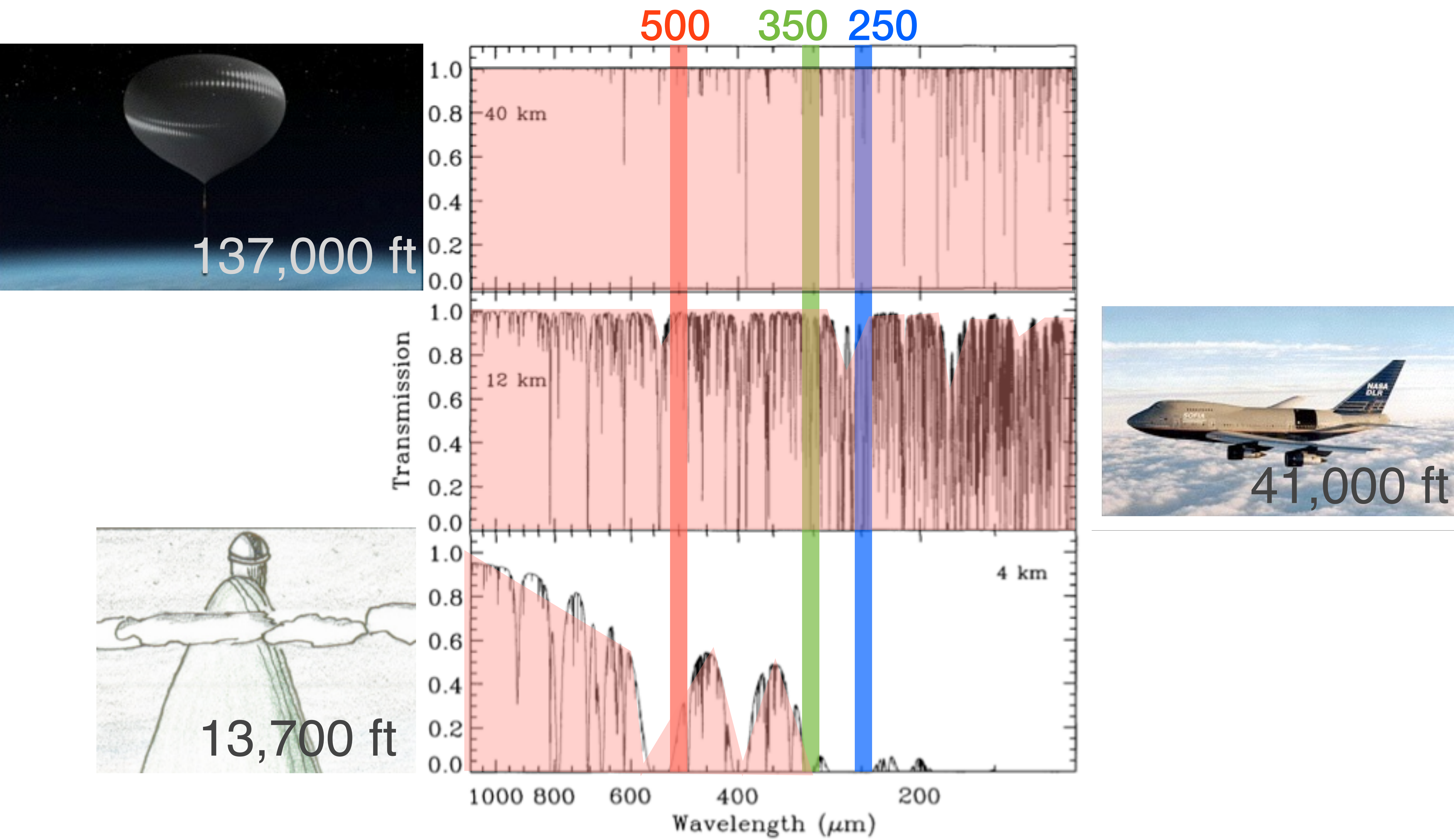
Dole+ (2006)

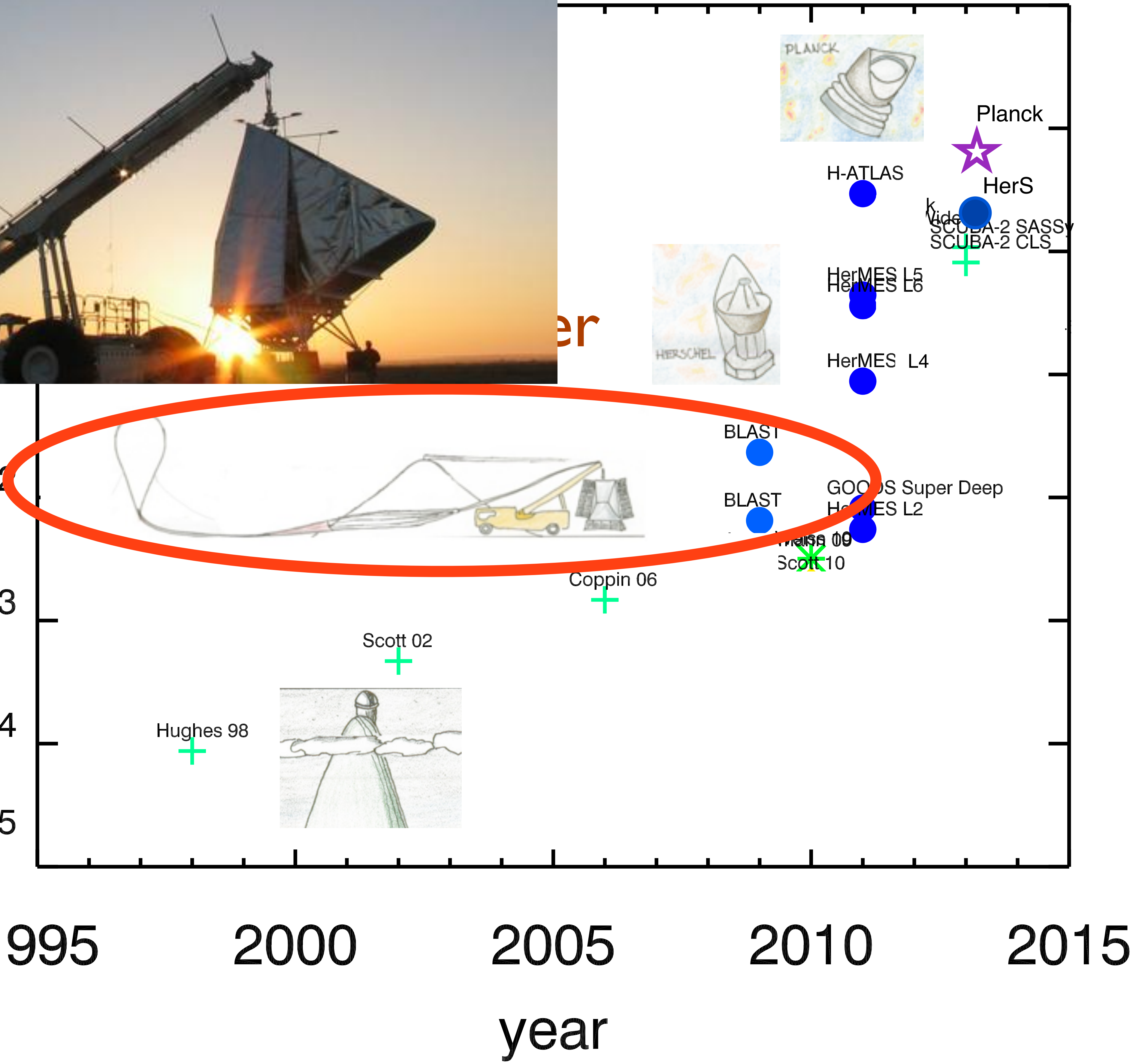
optical and infrared backgrounds



Submm Visibility

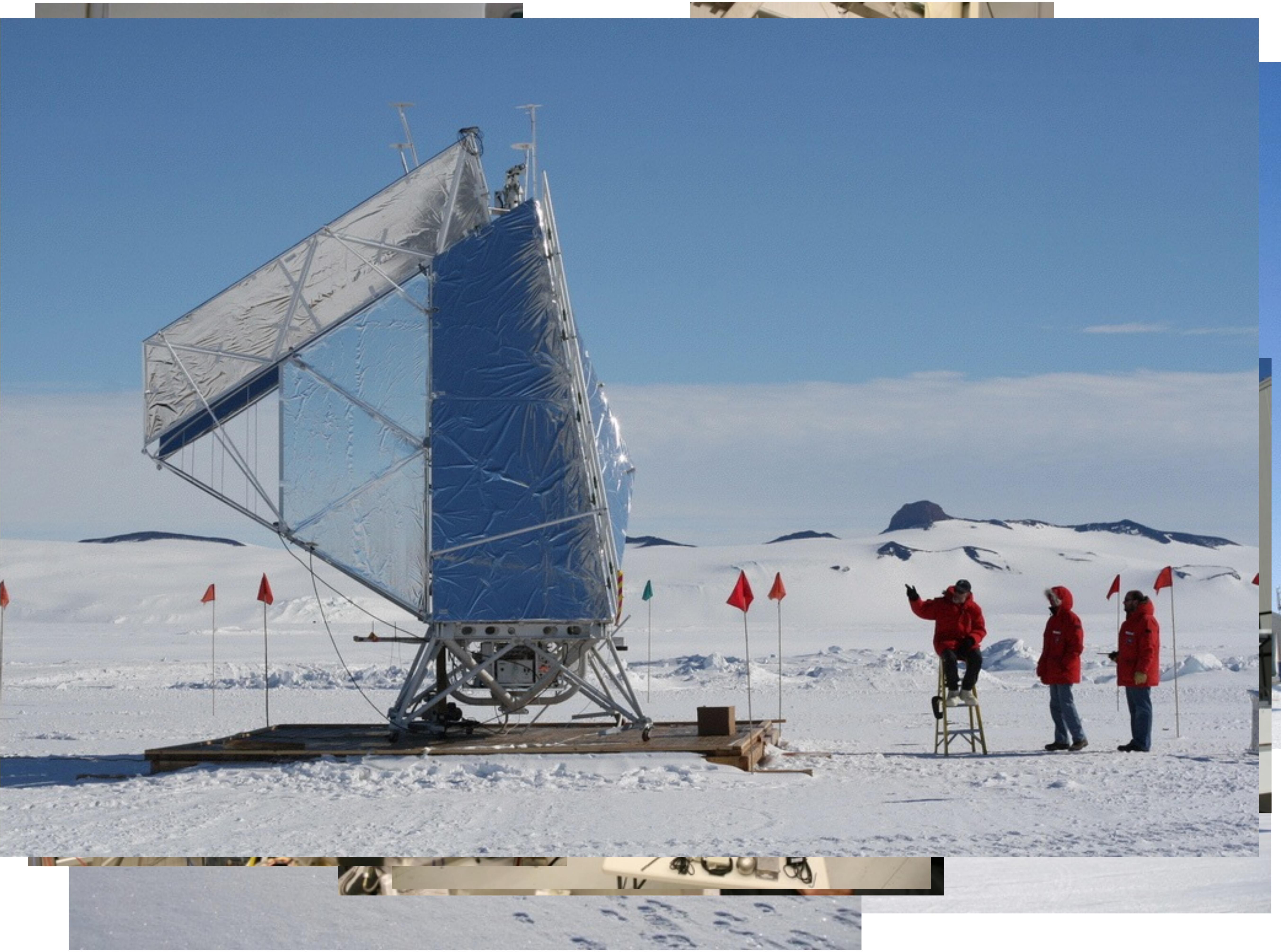
Submm Visibility

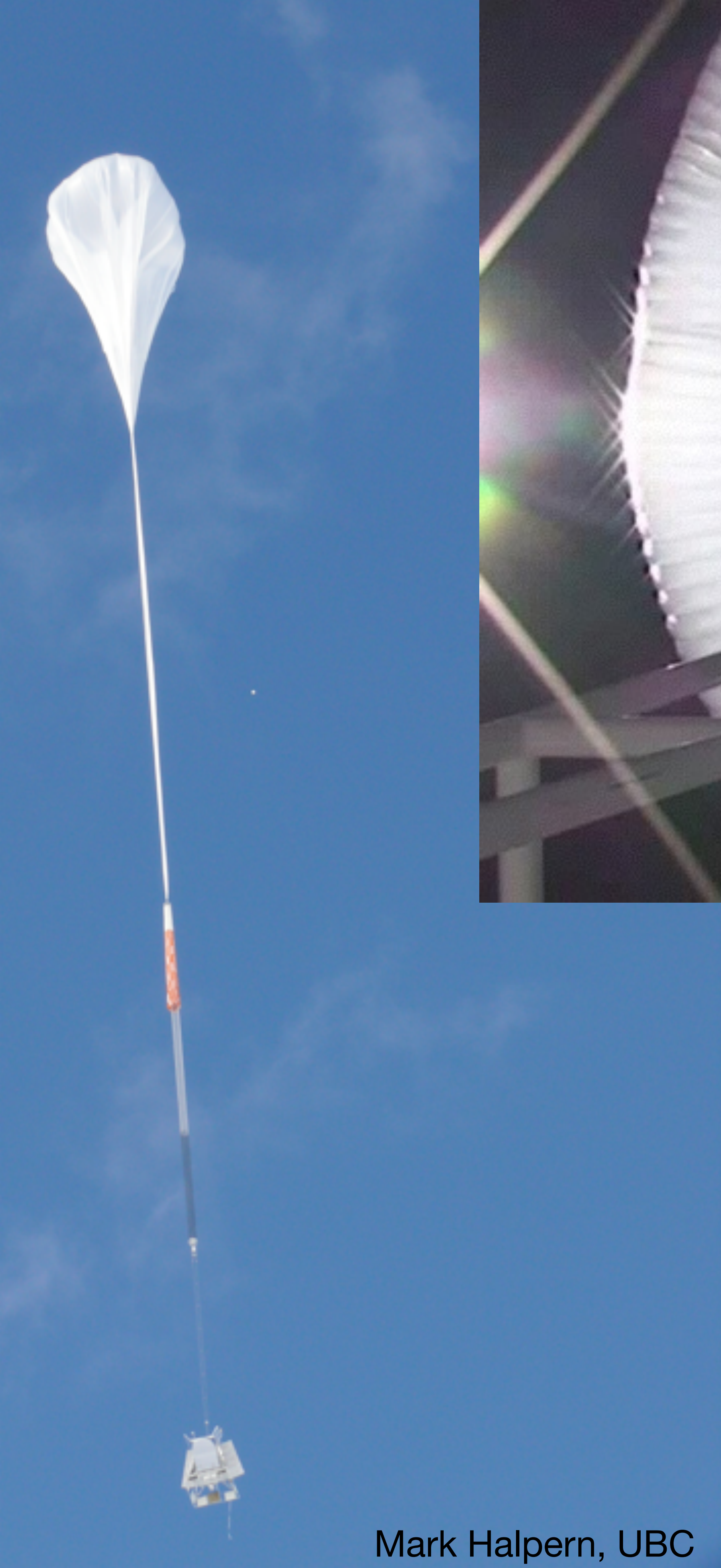




Explosion of Submillimeter Data

BLAST



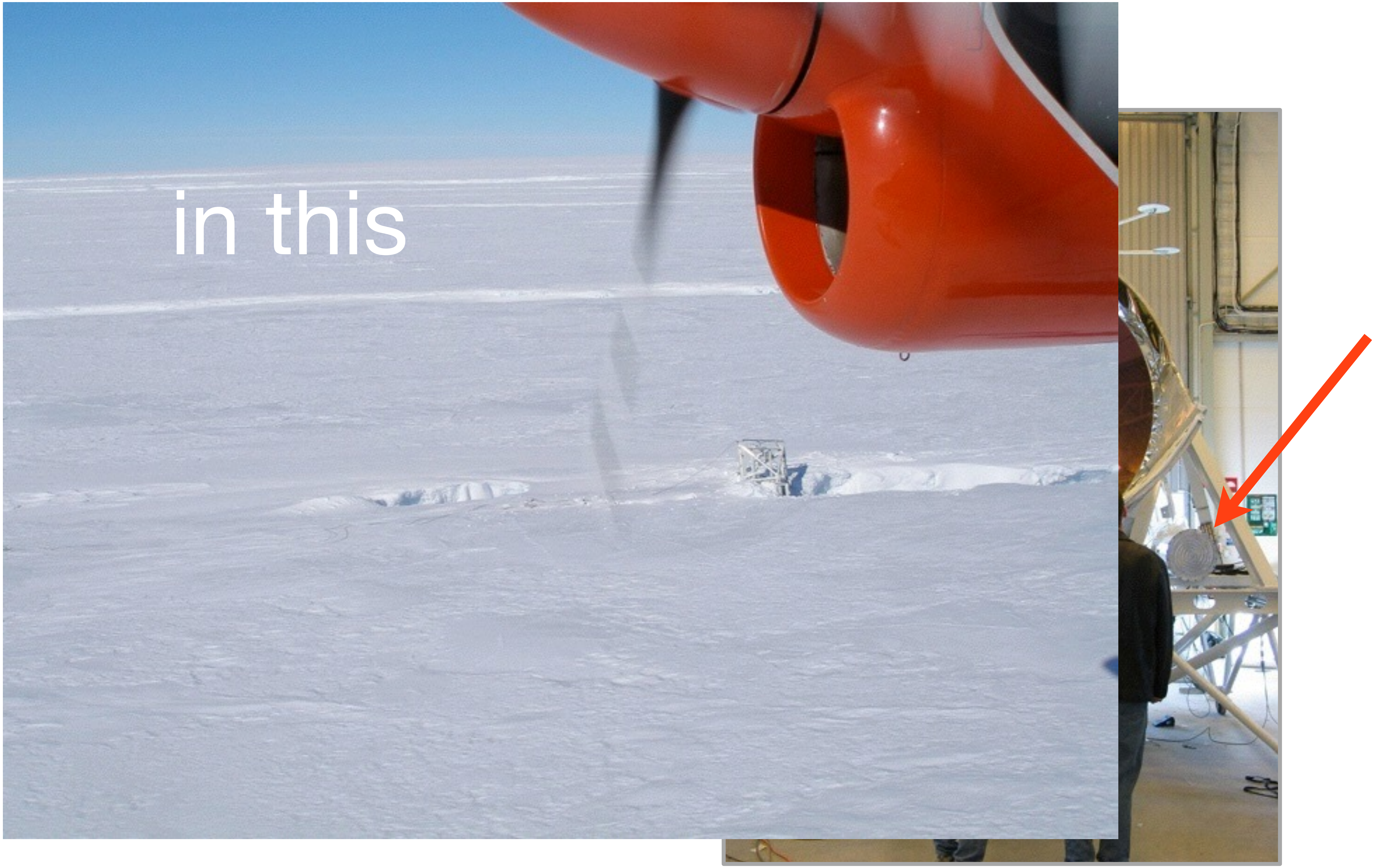


Perfect Flight!

BLAST payload hanging from balloon
float altitude of 120,000 ft.

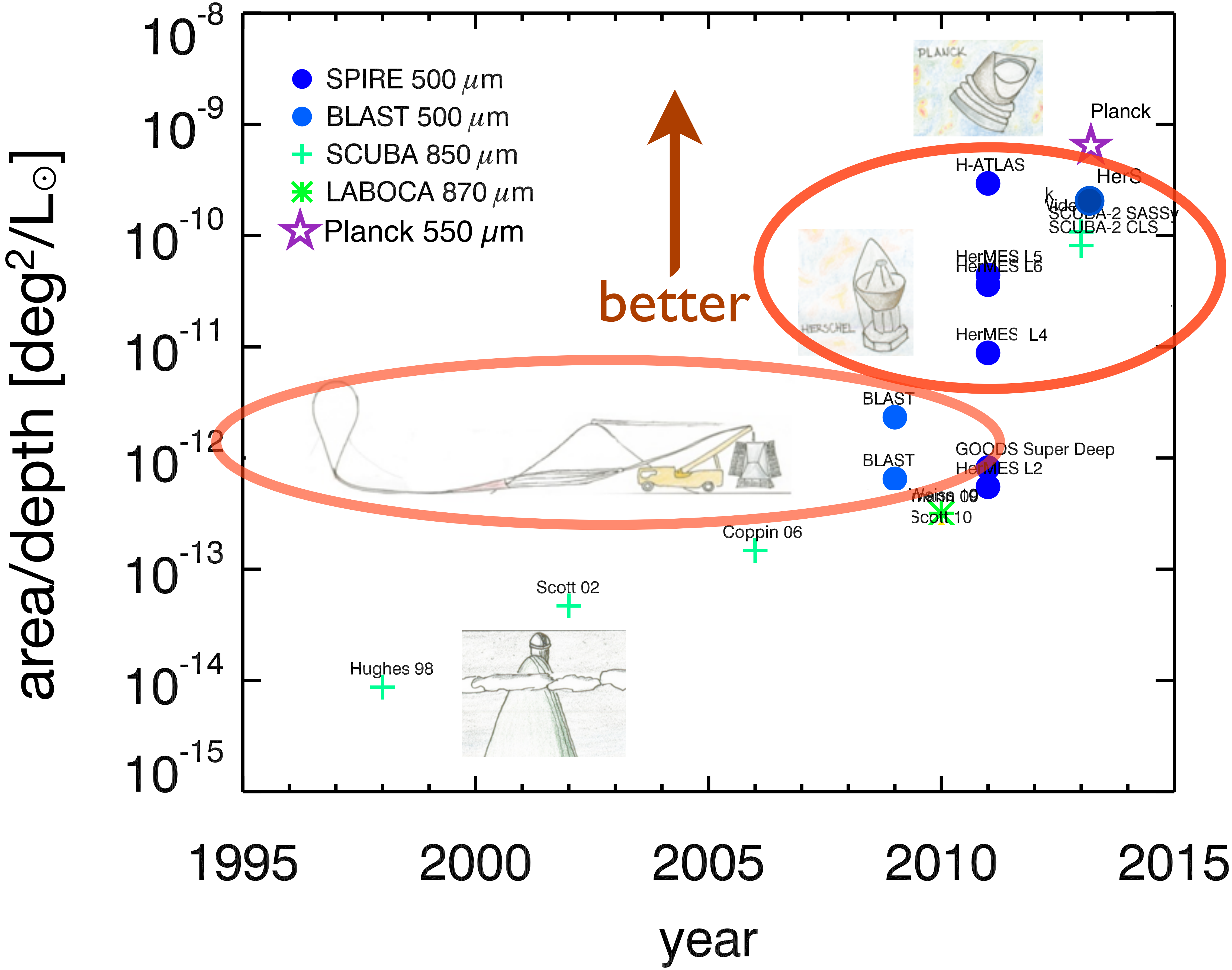
Perfect Landing!
Landing?

BLAST


in this

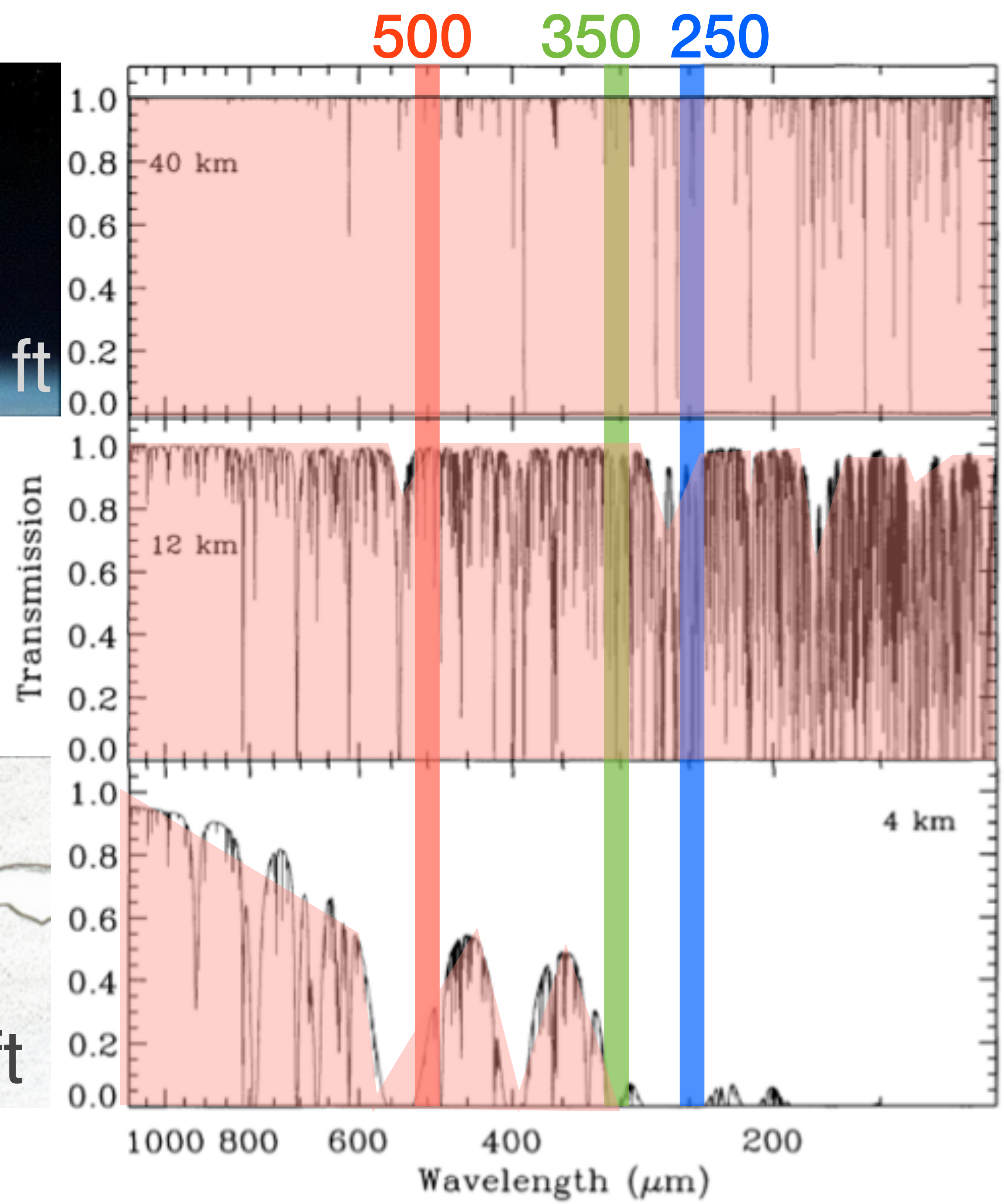
see it all in "BLAST!" the movie

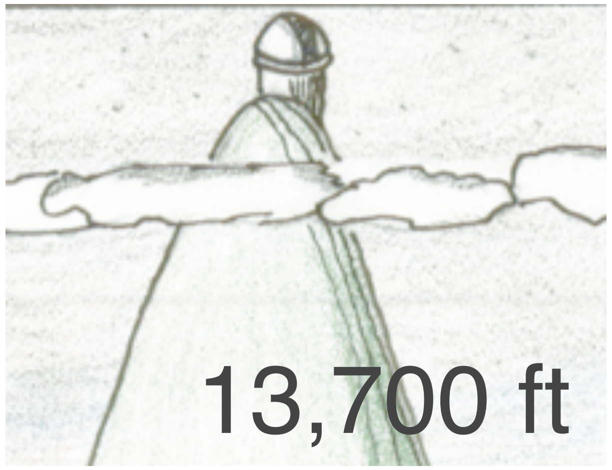
BLAST



Explosion of Submillimeter Data

Submm Visibility





HERMES

Astronomy Technology Centre
California Institute of Technology
Cardiff University
CEA, Saclay
Cornell
ESAC
Godard Space Flight Centre
Imperial College, London
Infrared Processing Analysis Centre
Institut d'Astrophysique de Paris
Institut d'Astrophysique Spatiale
Institute Astrophysica Canarias
Jet Propulsion Lab.
Laboratory of Astrophysics of Marseilles
Mullard Space Science Laboratory
OAPd University of Padova
UC Irvine
University of British Columbia
University of Colorado
University of Hertfordshire
University of Sussex

HERMES

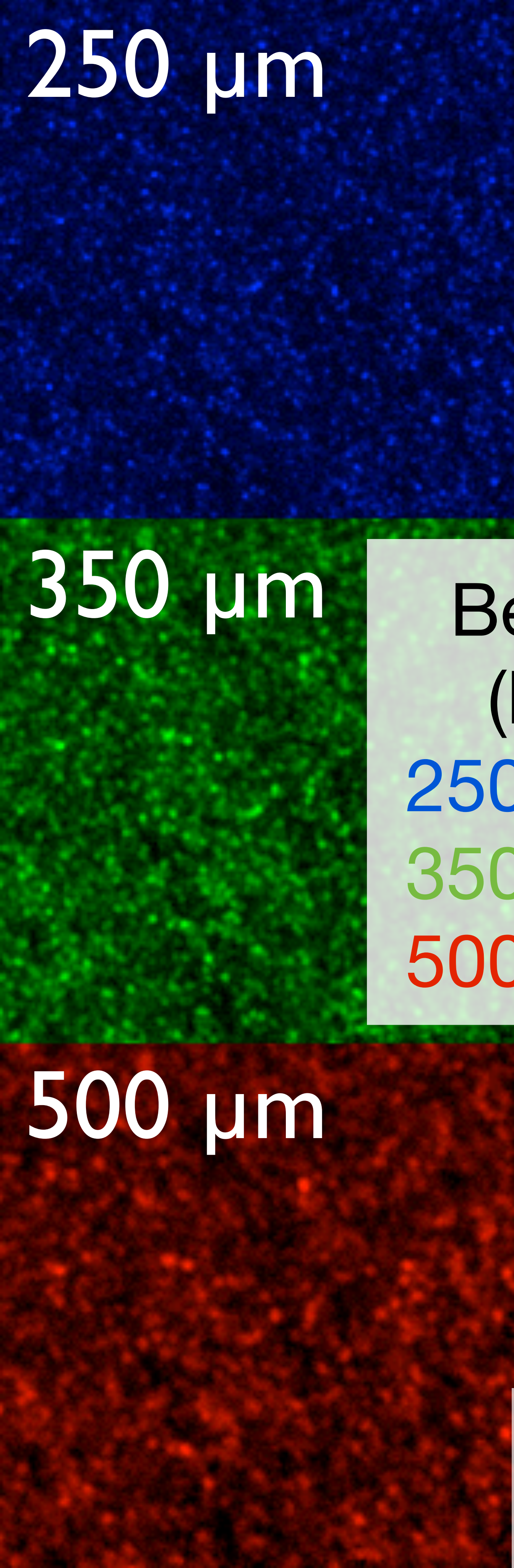
The Team

Bruno Altieri, Alex Amblard, Rick Arendt, Vinod Arumugam, Robbie Auld, Herve Aussel, Alexandre Beelen, Andrew Blain, Jamie Bock, Alessandro Boselli, Carrie Bridge, Drew Brisbin, Veronique Buat, Denis Burgarella, Nieves Castro-Rodriguez, Antonia Cava, Pierre Chanial, Ed Chapin, Michele Cirasuolo, Dave Clements, Alex Conley, Luca Conversi, Asantha Cooray, Emanuele Daddi, Gianfranco De Zotti, Darren Dowell, Jim Dunlop, Eli Dwek, Simon Dye, Steve Eales, David Elbaz, Erica Ellingson, Tim Ellsworth-Bowers, Duncan Farrah, Patrizia Ferrero, Mark Frost, Ken Ganga, Elodie Giovannoli, Jason Glenn, Eduardo Gonzalez-Solares, Matt Griffin, Mark Halpern, Martin Harwit, Evanthia Hatziminaoglou, George Helou, Jiasheng Huang, Ho Seong Hwang, Edo Ibar, Olivier Ilbert, Kate Isaak, Rob Ivison, Martin Kunz, Guilaine Lagache, Glenn Laurent, Louis Levenson, Carol Lonsdale, Nanyao Lu, Suzanne Madden, Bruno Maffei, Georgios Magdis, Gabriele Mainetti, Lucia Marchetti, Gaelen Marsden, Jason Marshall, Glenn Morrison, Angela Mortier, Hien Trong Nguyen, Brian O'Halloran, Seb Oliver, Alain Omont, Francois Orieux, Frazer Owen, Matthew Page, Biswajit Pandey, Maruillo Pannell, Pasquale Panuzzo, Andreas Papageorgiou, Harsit Patel, Chris Pearson, Ismael Perez Fournon, Michael Pohlen, Naseem Rangwala, Jason Rawlings, Gwen Raymond, Dimitra Rigopoulou, Laurie Riguccini, Guilia Rodighiero, Isaac Roseboom, Michael Rowan-Robinson, Miguel Sanchez Portal, Bernhard Schulz, Douglas Scott, Paolo Serra , Nick Seymour, David Shupe, Anthony Smith, Jason Stevens, Veronica Strazzu, Myrto Symeonidis, Markos Trichas, Katherine Tugwell, Mattia Vaccari, Elisabetta Valiante, Ivan Vatchanov, Joaquin Vieira, Marco Viero, Lingyu Wang, Don Wiebe, Kevin Xu, Michael Zemcov

Faculty & Researchers PostDocs PhD Students

Plus engineers, instrument builders, software developers etc.

HERMES

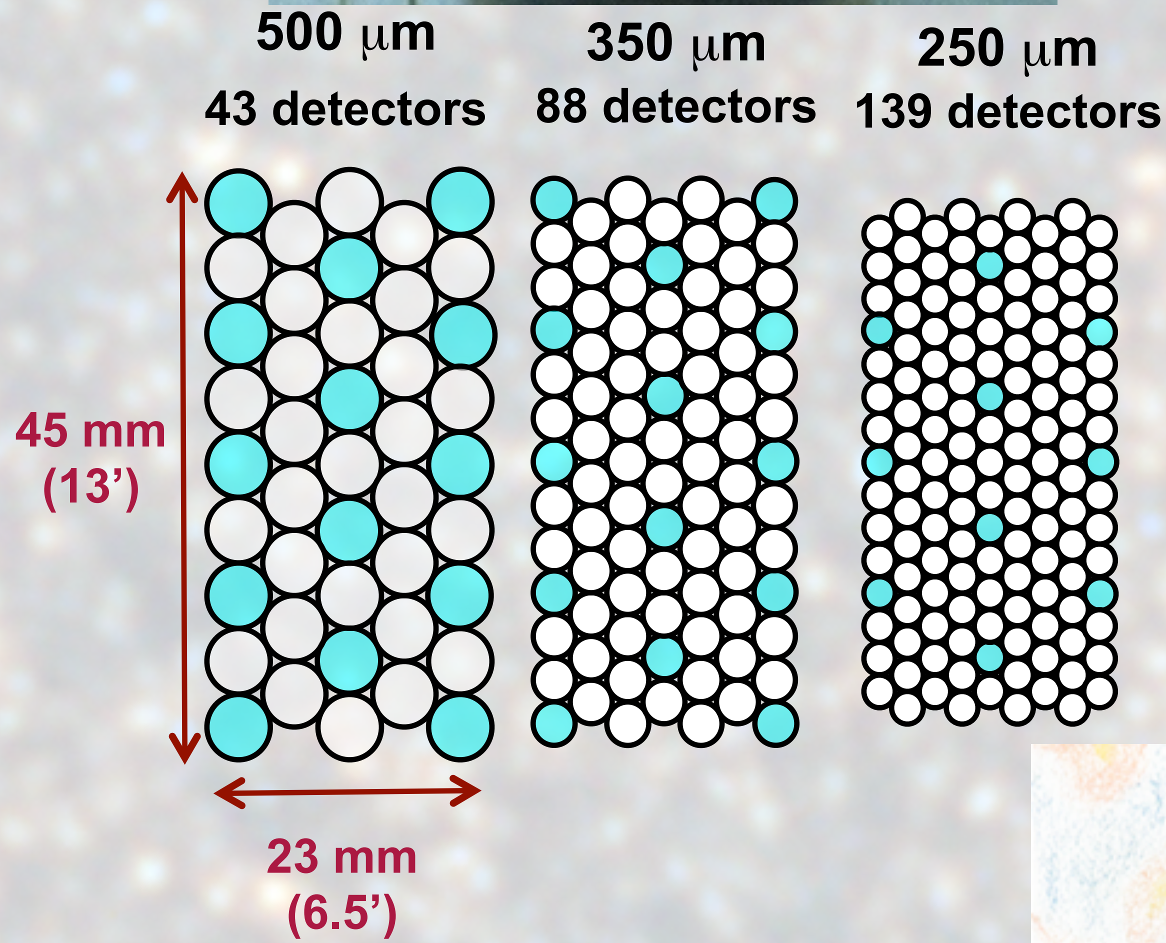


Beam size (FWHM)

250 µm - 16”

350 µm - 25”

500 µm - 36”



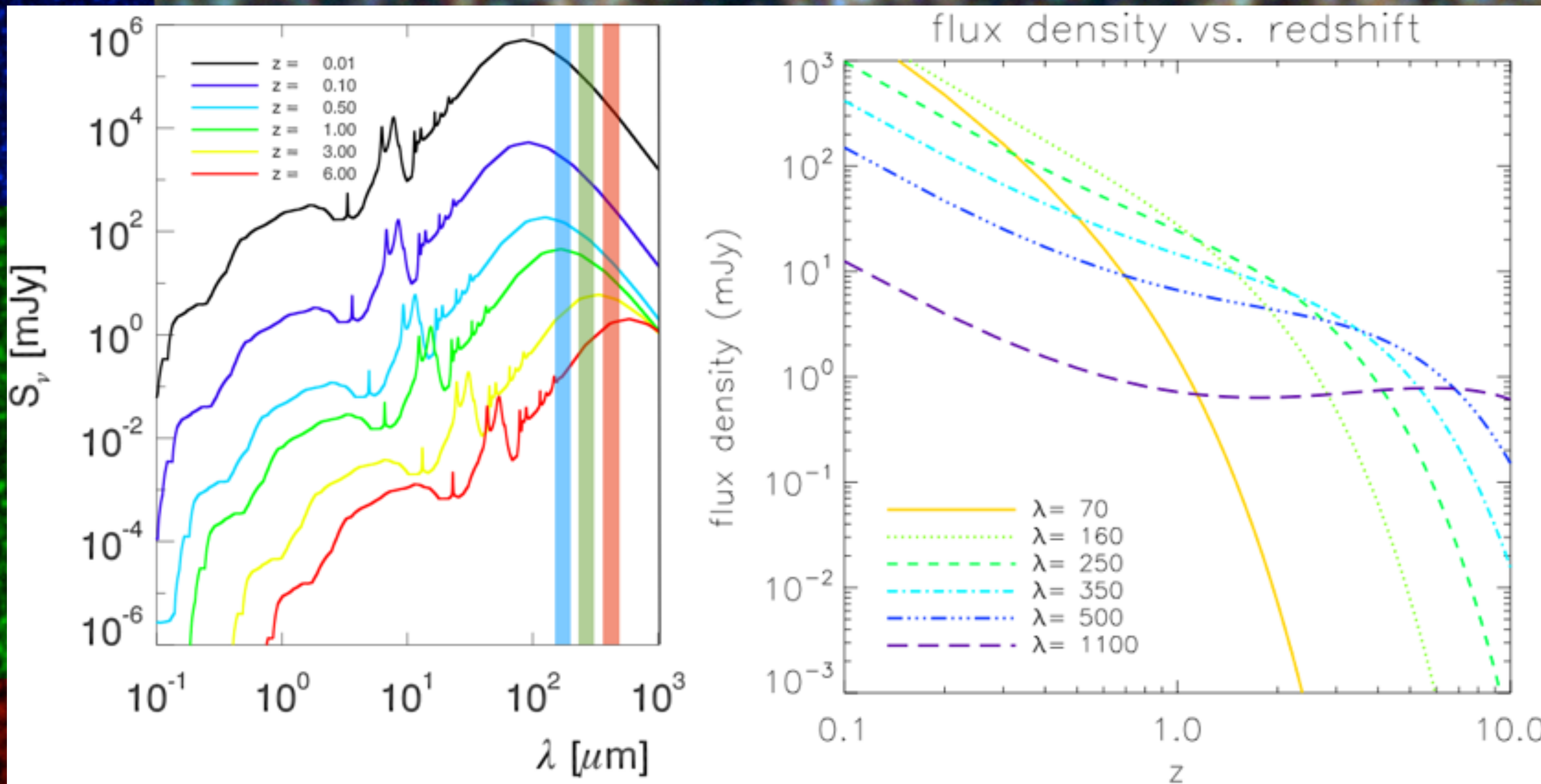
Herschel/SPIRE

Herschel/SPIRE

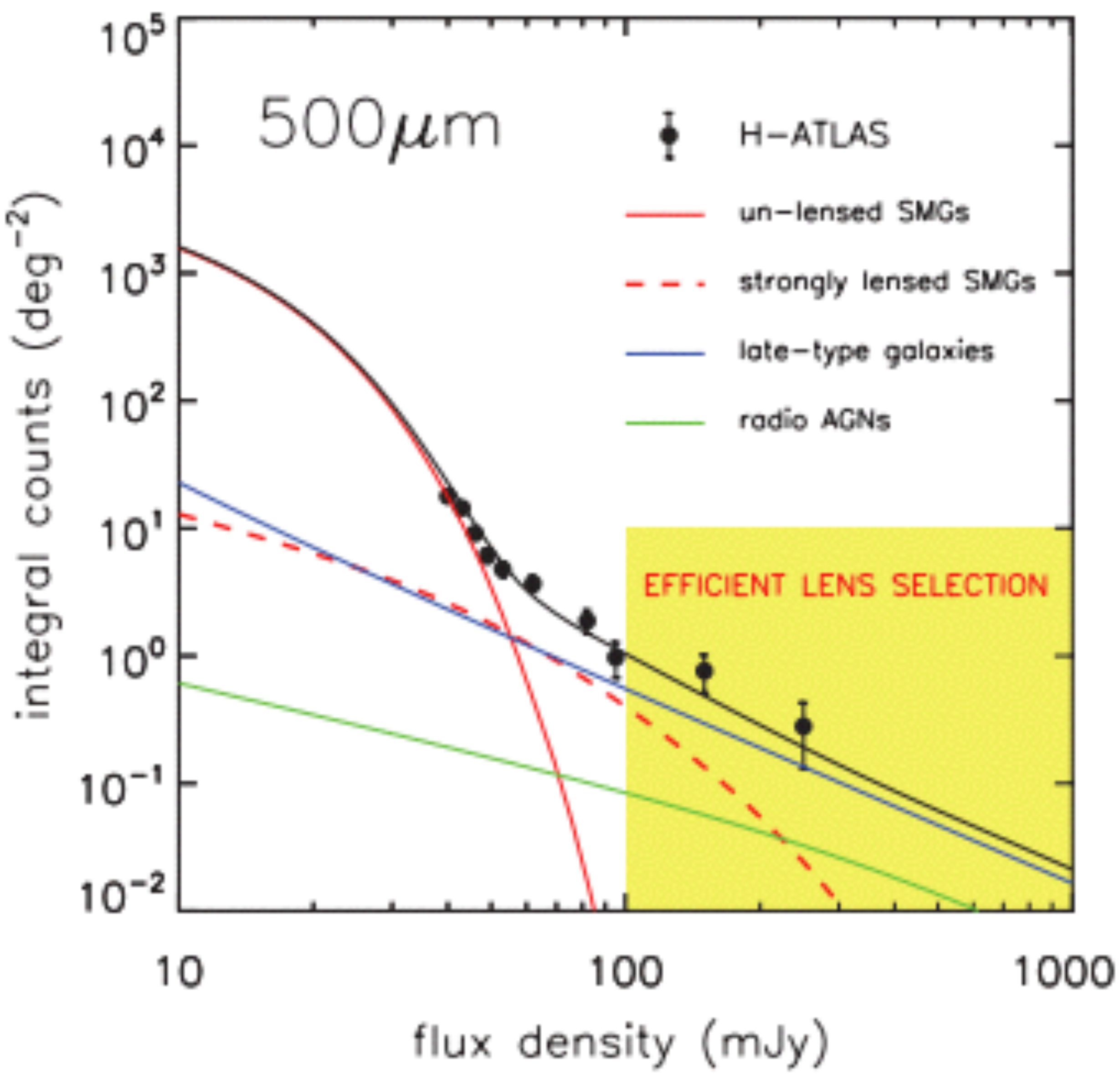
250 μm
16''

350 μm
25''

500 μm
36''



Lensed Sources

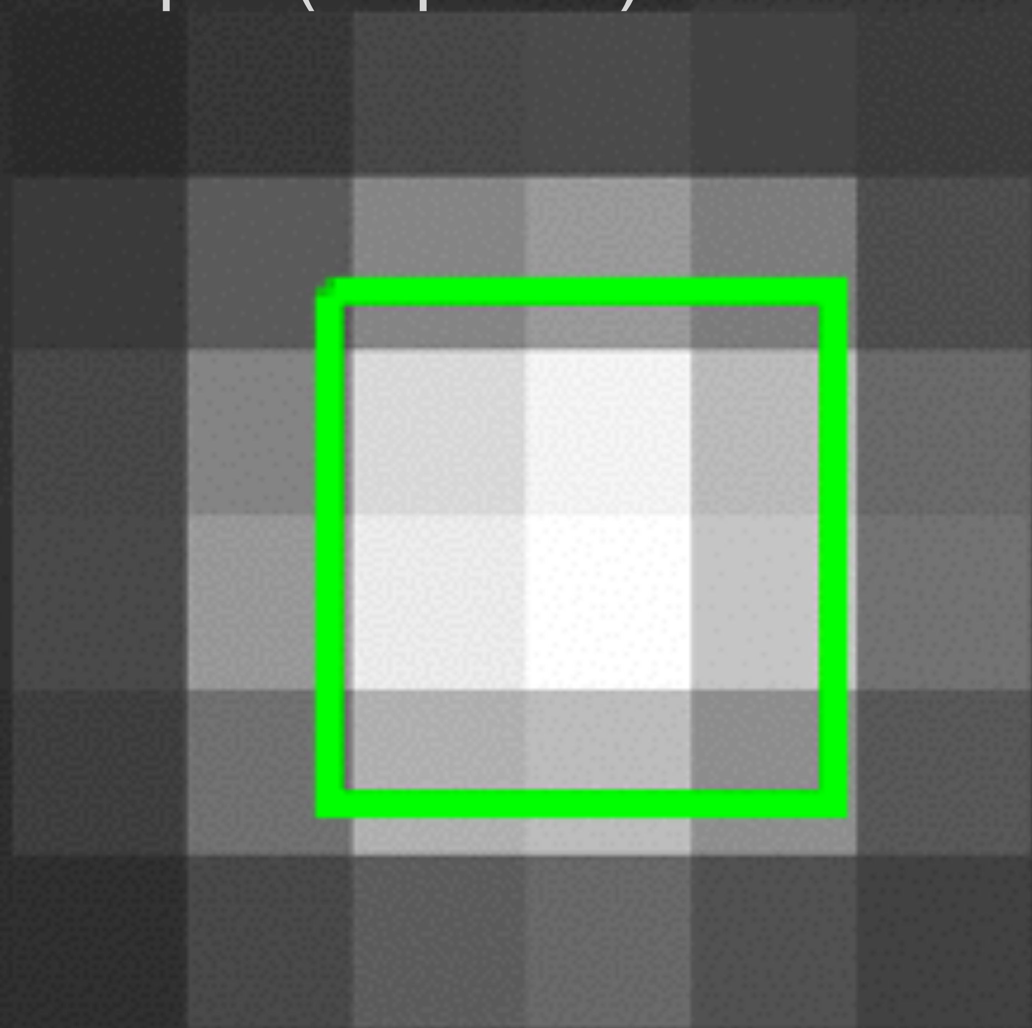


- Sources with flux density S > 100mJy at 500μm have high probability of being lensed

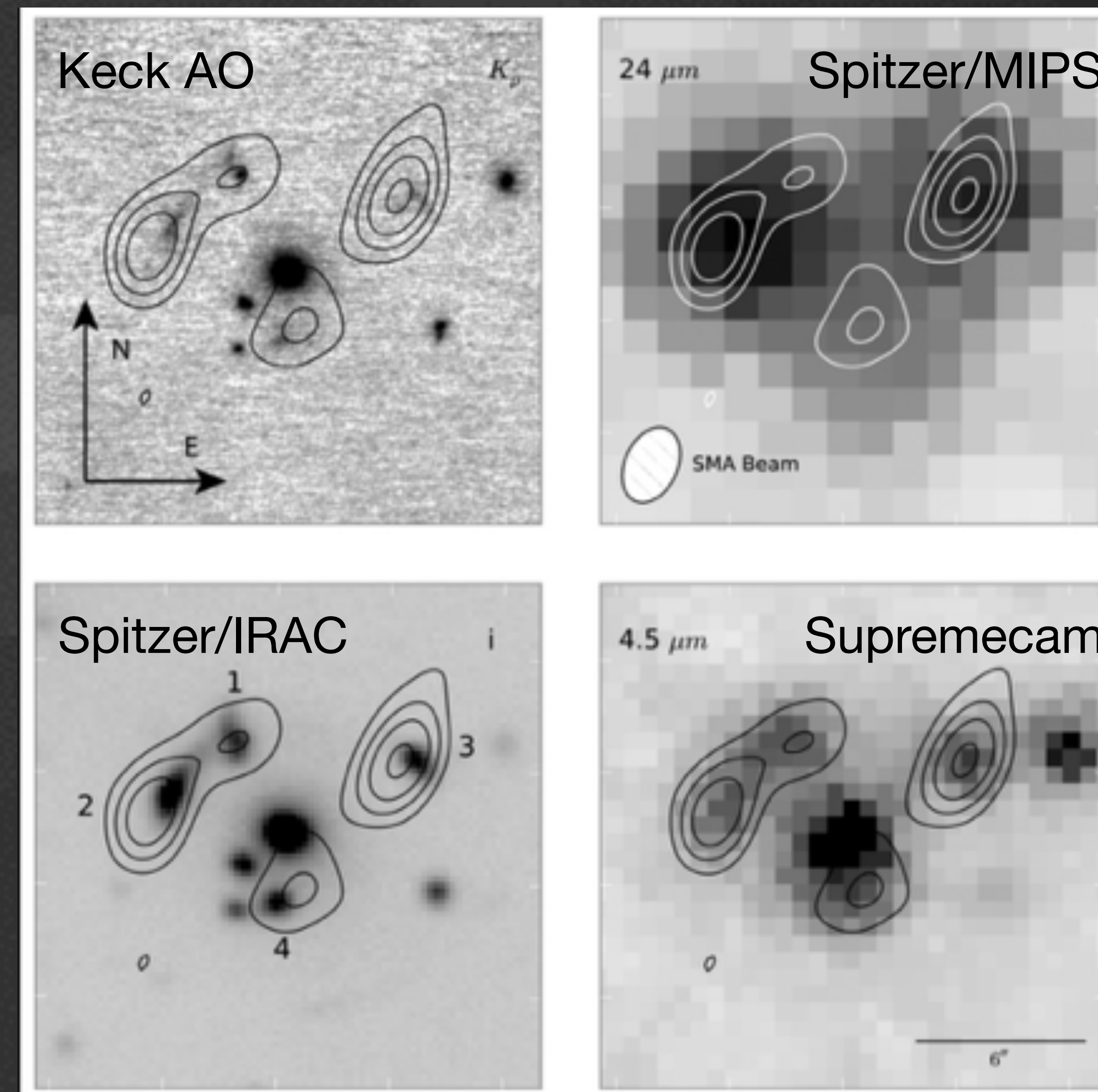
Negrello et al. (2010), Science
The Detection of a Population of Submillimeter-Bright, Strongly Lensed Galaxies. Science 330, 800.

Lensed Sources

SPIRE 250μm (6” pixels)



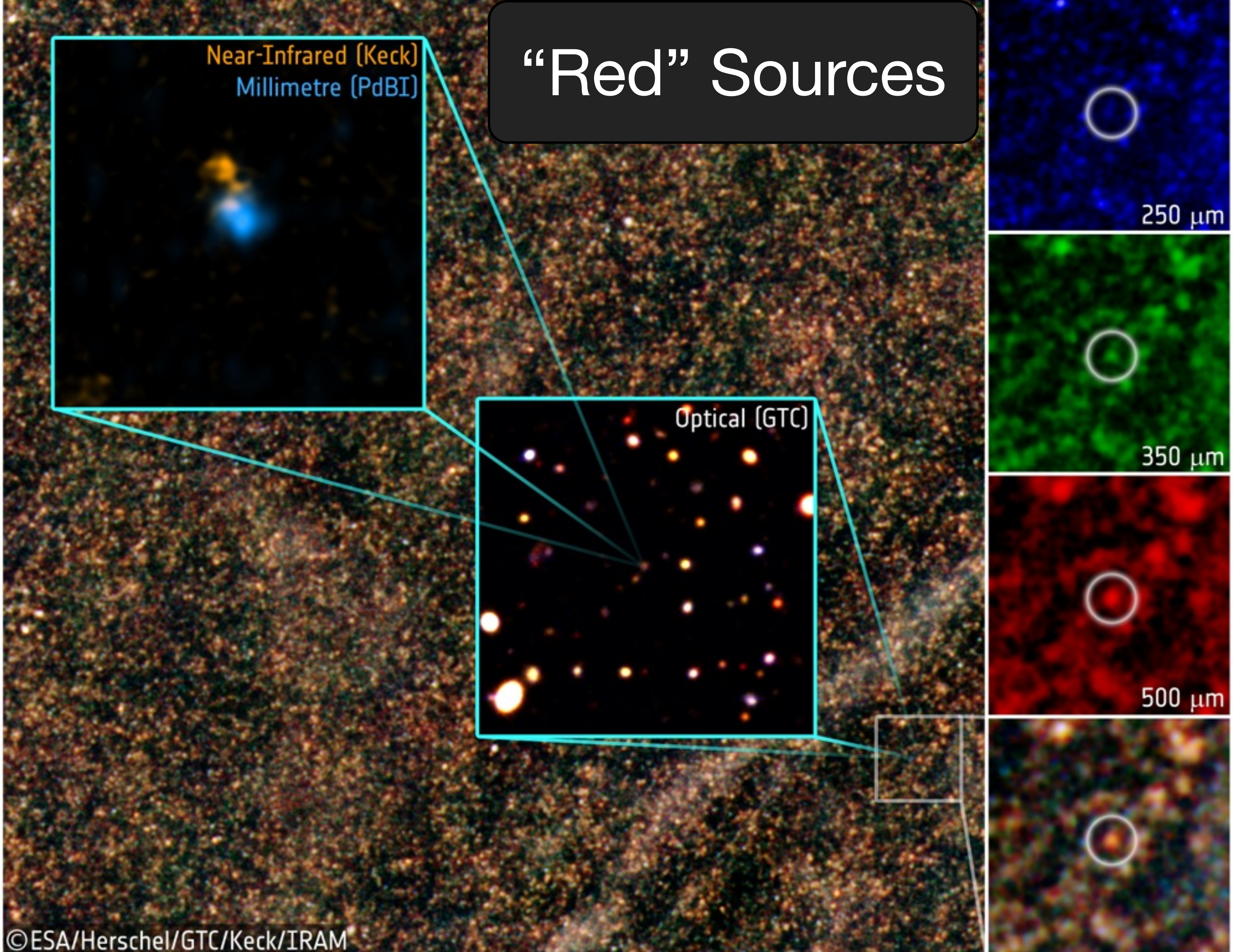
z=2.97 from spectroscopic follow-up



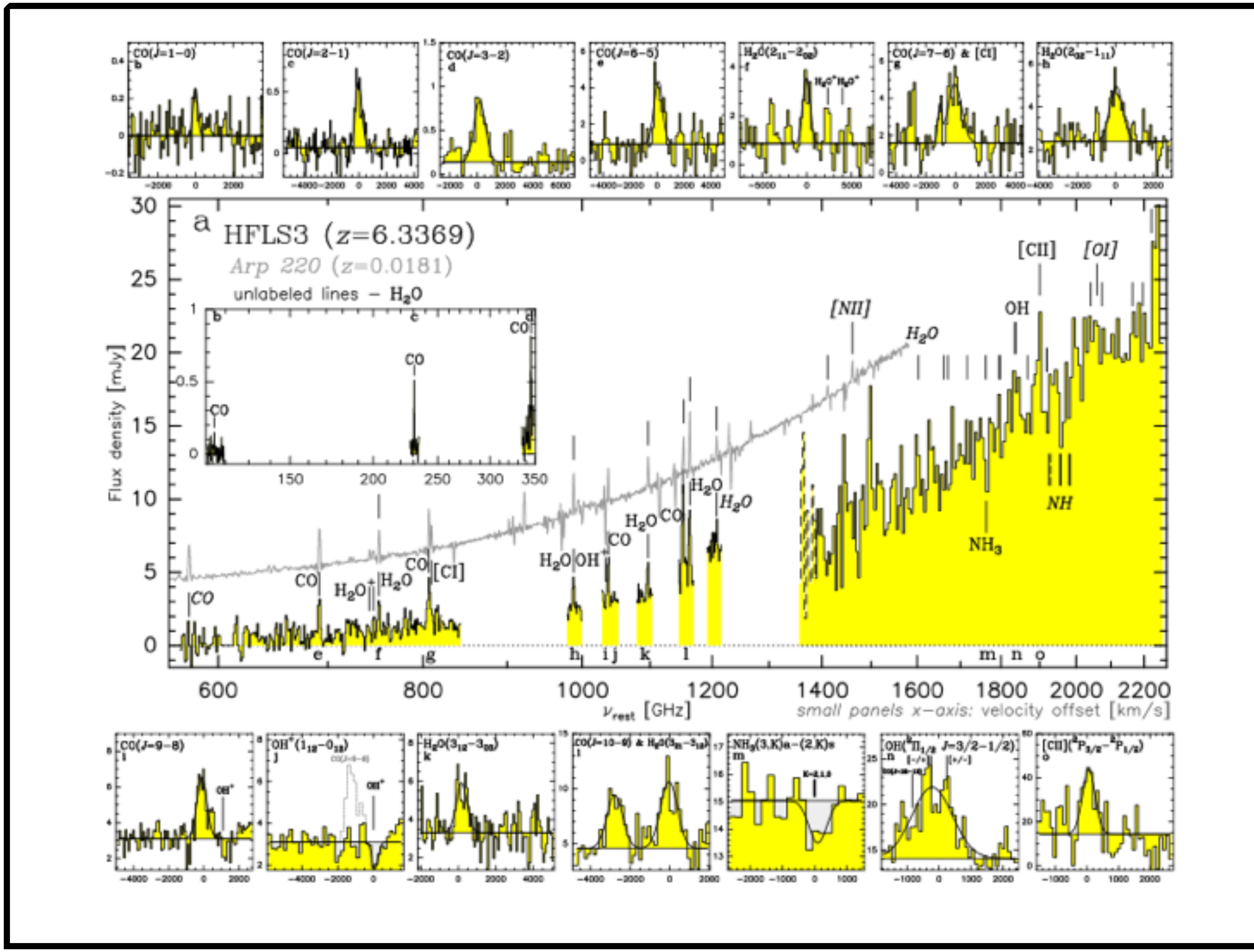
Contours From Submillimeter Array (SMA)

Conley et al. (2011)
also see: Vieira+ 2013, Gonzalez-Nuevo+ 2012, Wardlow+ 2012, Fu+ 2013

“Red” Sources


Near-Infrared (Keck)
Millimetre (PdBI)
Optical (GTC)
250 μm
350 μm
500 μm
©ESA/Herschel/GTC/Keck/IRAM

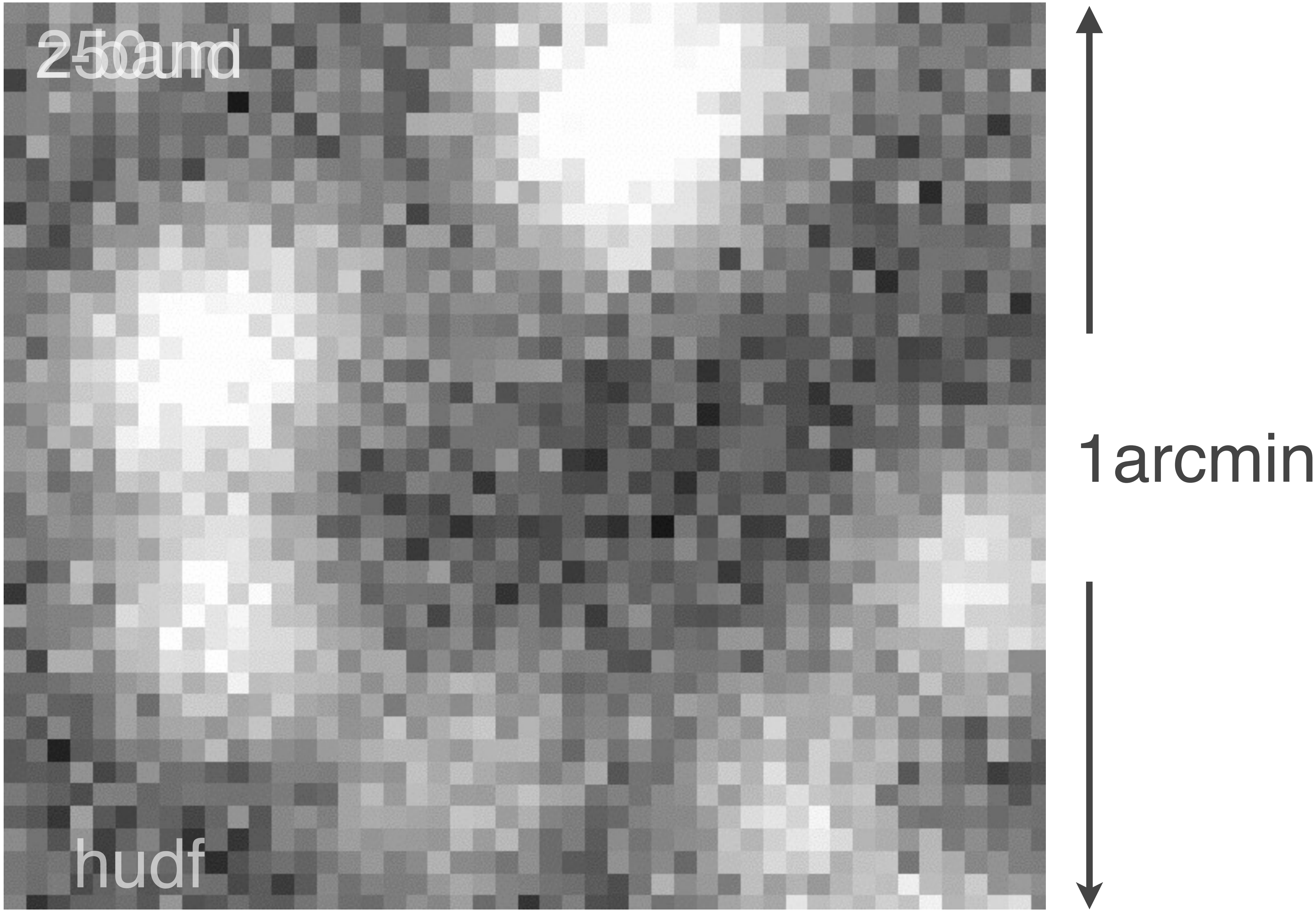
z=6.337 “Red” source



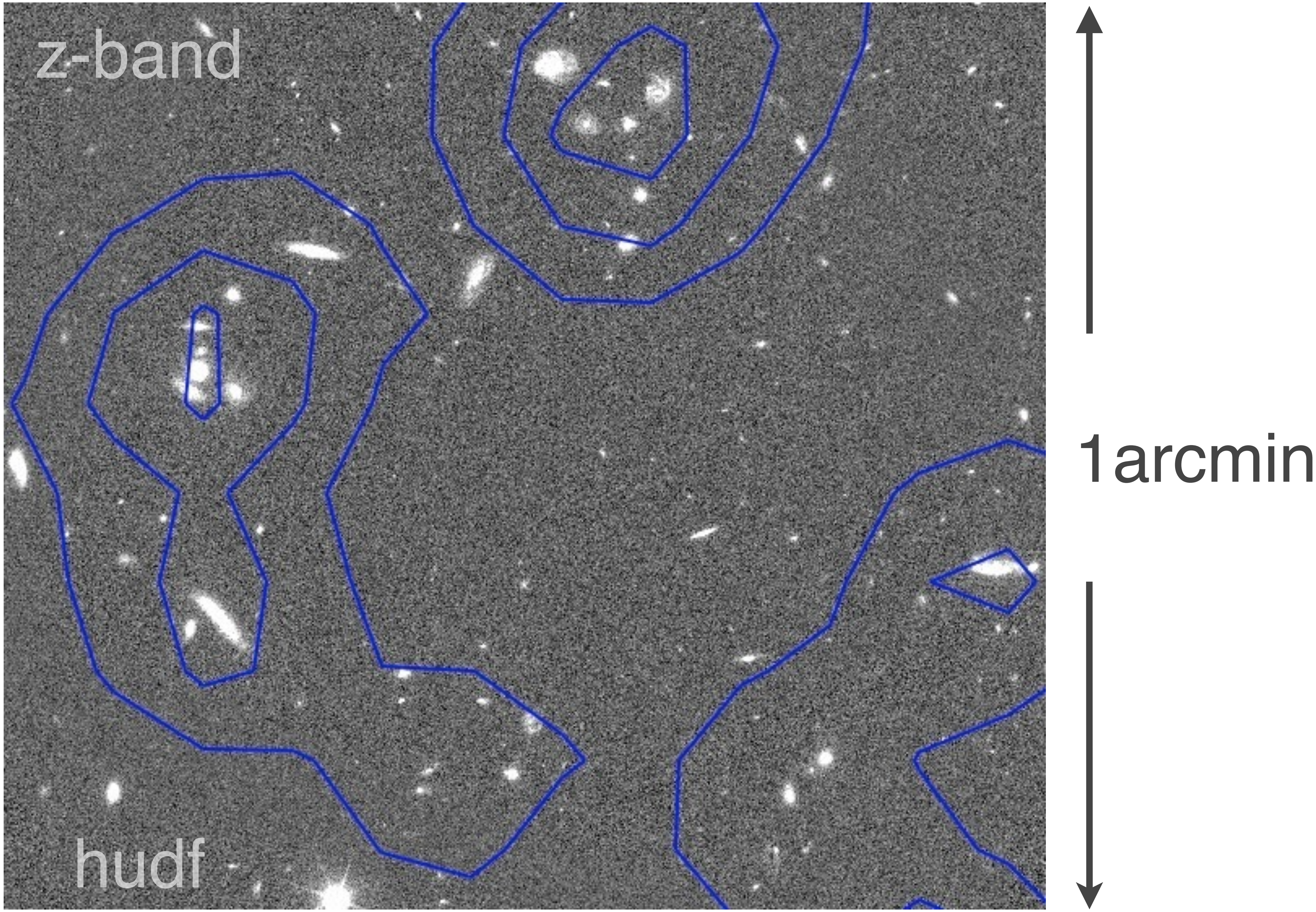
Riechers+ 2013, *Nature*, 496(7), pp.329–333

“A dust-obscured massive maximum-starburst galaxy at a redshift of 6.34”

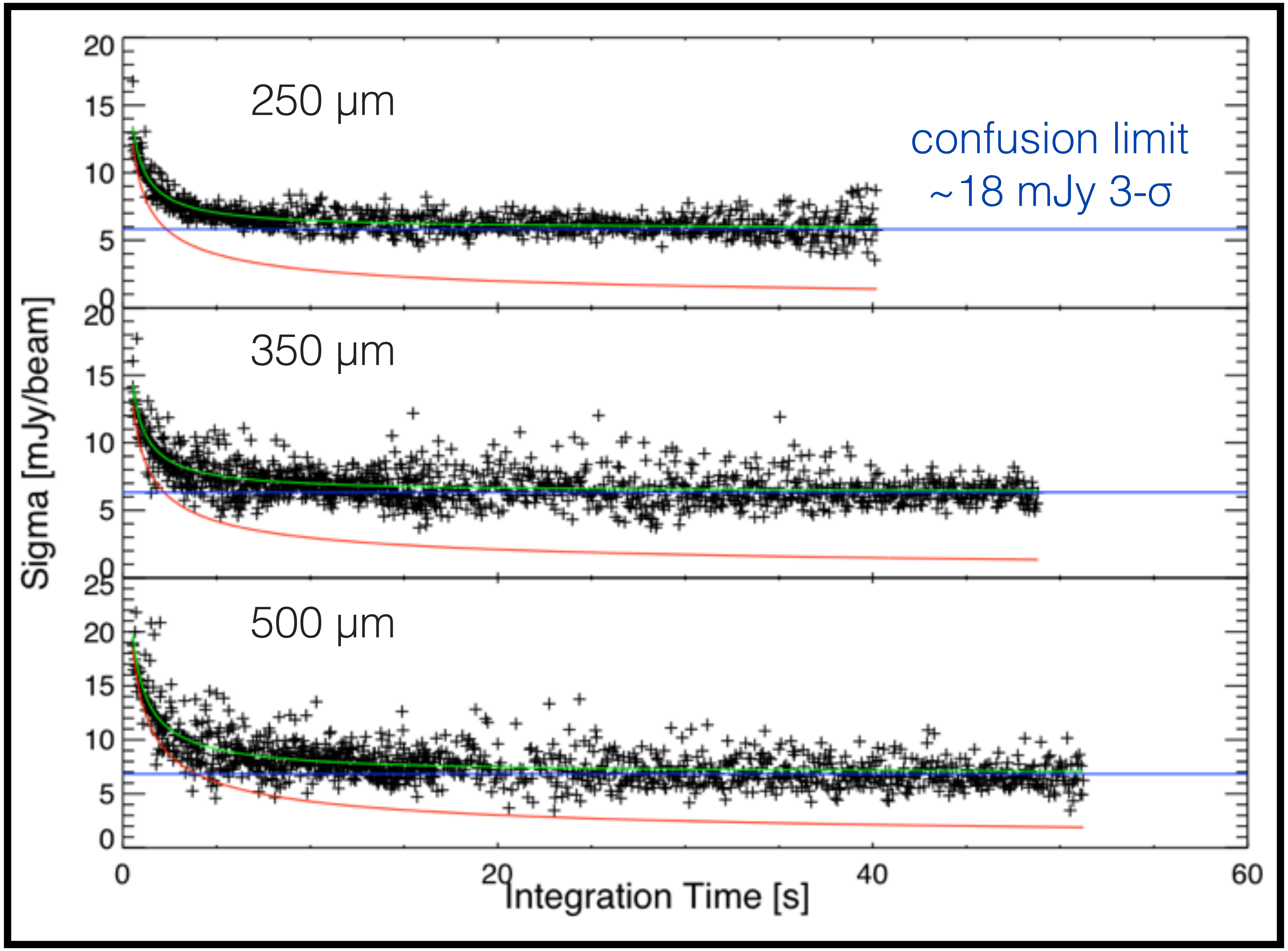
See also: Dowell+ 2013, Gill+ in prep.



source confusion



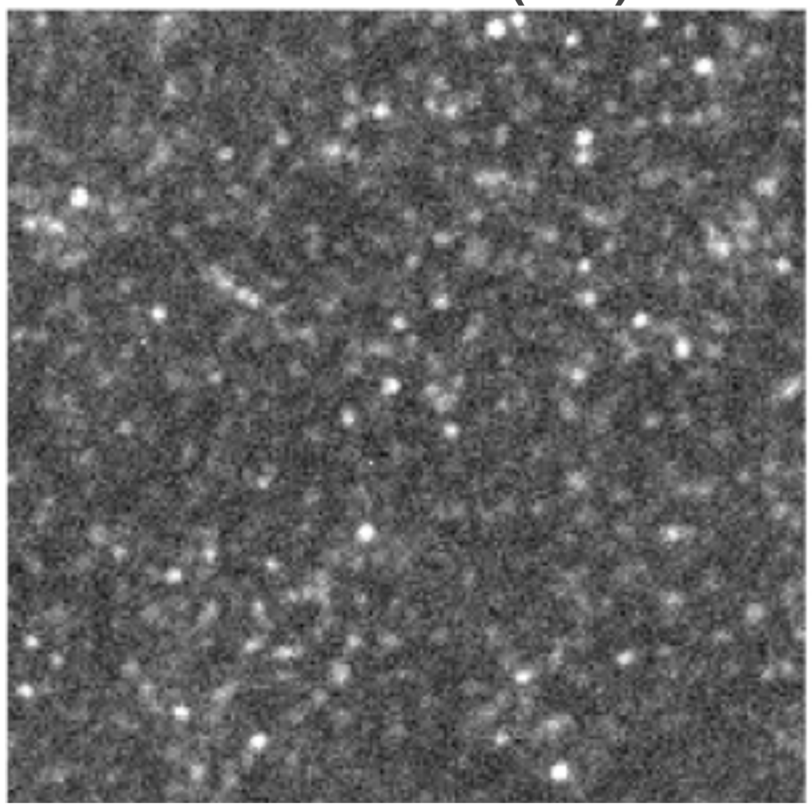
source confusion



Nguyen et al. (2009)

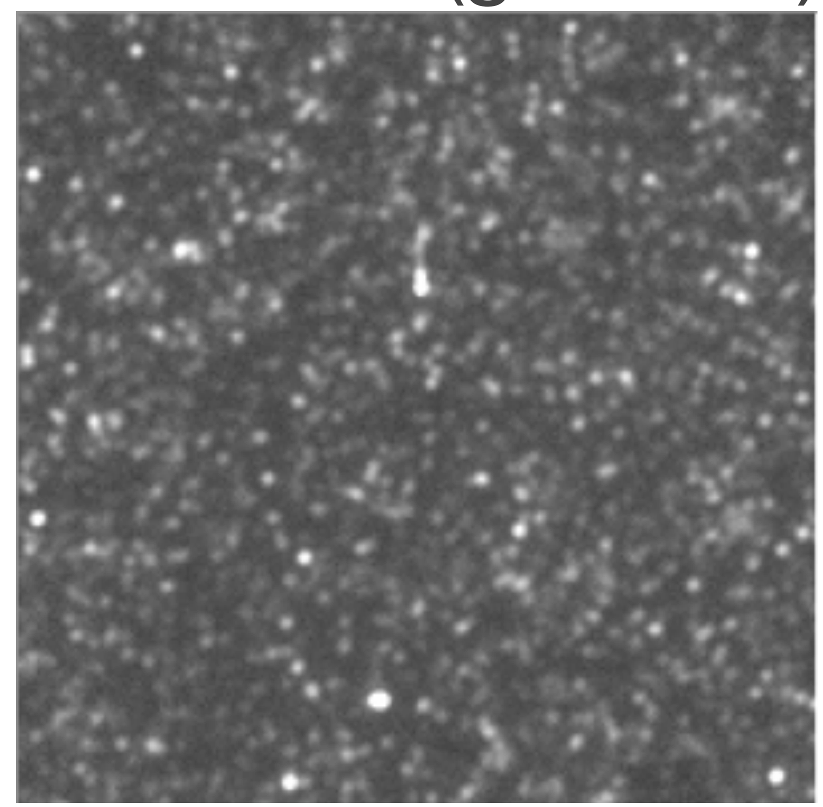
source confusion

4 scans (fls)



RMS = 33.5 mJy (3σ)

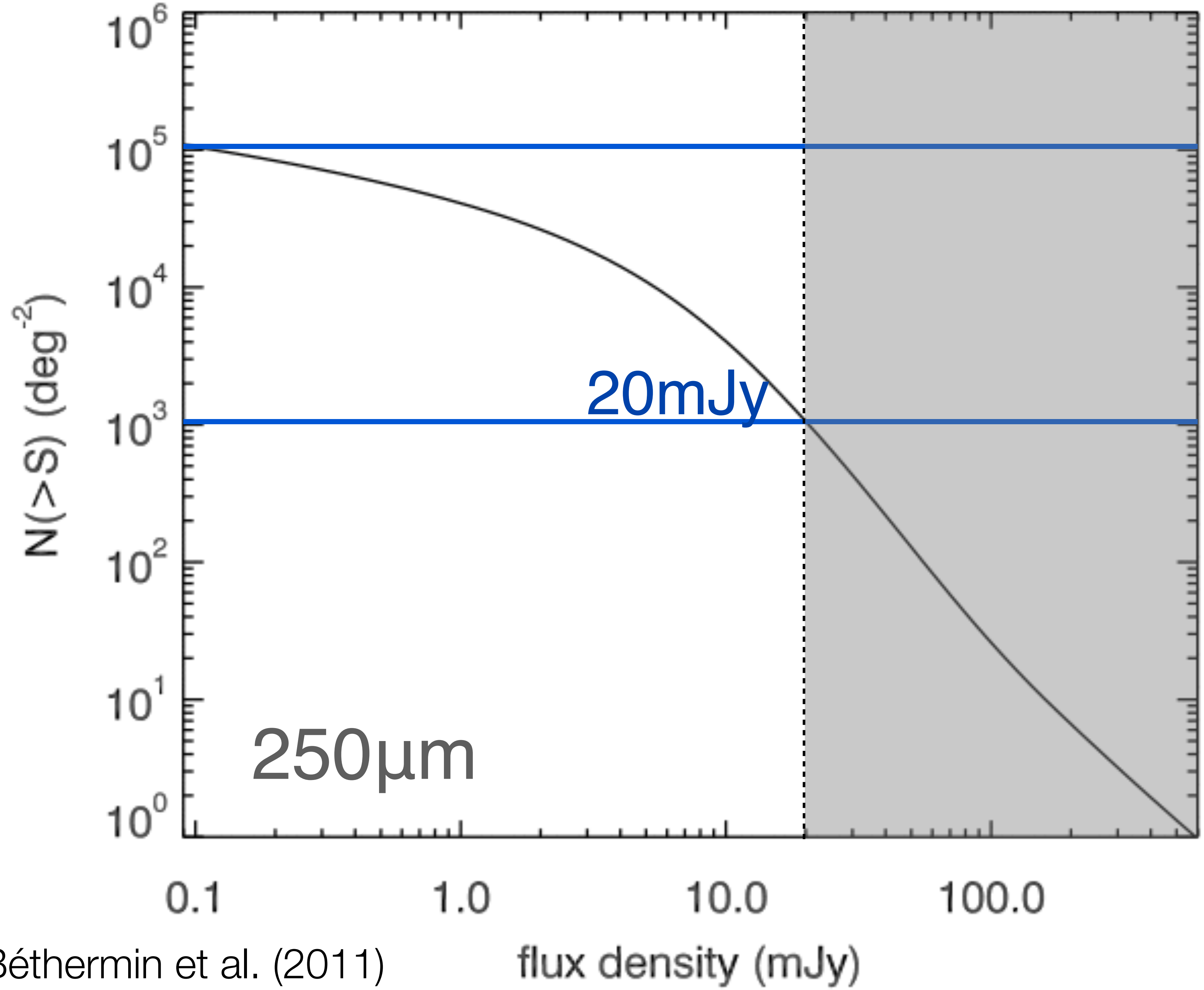
152 scans (goods-s)



20.2 mJy (3σ)

Source Confusion

Number Counts

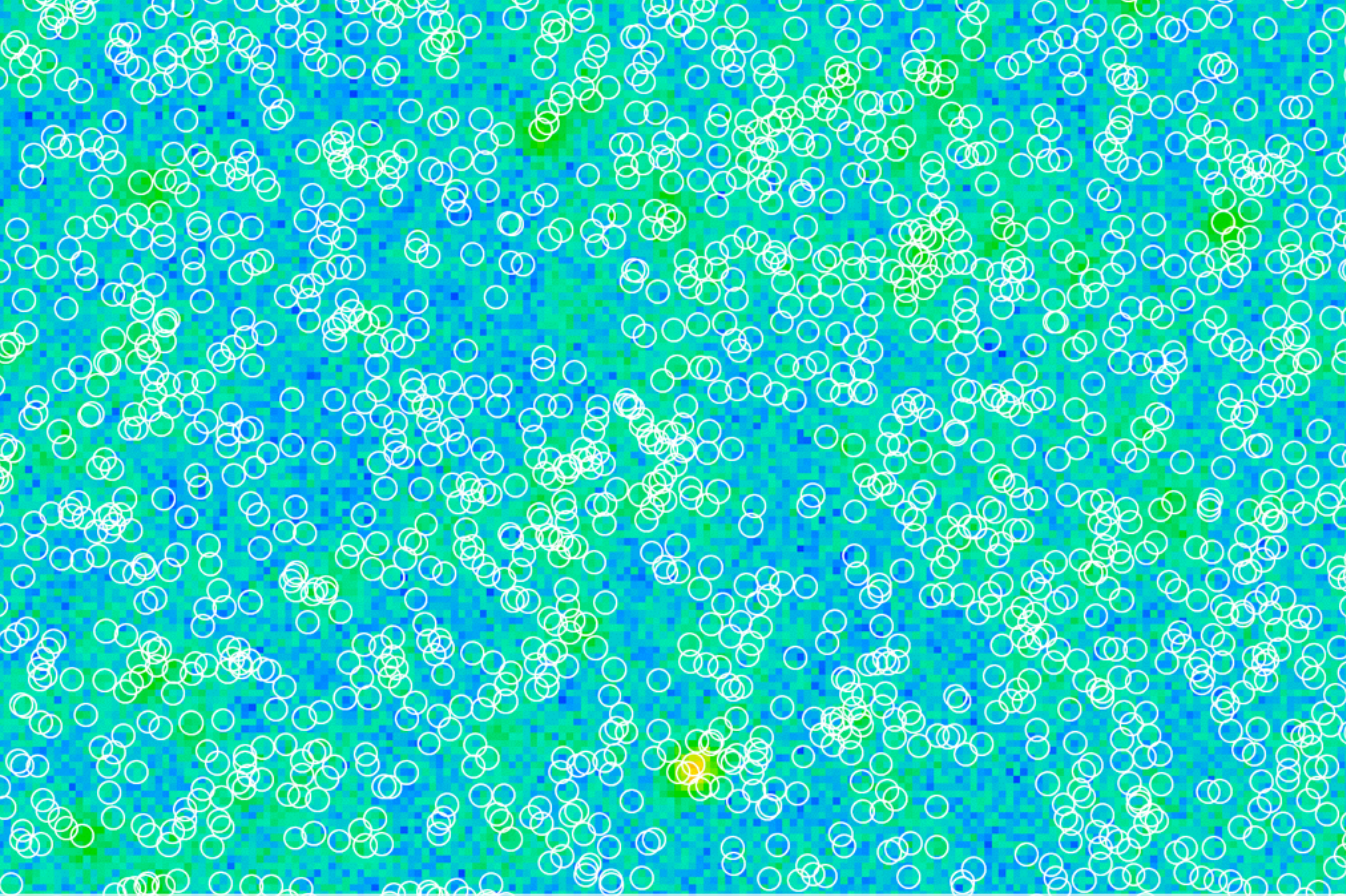


~ 30 sources/ arcmin²

~ 0.3 sources/ arcmin²

i.e. < 1% of sources are resolved with SPIRE

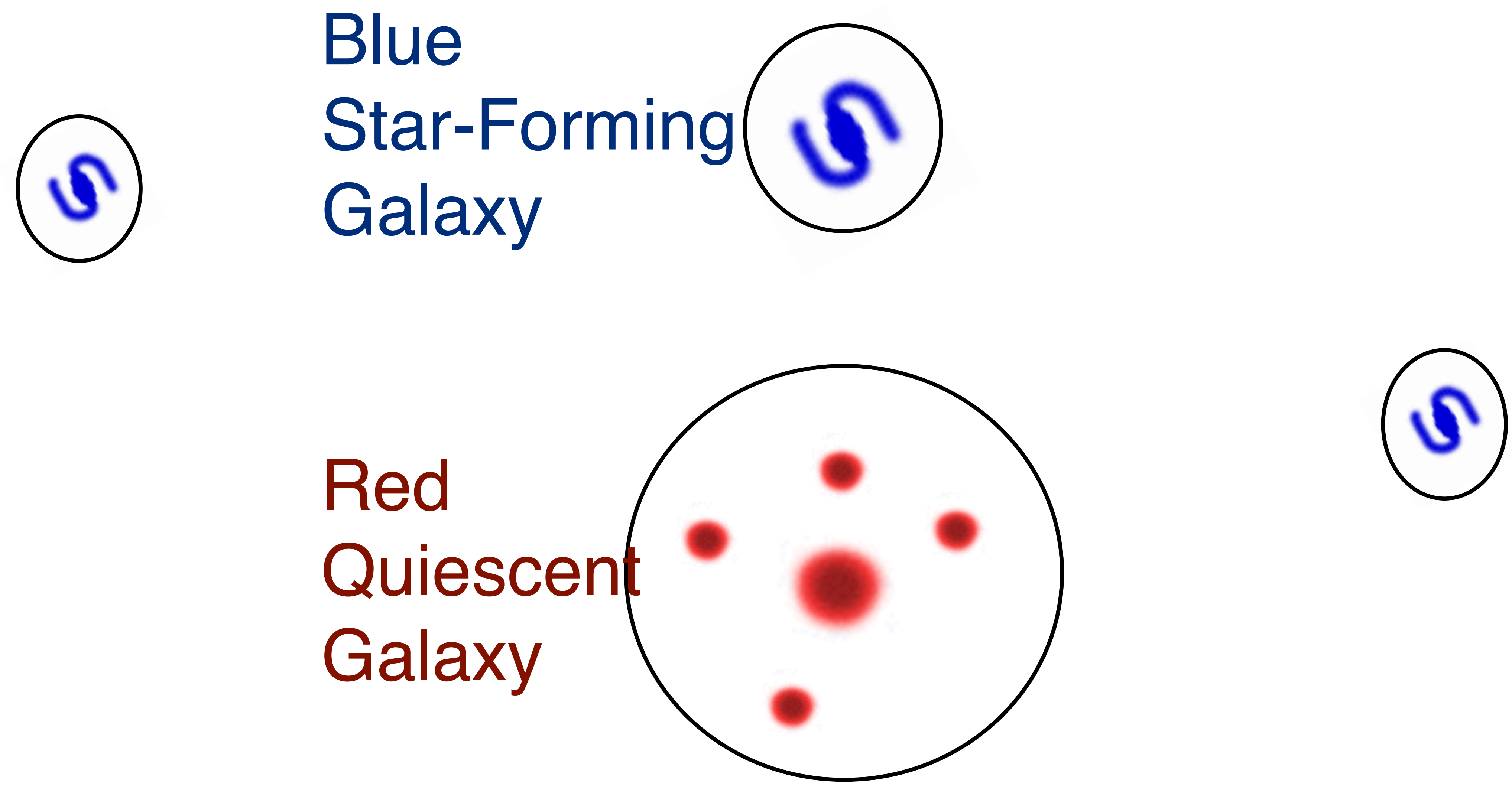
Béthermin et al. (2011) arXiv:1010.1150



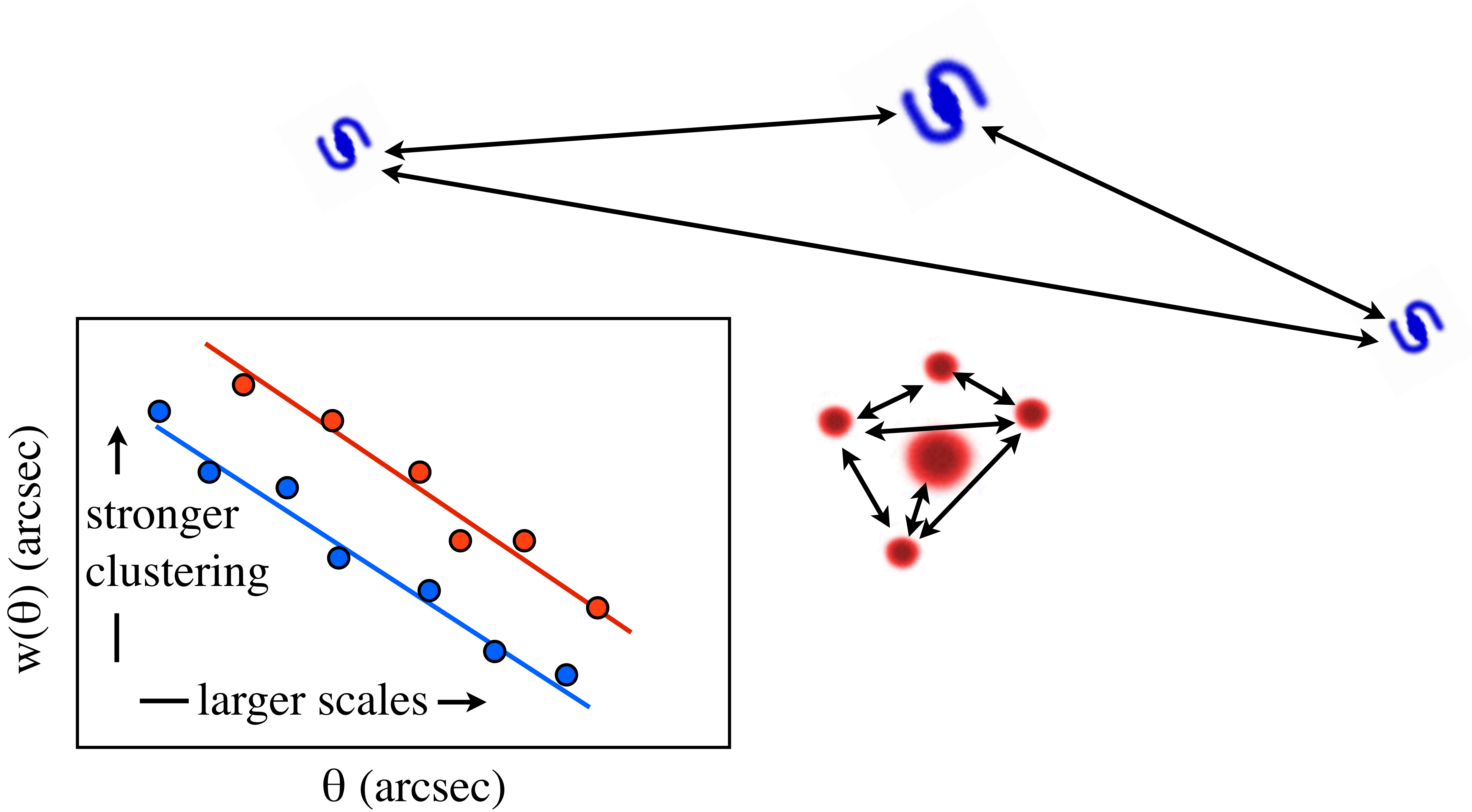
Cross-Correlations with the CIB

Outline

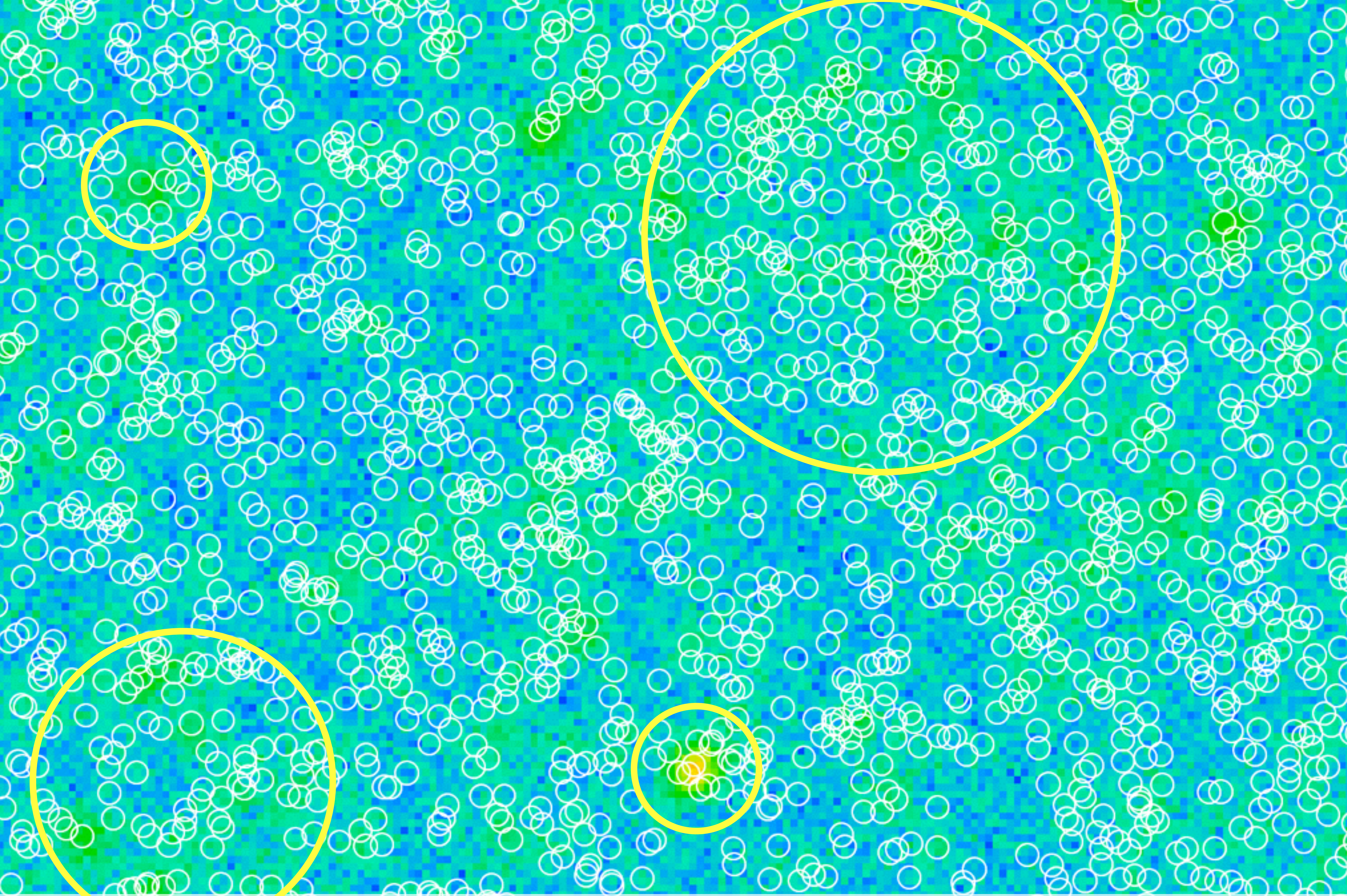
- Why the Cosmic Infrared Background (CIB)?
- Auto and cross-correlations of CIB as a tool to:
  - measure galaxy-galaxy clustering to determine the dark matter hosts of dusty star-forming galaxies
  - determine the COB-CIB connection
  - cosmological applications
- The Future in Surveys



Galaxy Clustering

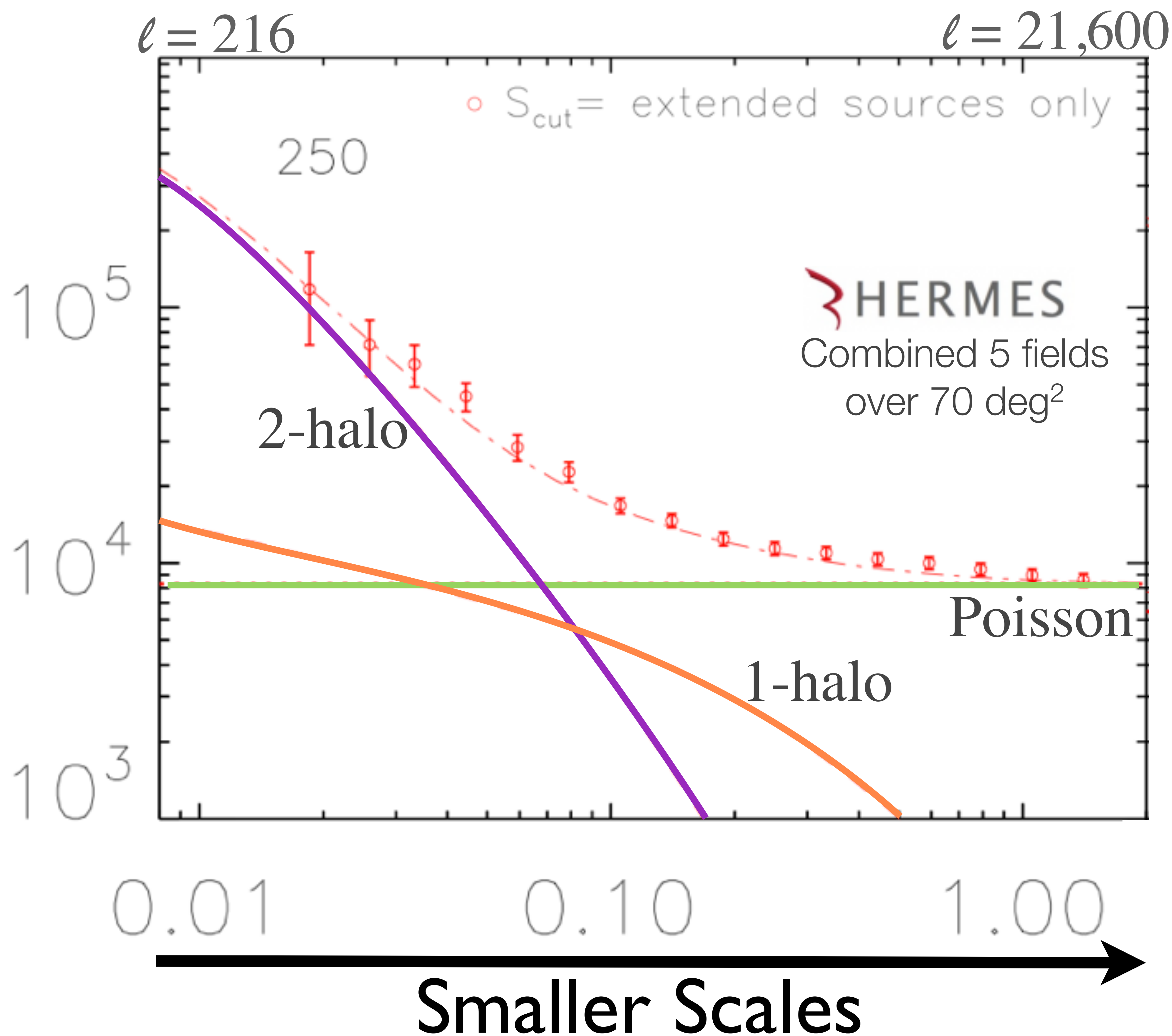


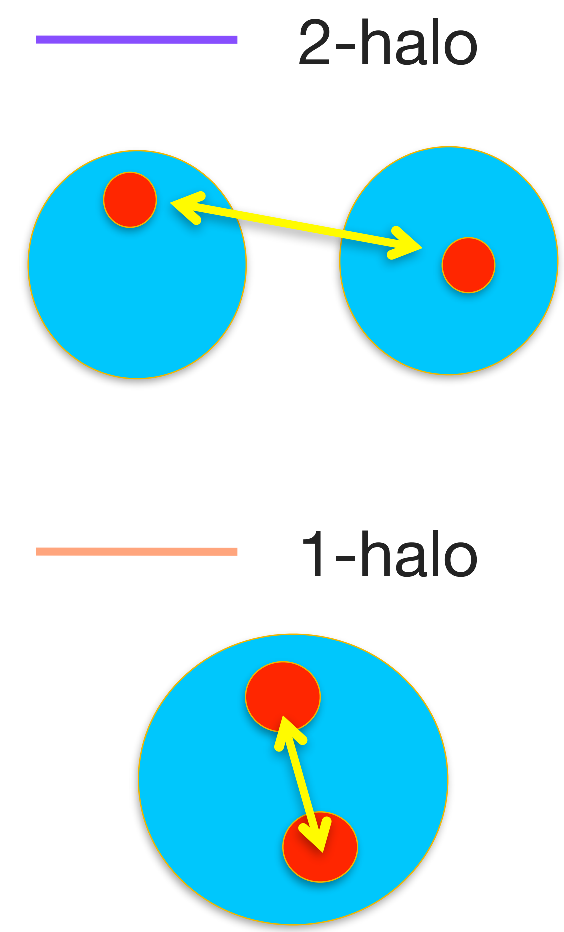
Correlation Function



Power Spectrum of CIB Anisotropies

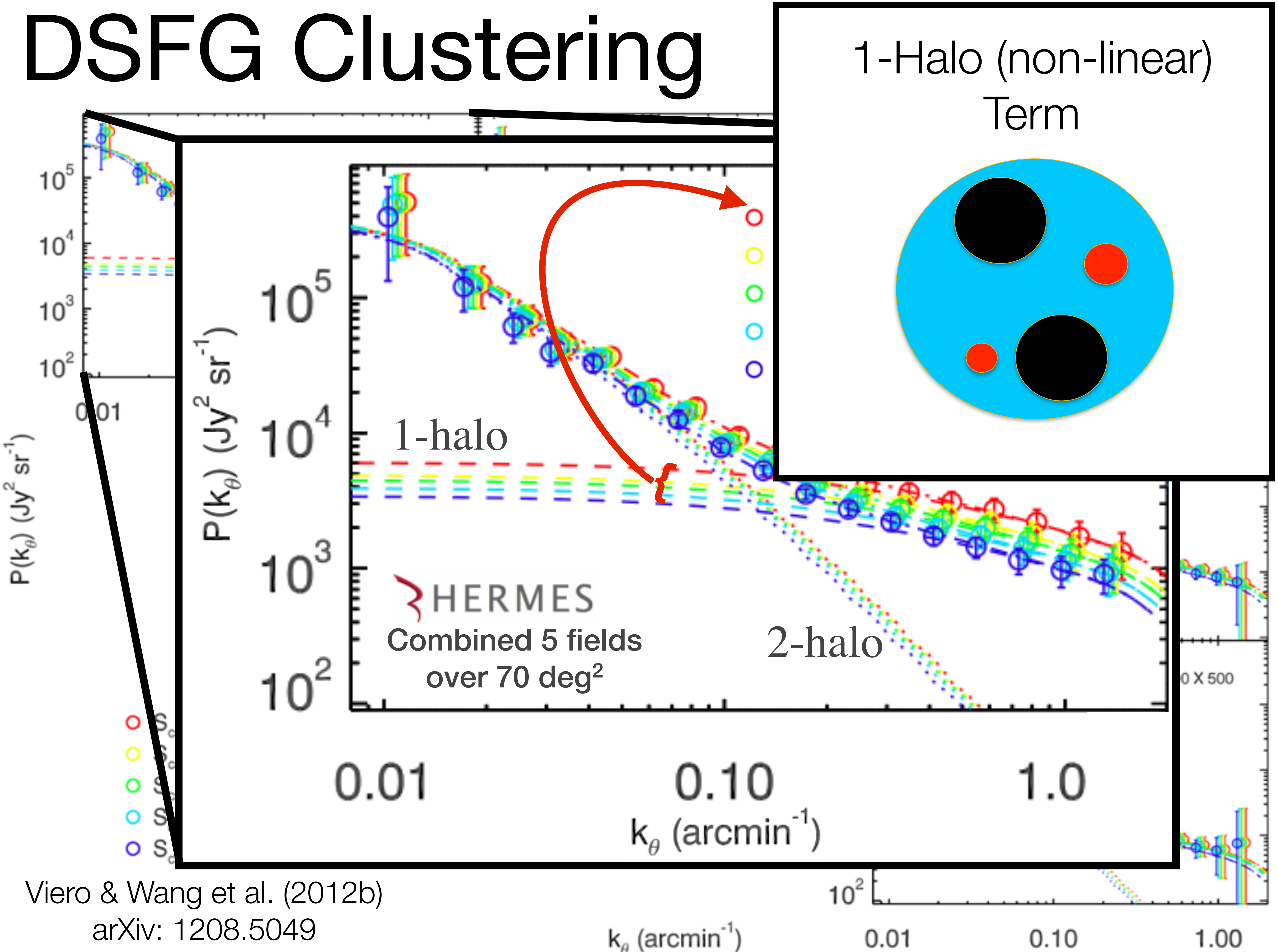
CIB Power Spectrum





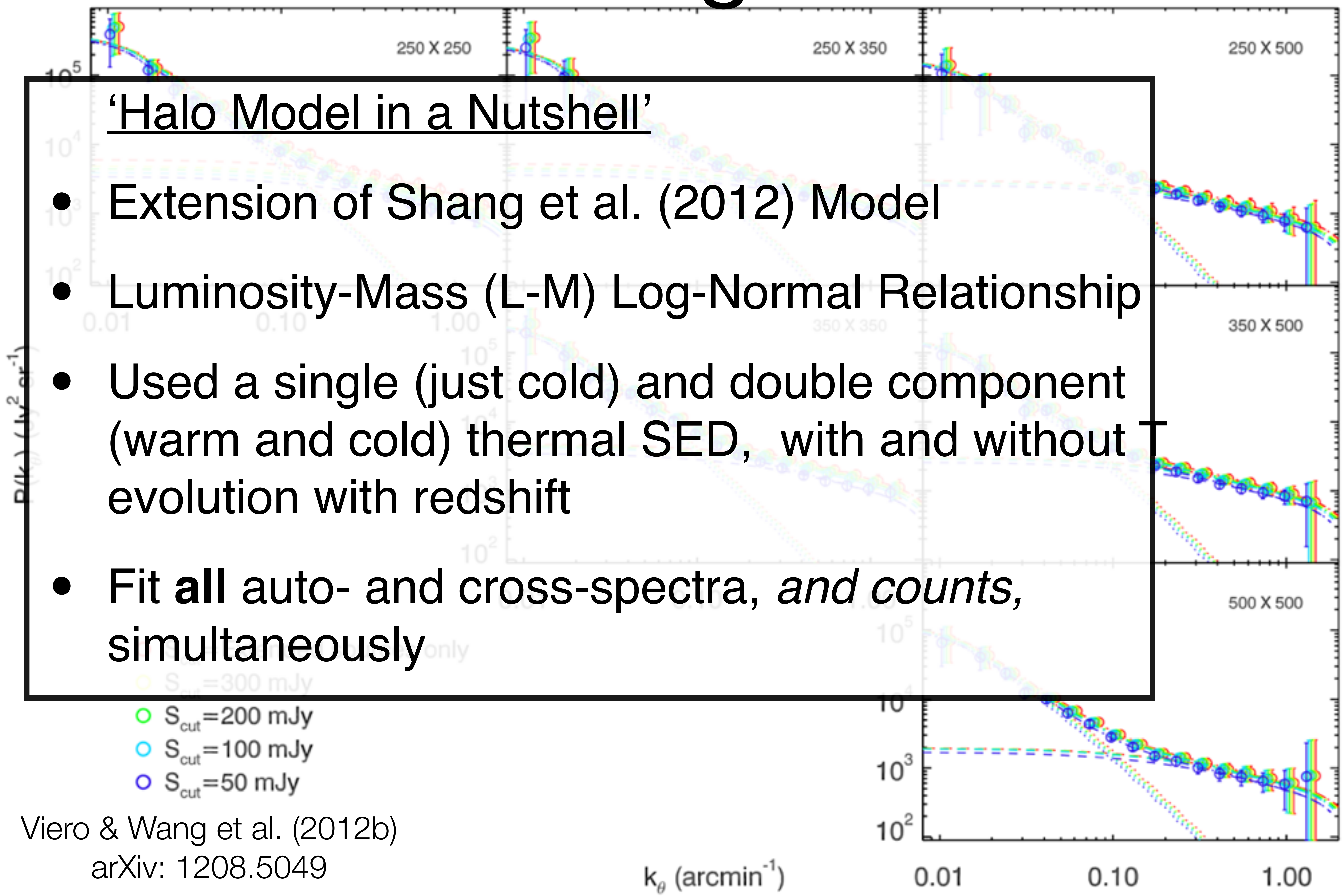
Halo Model: see e.g., Cooray & Sheth (2000), Zehavi et al. (2005, 2008)

DSFG Clustering



Viero & Wang et al. (2012b)
arXiv: 1208.5049

DSFG Clustering



<u>'Halo Model in a Nutshell'</u>

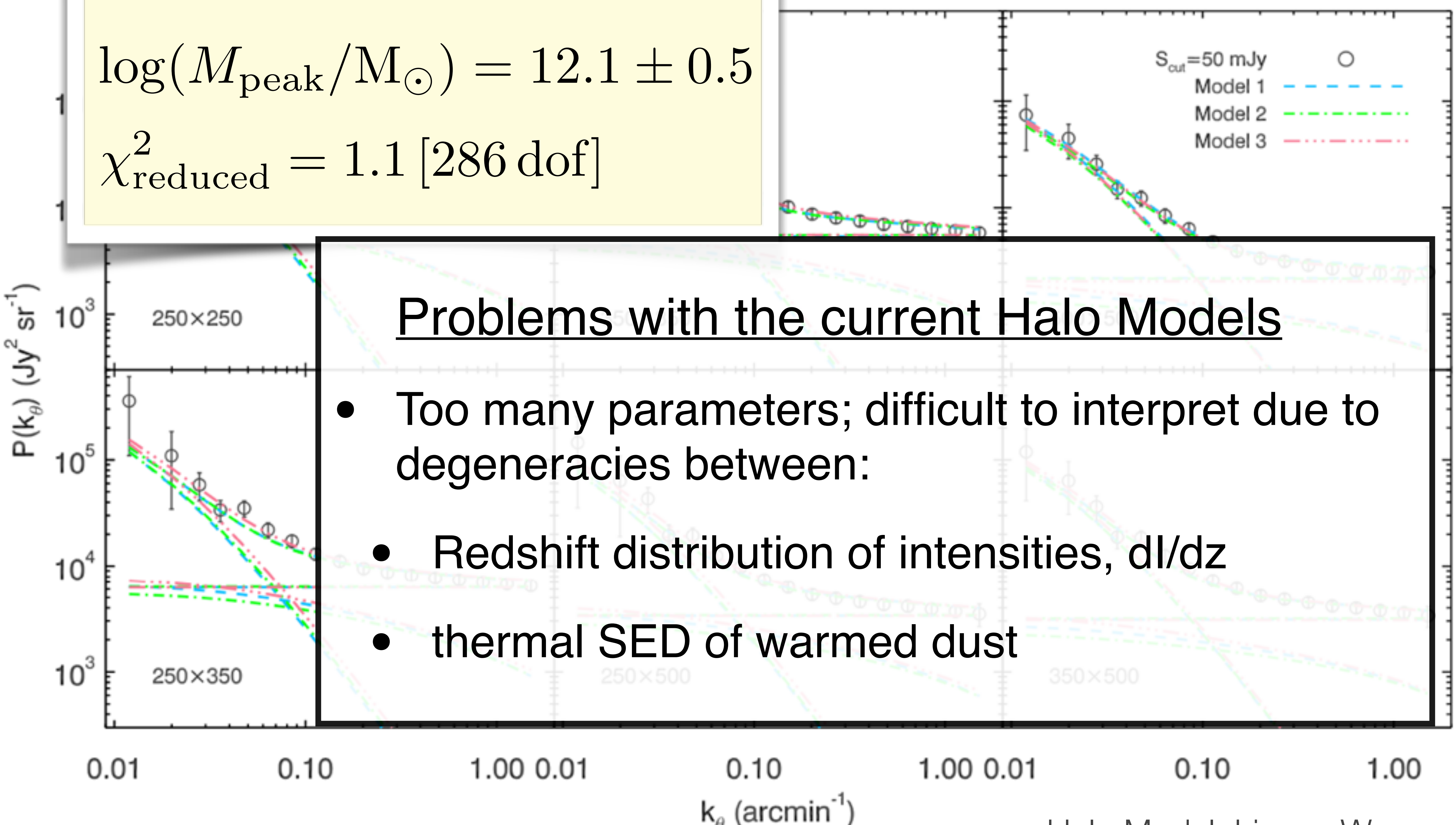
- Extension of Shang et al. (2012) Model
- Luminosity-Mass (L-M) Log-Normal Relationship
- Used a single (just cold) and double component (warm and cold) thermal SED, with and without T evolution with redshift
- Fit **all** auto- and cross-spectra, *and counts,* simultaneously

Viero & Wang et al. (2012b)
arXiv: 1208.5049

Best-Fit Halo Models

$$\log(M_{\rm peak}/{\rm M}_\odot) = 12.1 \pm 0.5$$

$$\chi^2_{\rm reduced} = 1.1\,[286\,{\rm dof}]$$



<u>Problems with the current Halo Models</u>

- Too many parameters; difficult to interpret due to degeneracies between:
    - Redshift distribution of intensities, dI/dz
    - thermal SED of warmed dust

Halo Model: Lingyu Wang

Take-away from Clustering

- DSFG emission traces the dark matter distribution
  - SFGs most efficient in $\log(M_{\rm peak}/{\rm M}_{\odot}) = 12.1 \pm 0.5$
  - The redshift distribution depends on the wavelength
- More massive halos (groups and clusters!) host very luminous DSGFs
- Halo Model interpretations suffer from degeneracies, requiring *more constraints*!

Outline

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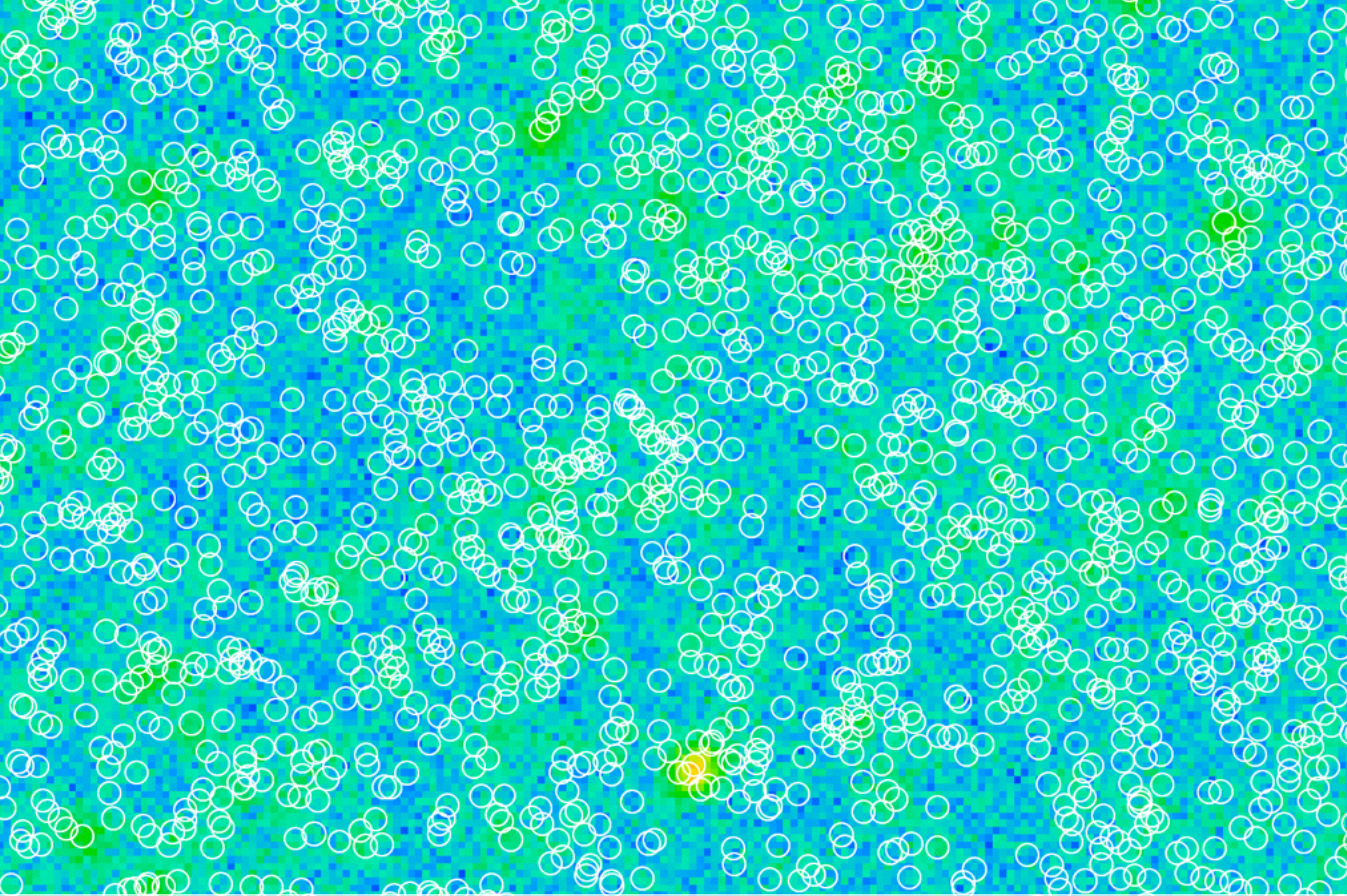
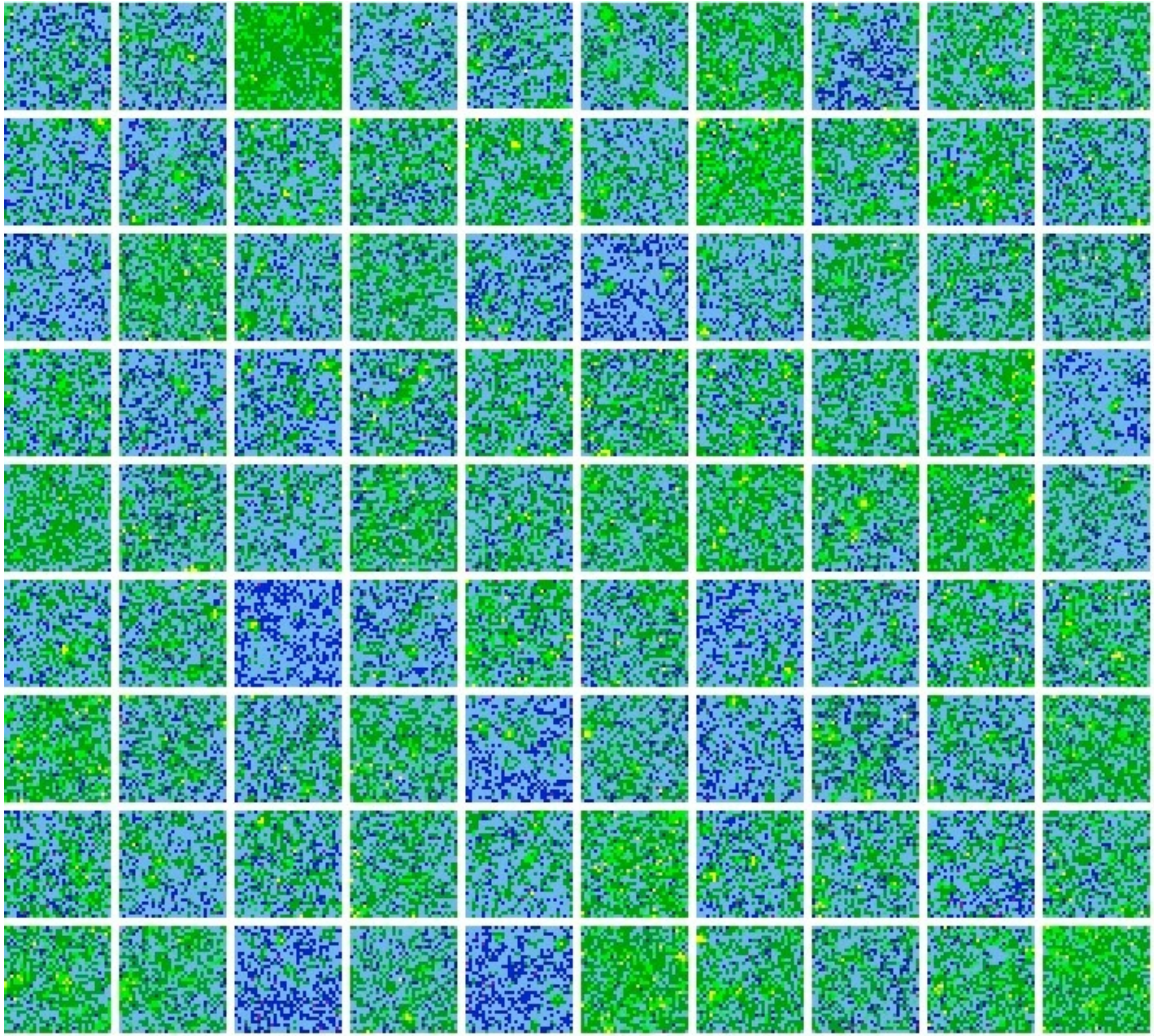
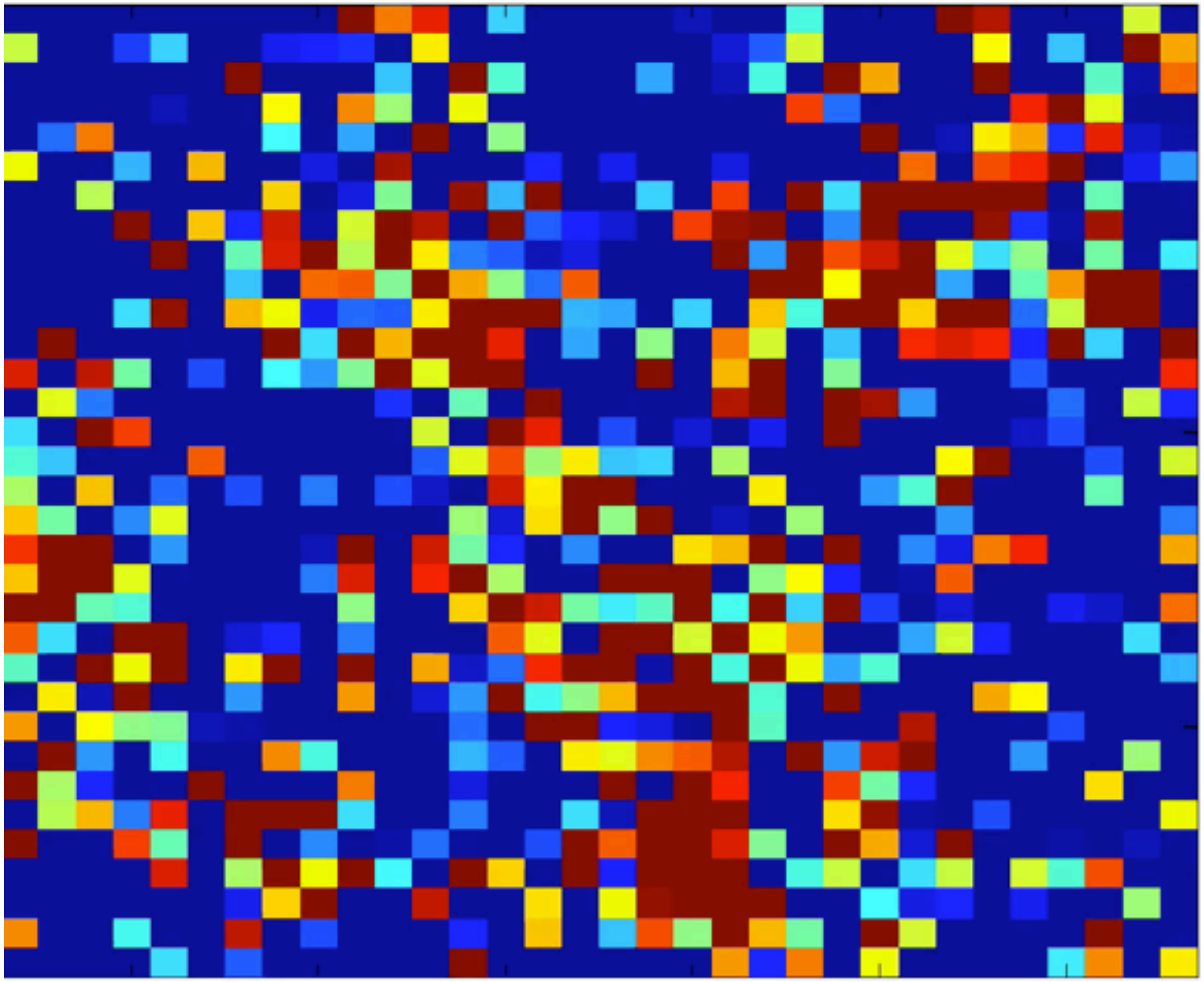
  - cosmological applications
- The Future in Surveys



Cross-Correlations w/ Ancillary Catalogs

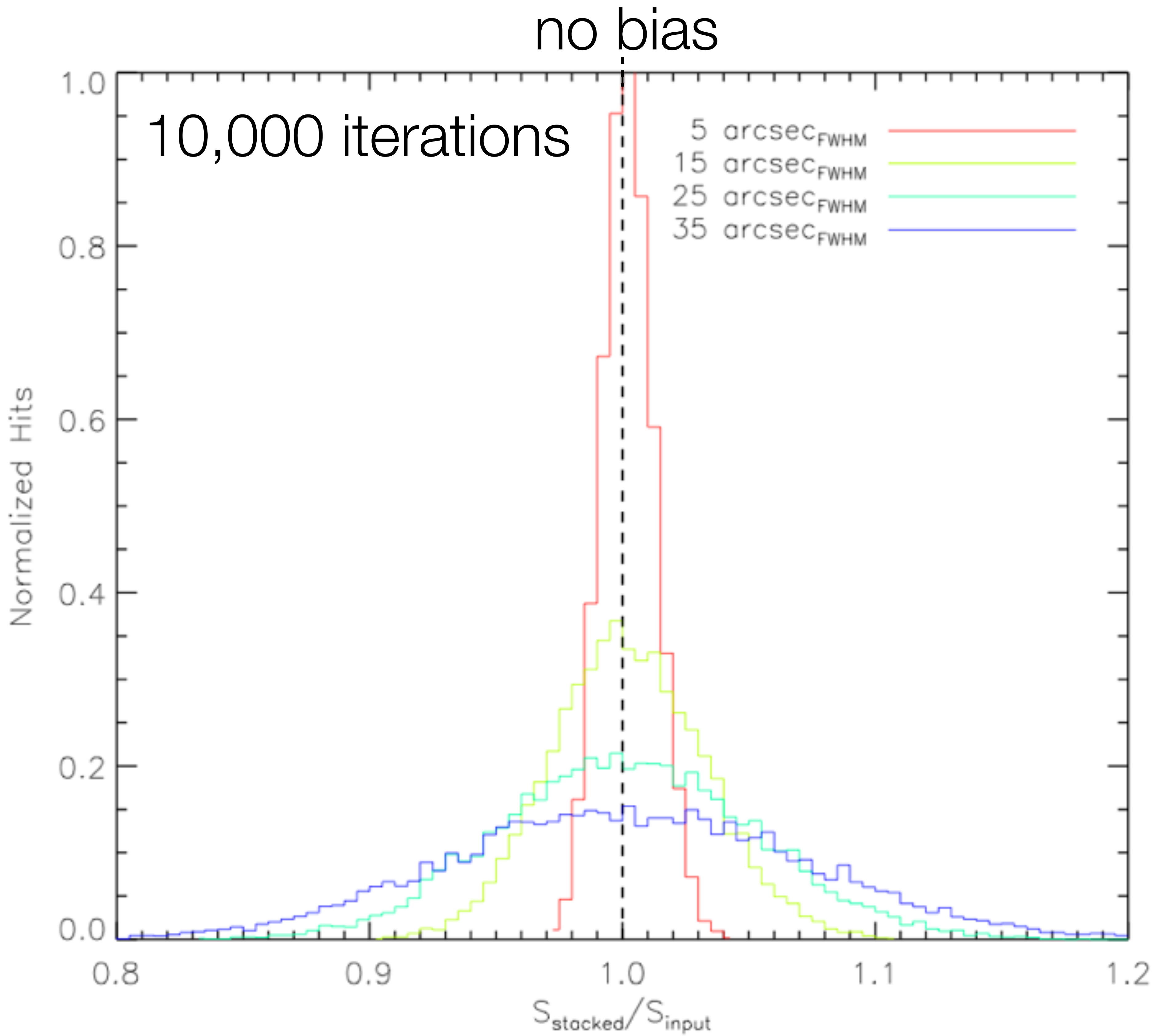


traditional stacking

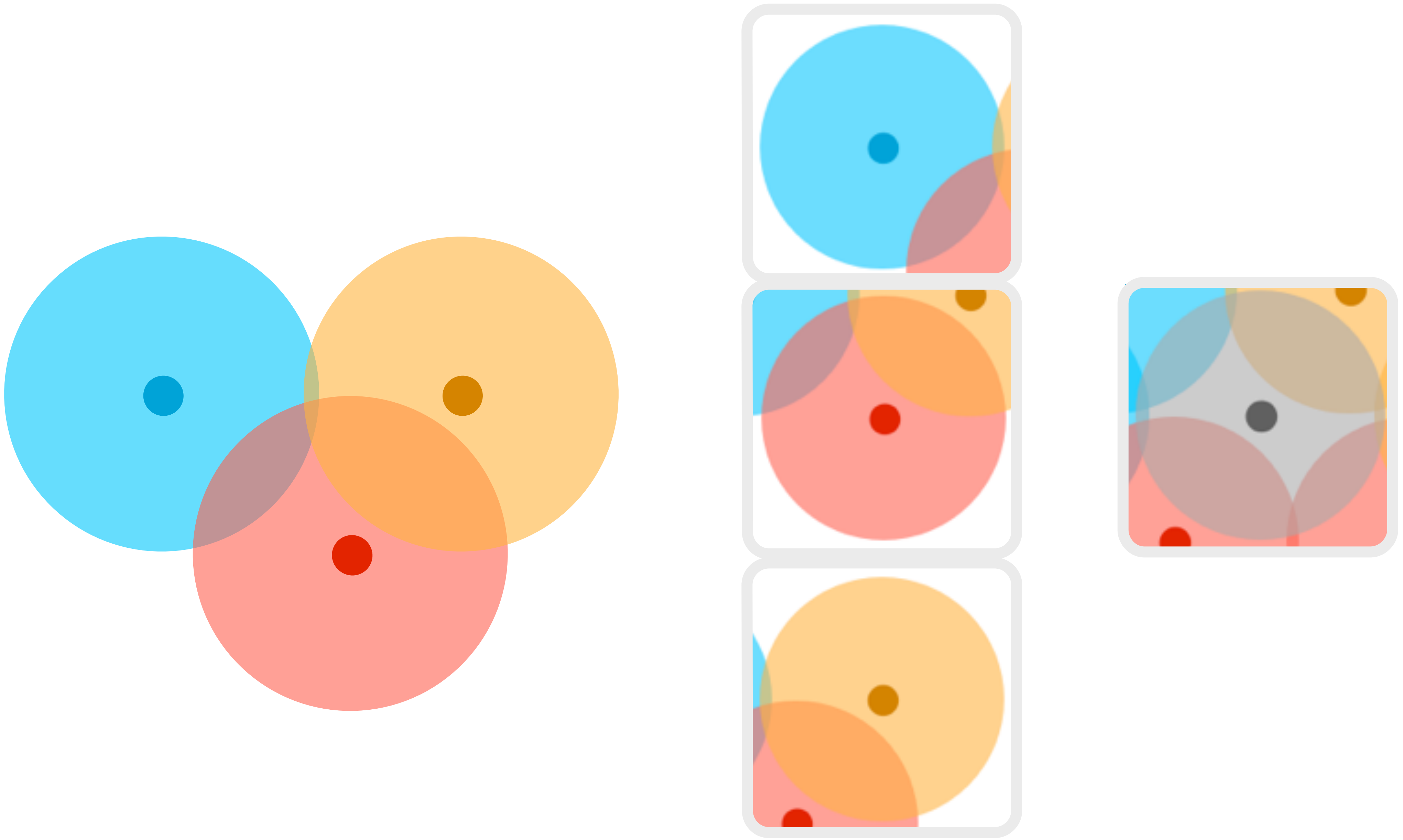


Phil Korngut (Caltech)

traditional stacking



uncorrelated (random) source simulation



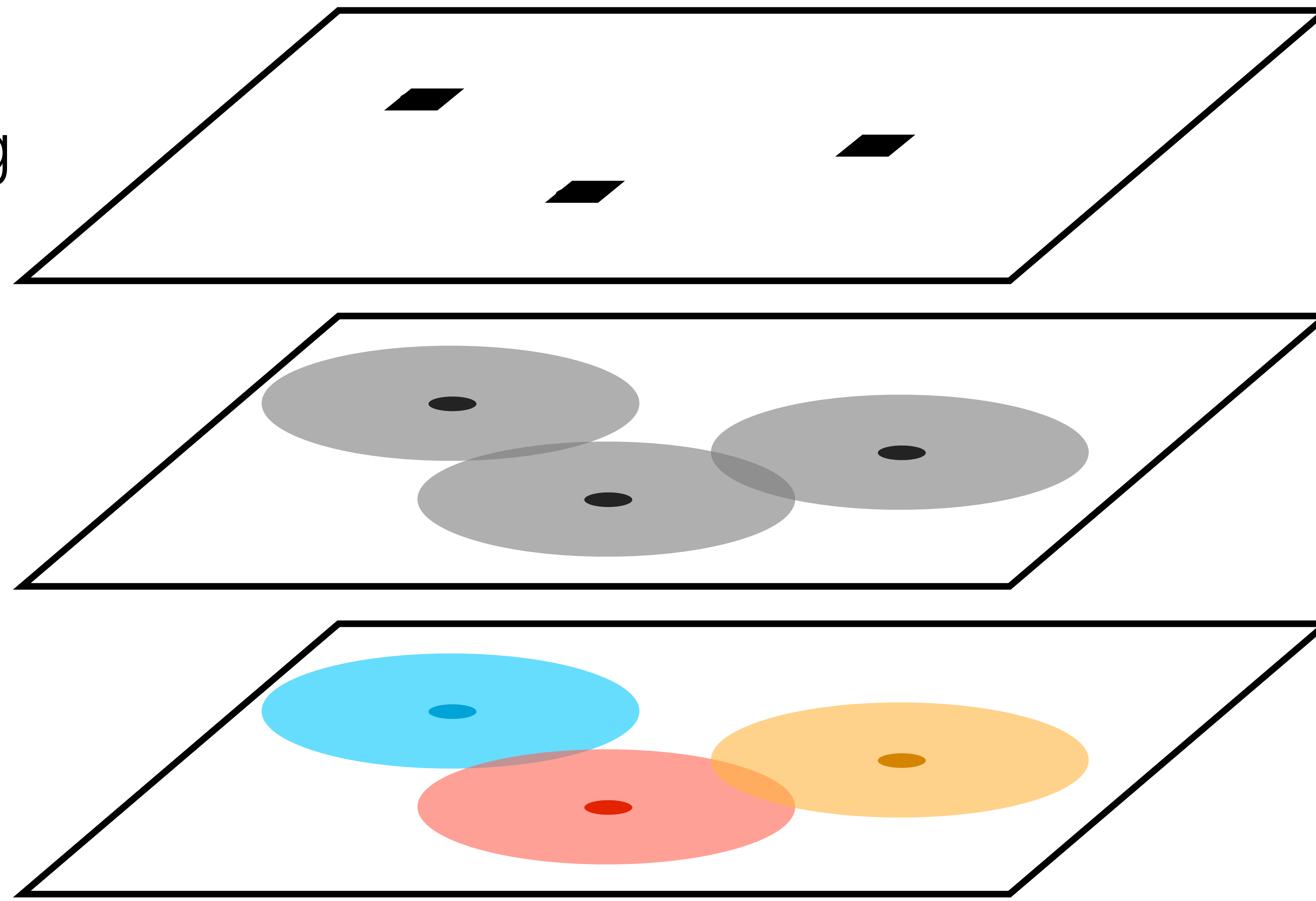
clustering induced bias

simultaneous stacking (SIMSTACK)

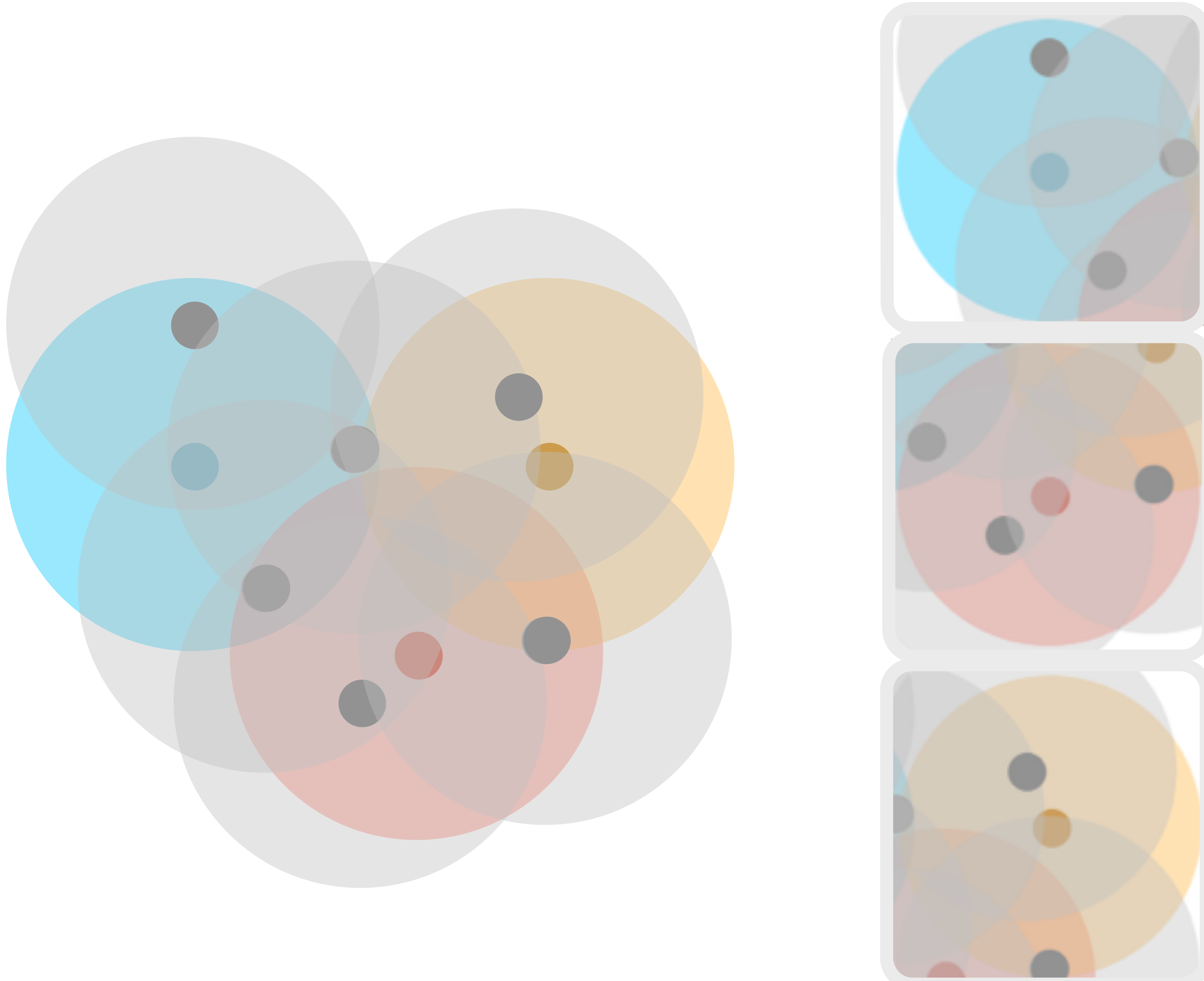
make hits map from catalog

convolve with map p.s.f.

regress to find stacked flux

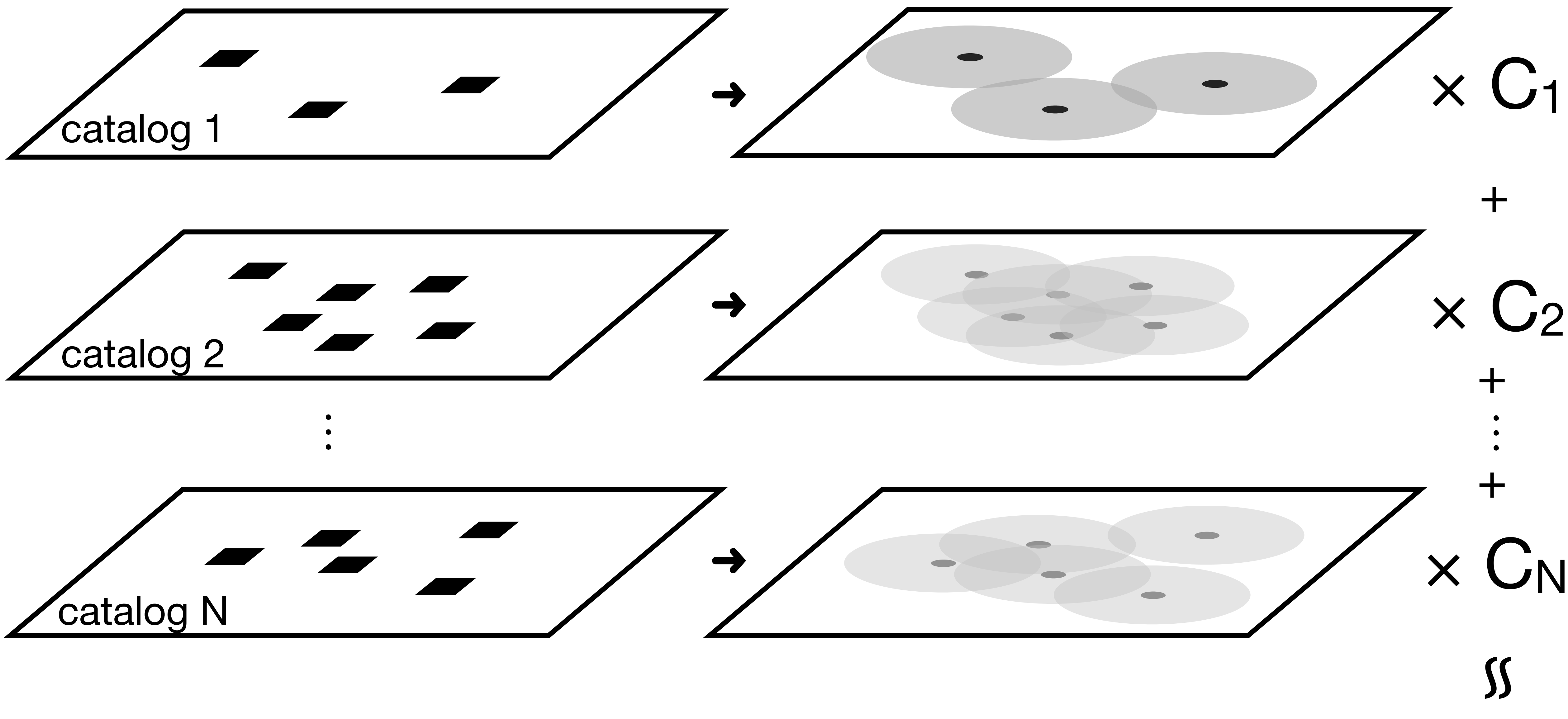


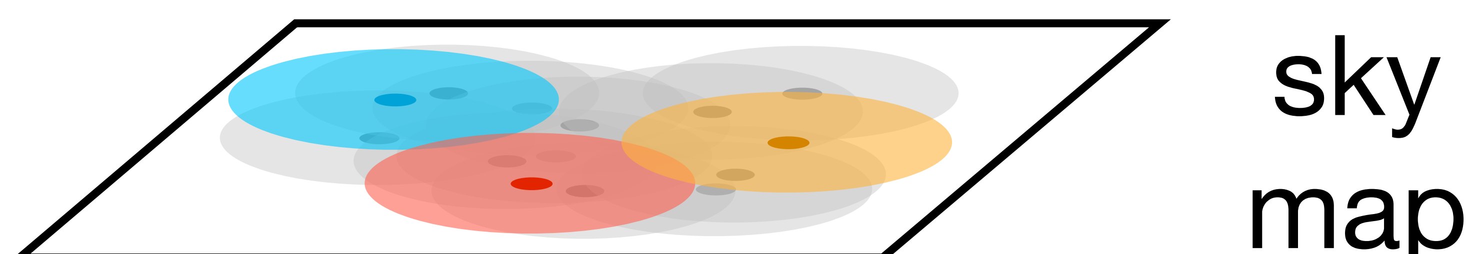
Formalism developed w/ Lorenzo Moncelsi (Caltech);
also see Kurczynski & Gawiser (2010), Roseboom et al. (2010)
SIMSTACK code publicly available in arXiv:1304.0446



non-target induced bias

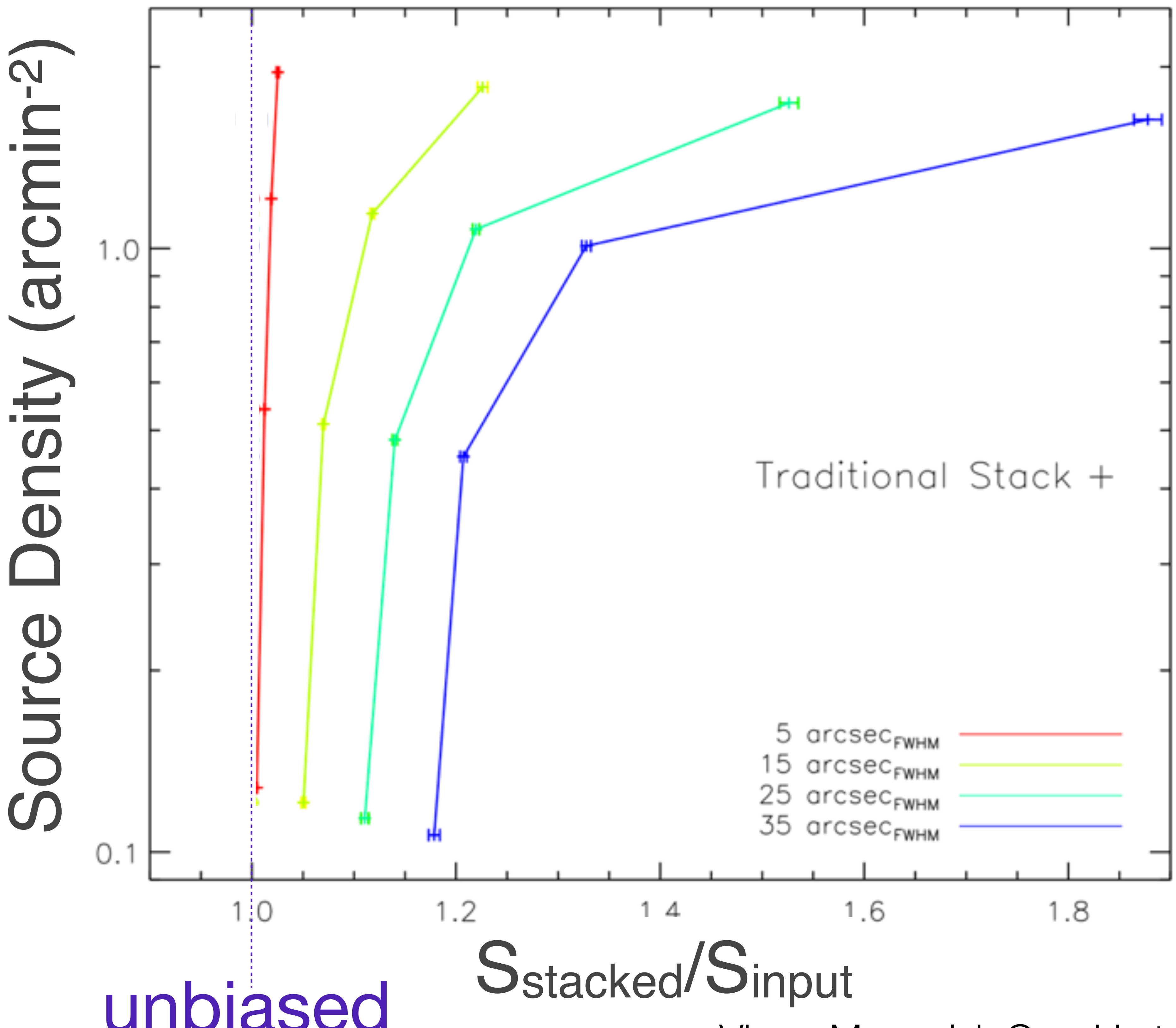
simultaneous stacking





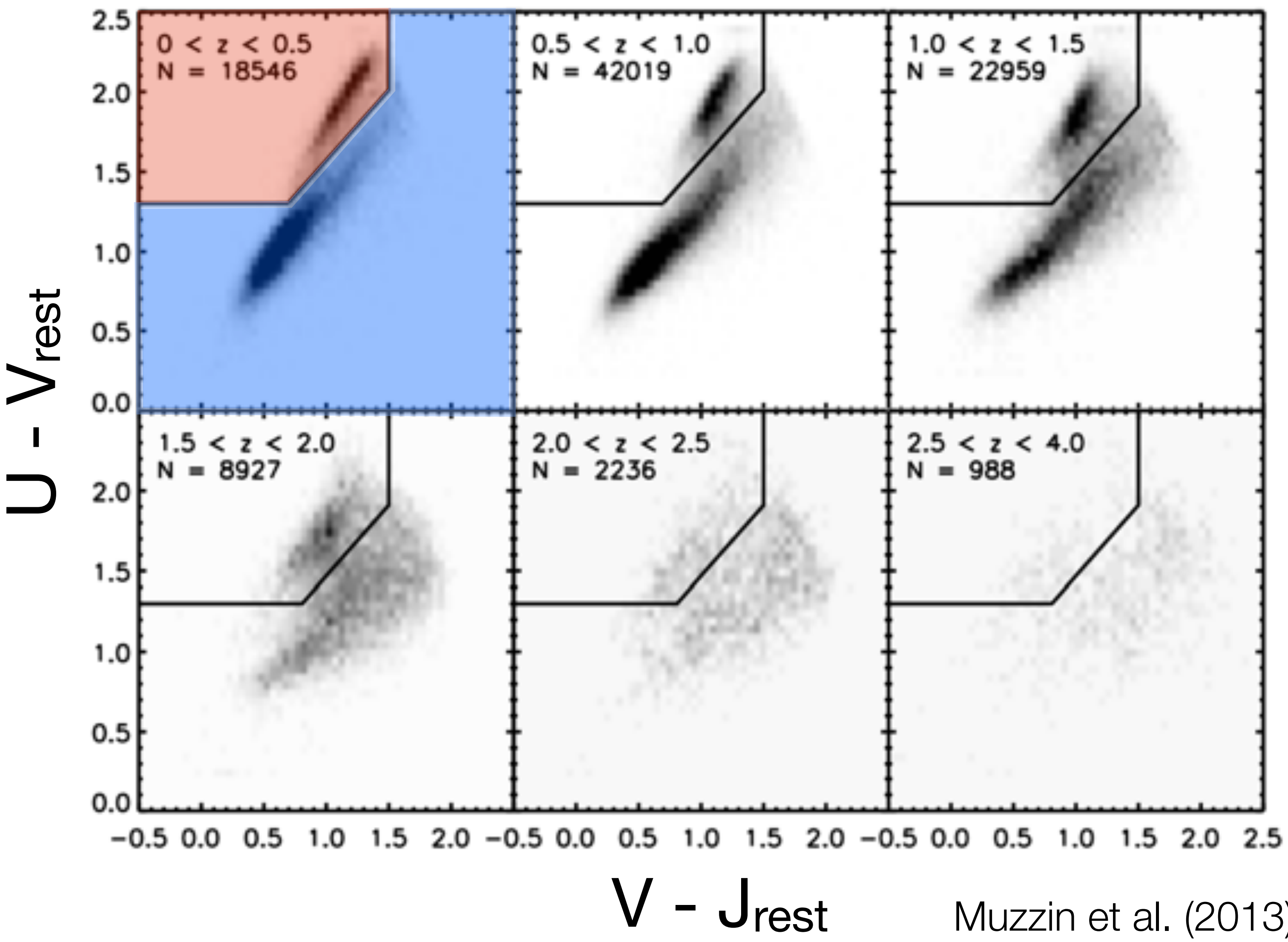
Formalism developed w/
Lorenzo Moncelsi (Caltech)
SIMSTACK code publicly available
see arXiv:1304.0446

simultaneous stacking sim



Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

Separating Quiescent from Star-forming



Muzzin et al. (2013)

Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

catalog (Williams & Quadri, in prep.)

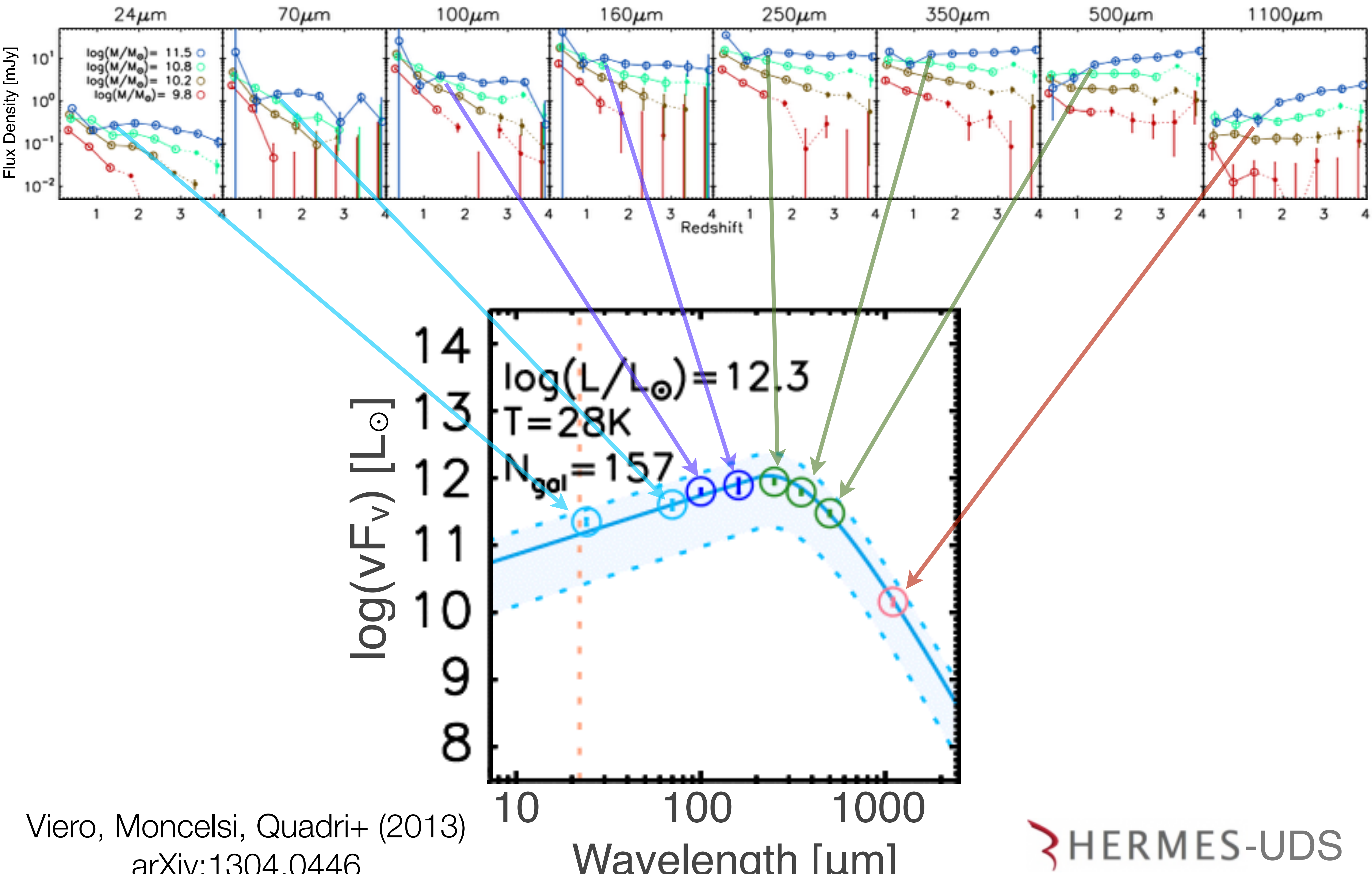
- UKIDSS/UDS [2/3 deg^2]
  - uBVRizJHK + IRAC ch1234
  - K-band magnitude cut 24 AB
  - 81,000 sources in ~0.63 deg^2
- redshifts - EAZY (Brammer 2008)
- masses - FAST (Kriek 2009)

HERMES-UDS

maps (HerMES; Oliver et al. 2012)

- *Spitzer*/MIPS
  - 24, 70um
- *Herschel*/PACS
  - 100, 160um
- *Herschel*/SPIRE
  - 250, 350, 500um
- ASTE/AzTEC
  - 1100um

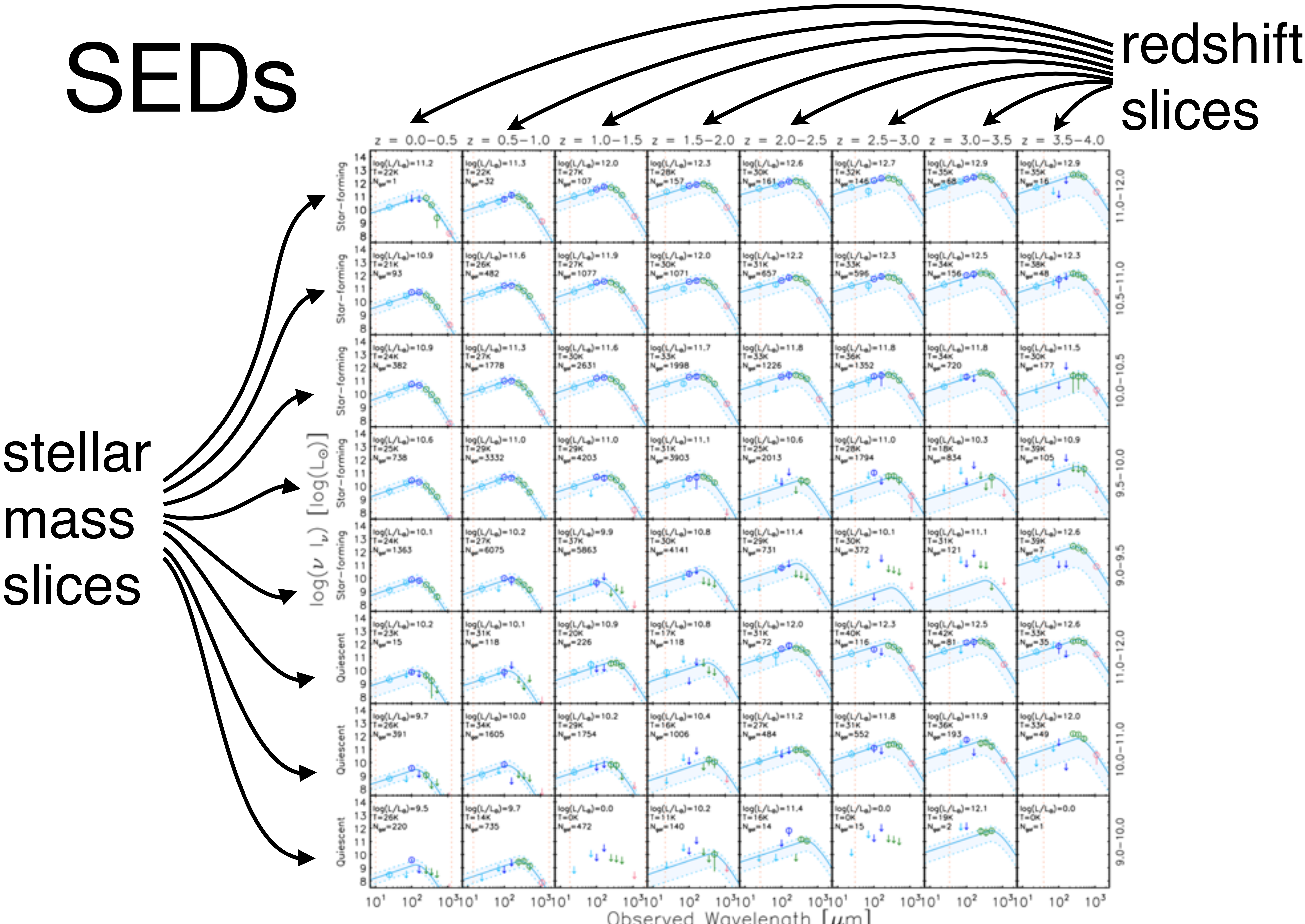
stacked flux



Viero, Moncelsi, Quadri+ (2013)
arXiv:1304.0446

HERMES-UDS

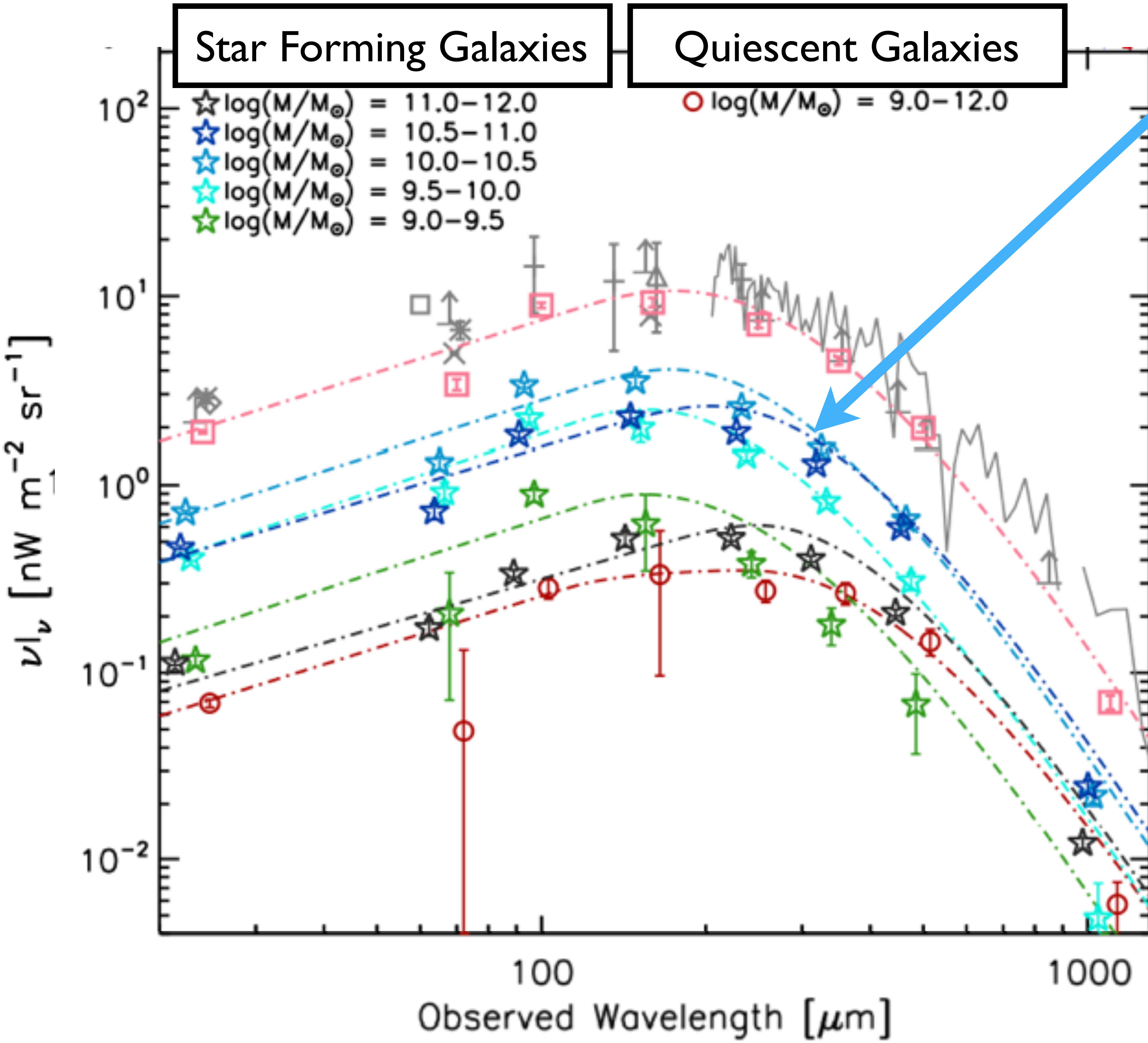
SEDs



Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

HERMES-UDS

stacked CIB



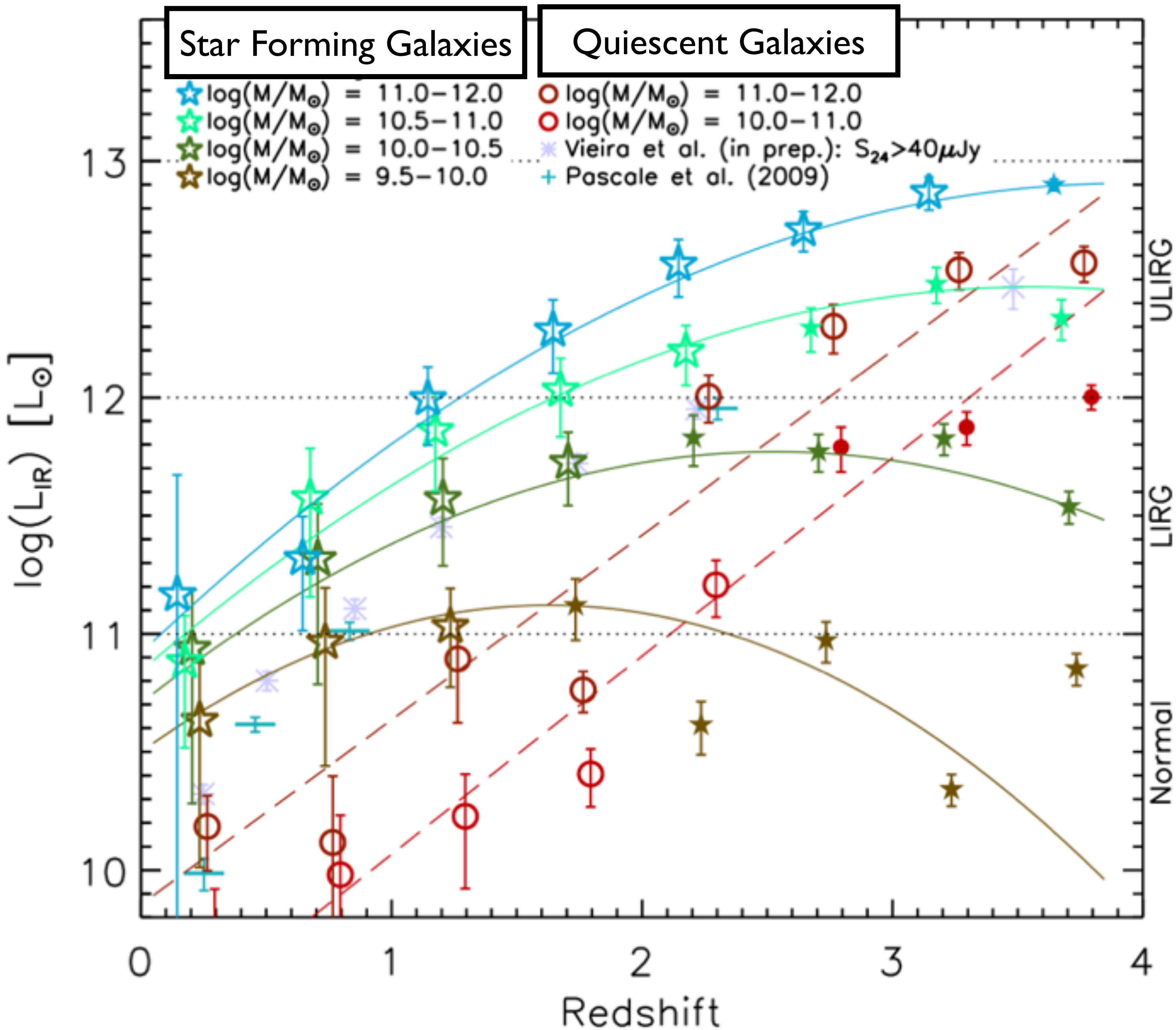
log(M/M☉~10-11)
i.e., M ≲ M*

~80% at SPIRE wavelengths

Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

HERMES-UDS

Infrared Luminosities

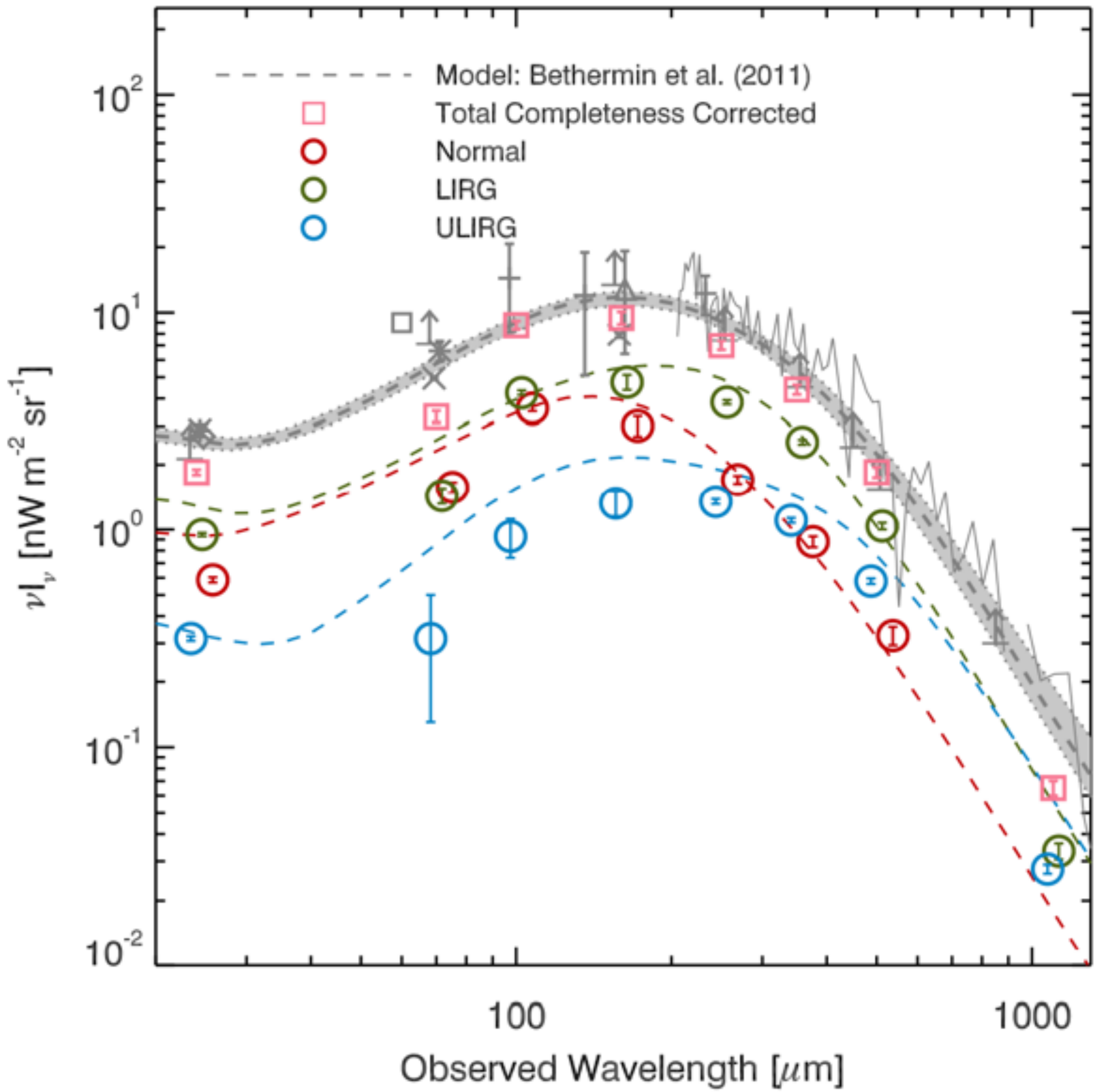


Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

HERMES-UDS

CIB by Luminosity Class

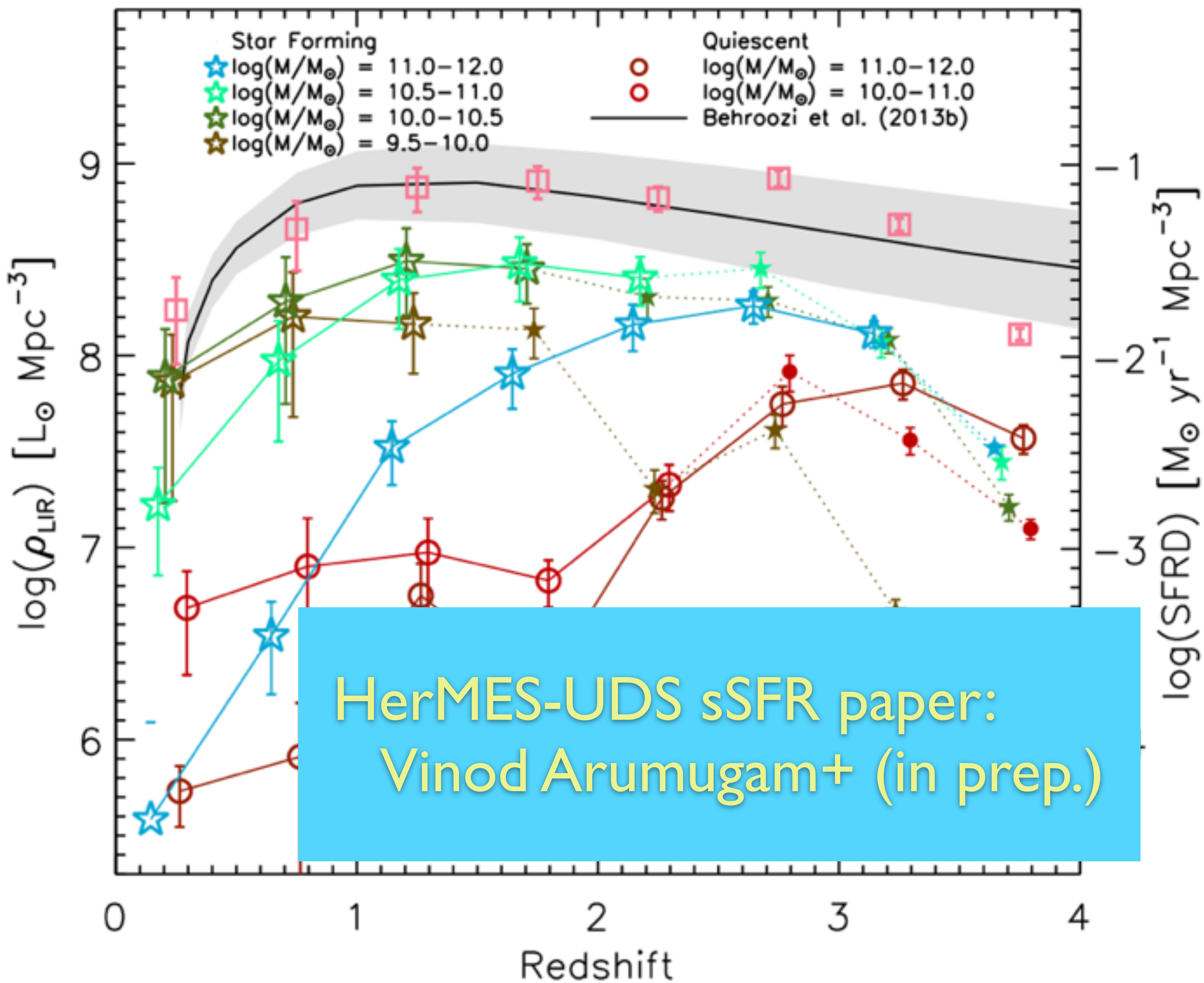
- ULIRG:
  $12 < \log(L/L_\odot) < 13$
- LIRG:
  $11 < \log(L/L_\odot) < 12$
- "Normal":
  $\log(L/L_\odot) < 11$



Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

HERMES-UDS

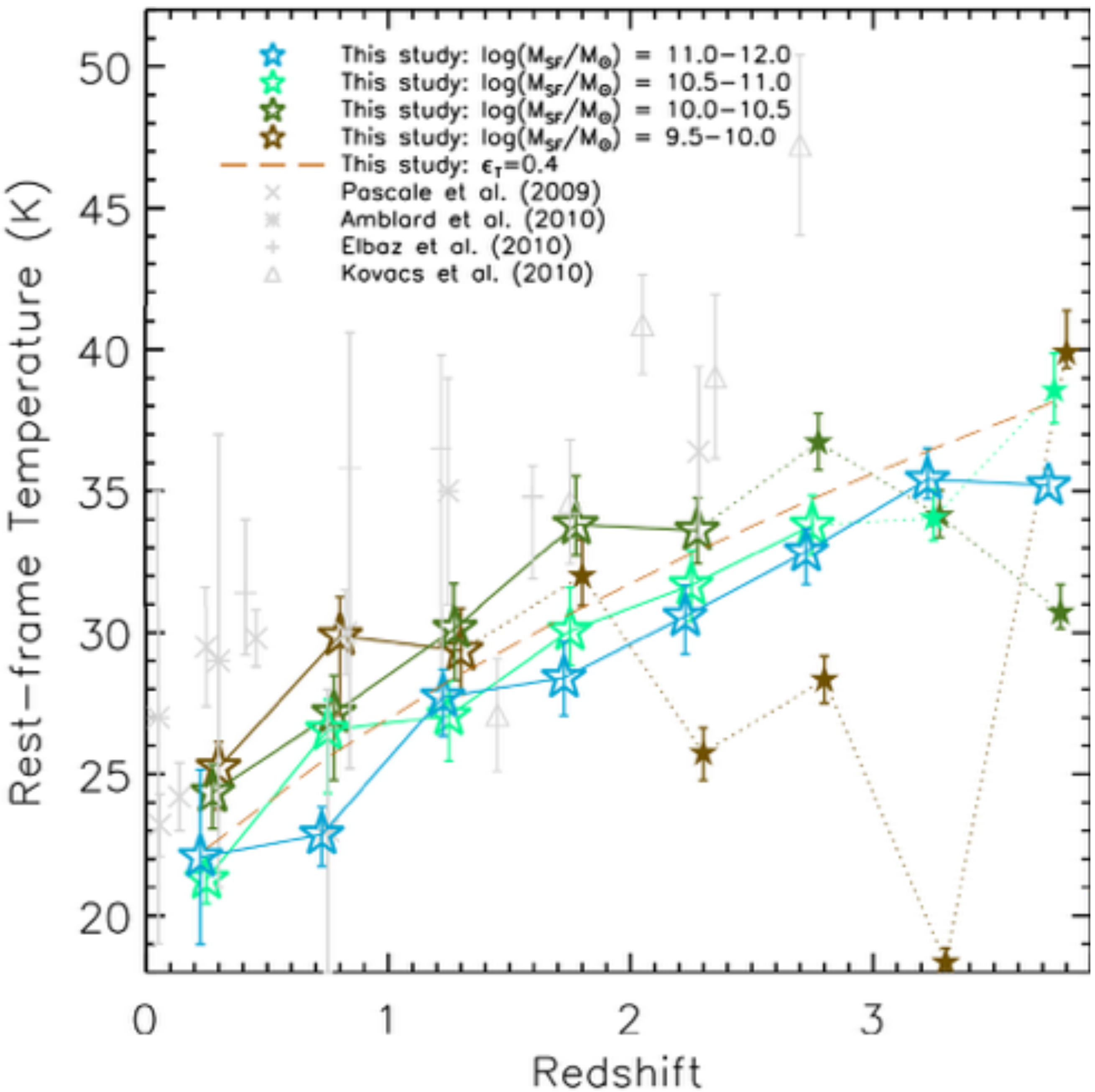
Infrared Luminosity Density

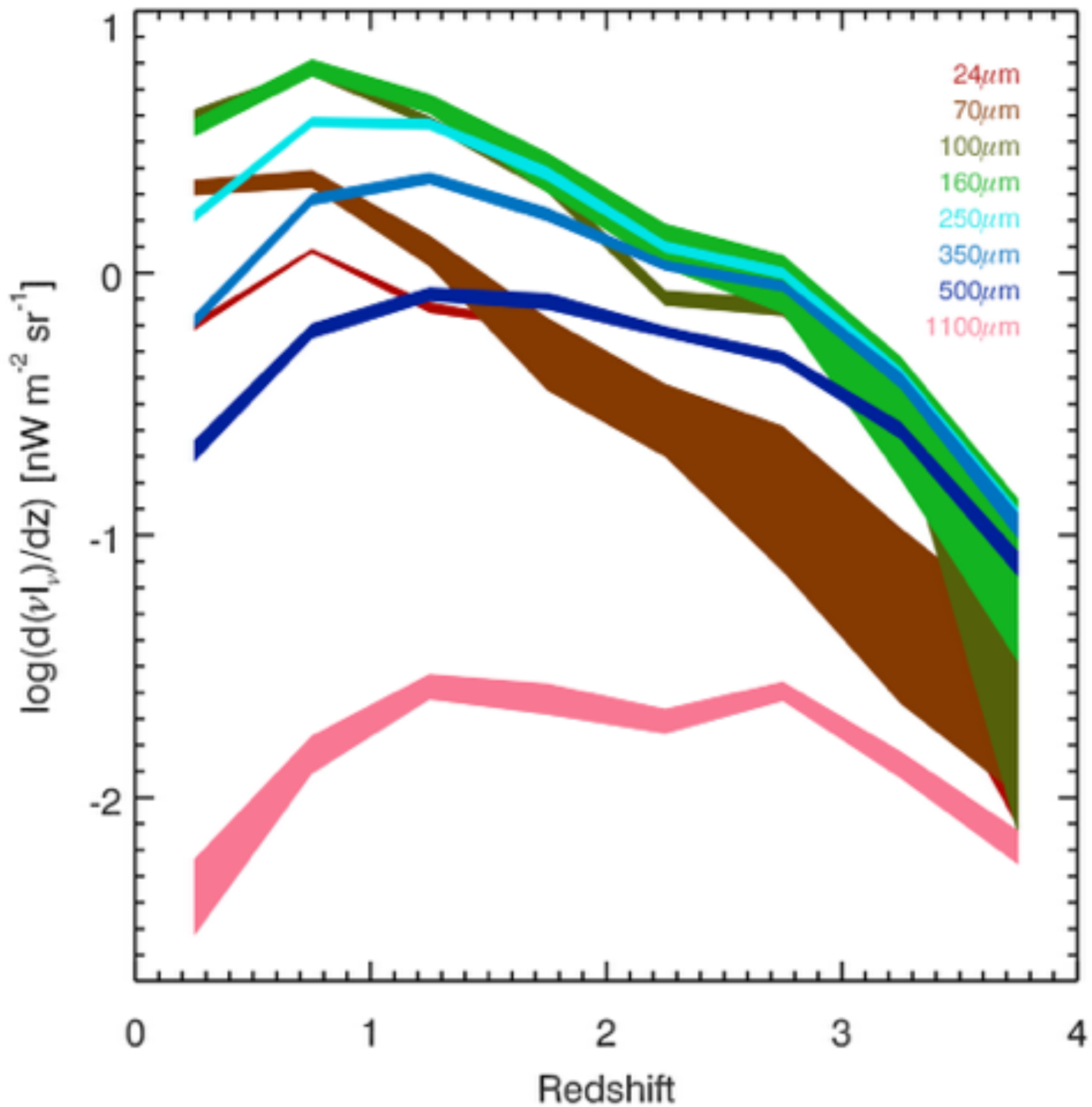


Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

HERMES-UDS

Temperature and Redshift Distribution





Viero, Moncelsi, Quadri et al. (2013)
arXiv:1304.0446

- Powerful Constraints for Galaxy and Halo Models

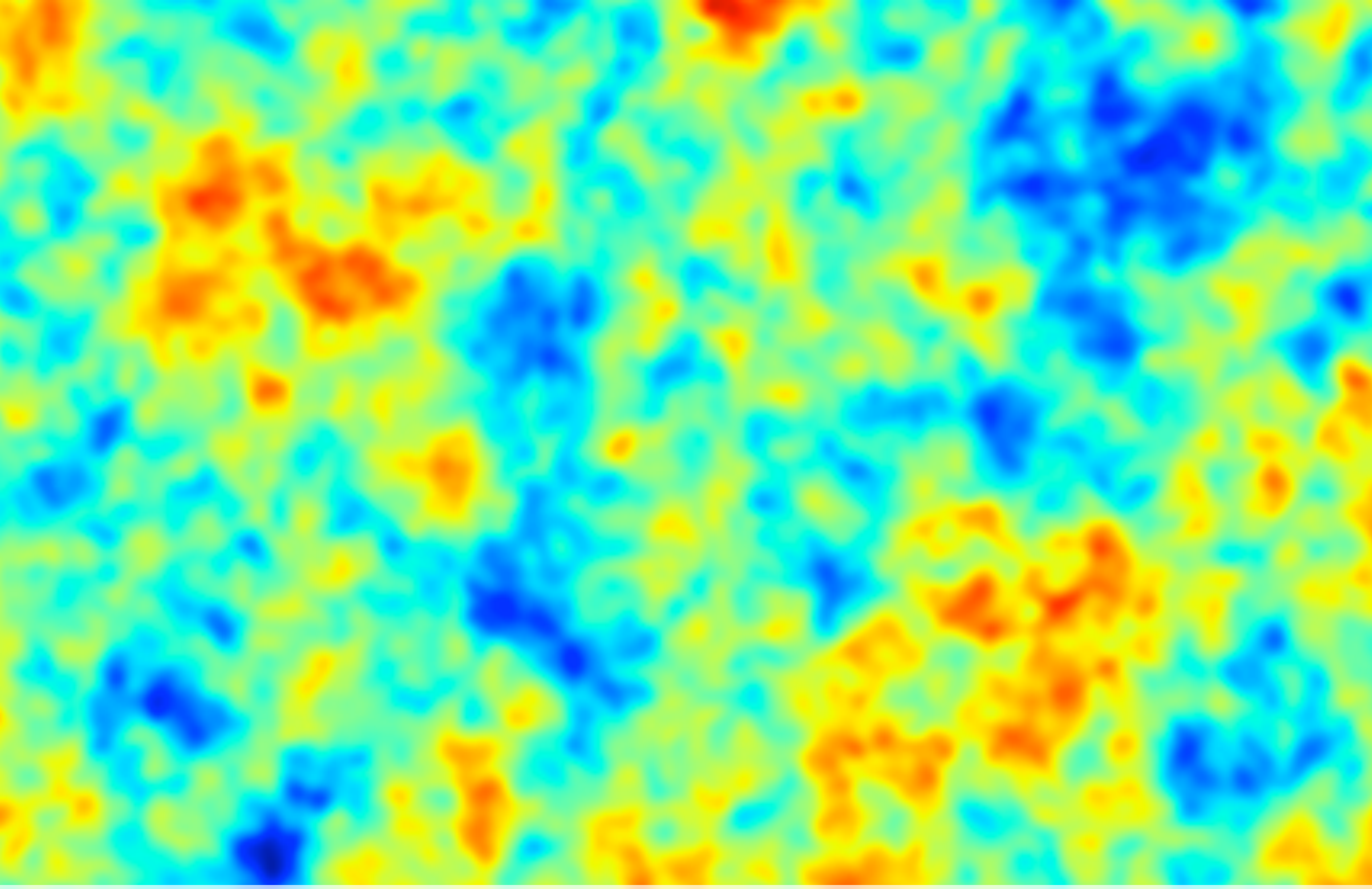
HERMES-UDS

Take-away from Stacking

- mass-selected sources (optical/NIR) make up ~80% of the CIB
- Mid-mass galaxies responsible for most of the CIB
  - BUT, Higher-mass galaxies make up a significant fraction of the luminosity density at higher redshifts
  - Puzzling signal from highest-redshift quiescent galaxies
- L-M-z relationship a strong constraint for future models

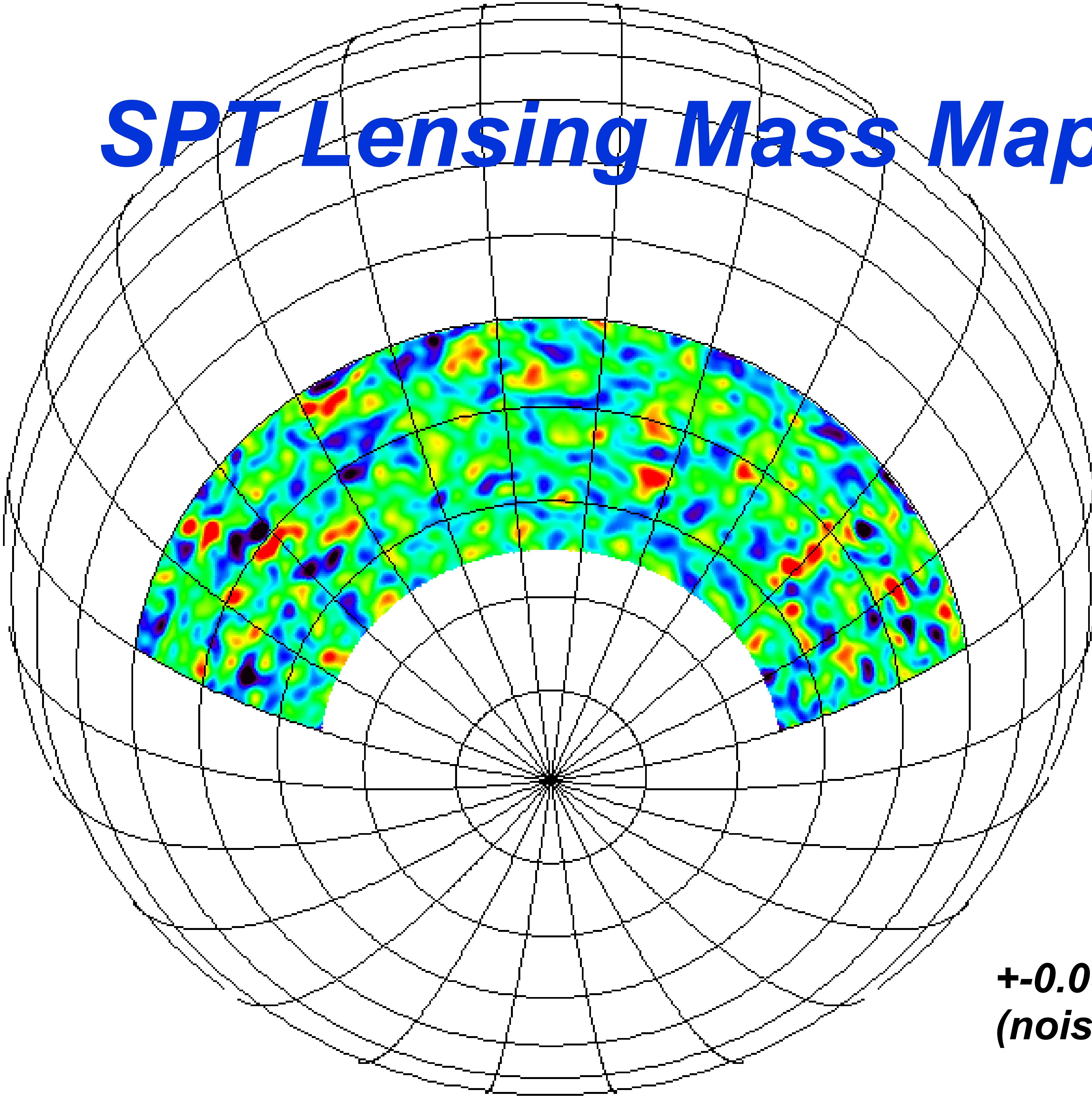
Outline

- Why the Cosmic Infrared Background (CIB)?
- Auto and cross-correlations of CIB as a tool to:
  - measure galaxy-galaxy clustering to determine the dark matter hosts of dusty star-forming galaxies
  - determine the COB-CIB connection
  - cosmological applications
- The Future in Surveys



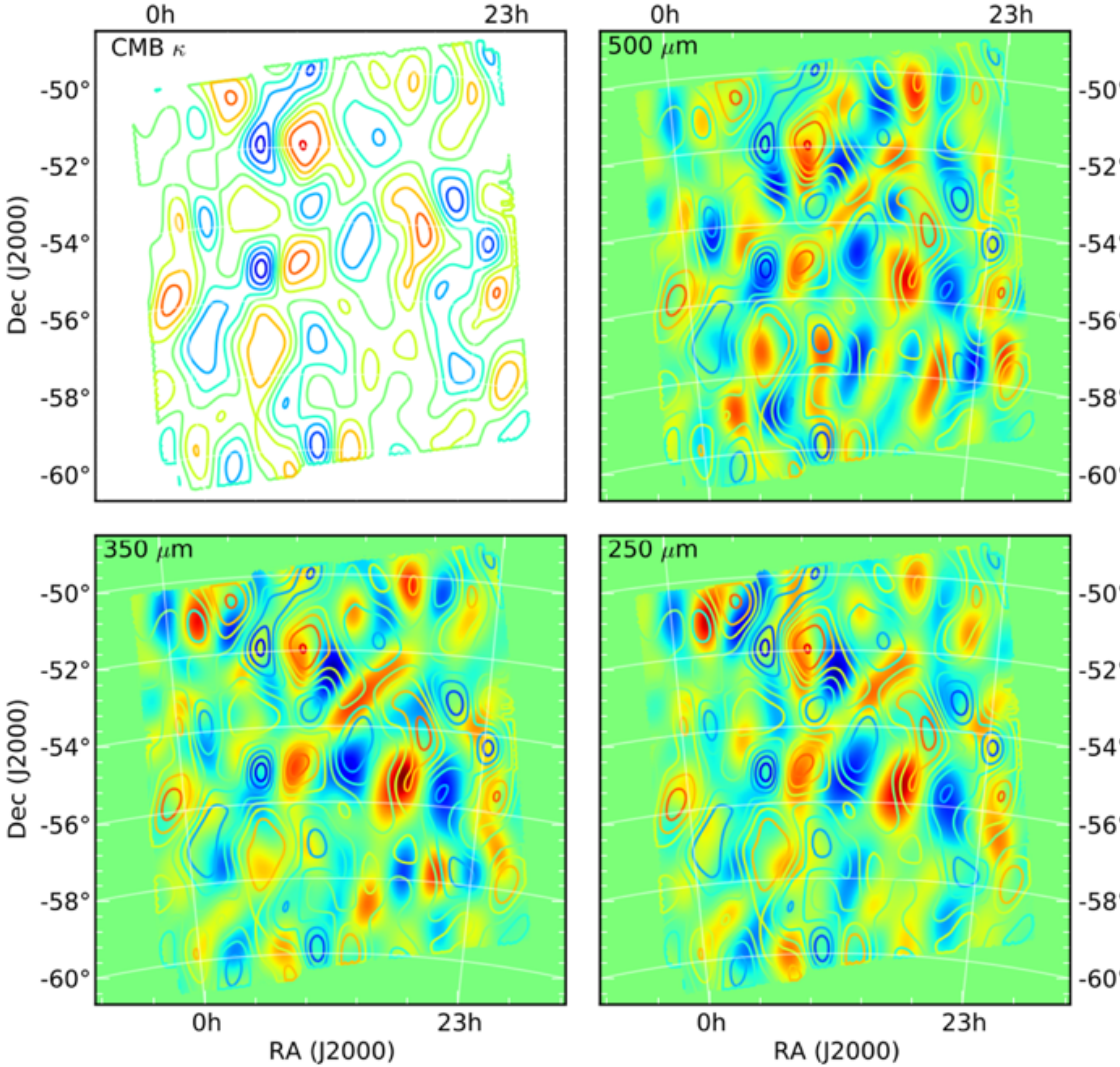
Cross-Correlations with CMB Lensing

SPT Lensing Mass Map



+-0.05 color bar
(noise ~0.01)

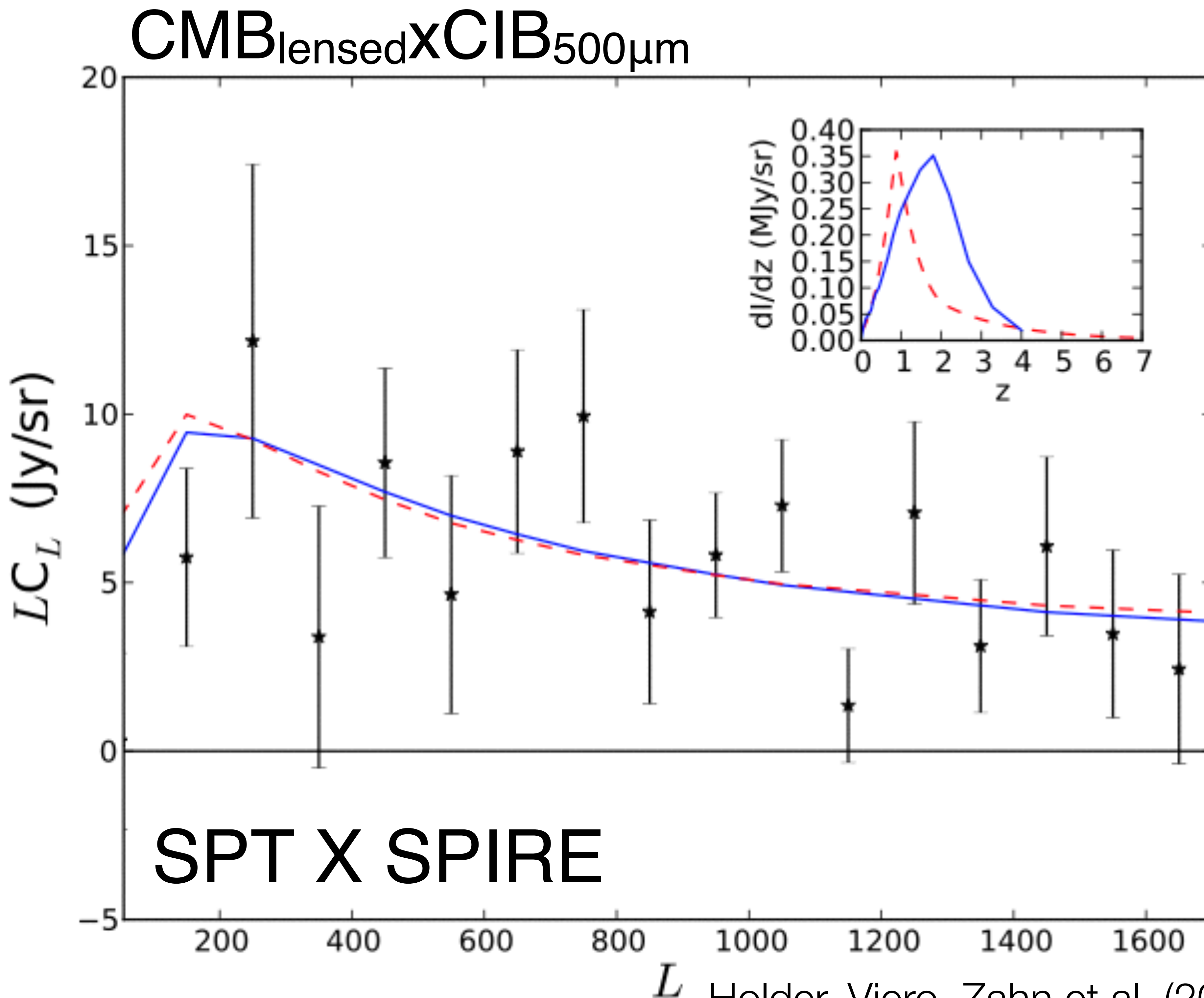
SPT X SPIRE



Lensed CMB x CIB

Holder, Viero, Zahn et al. (2013)
arXiv:1304.0446

- 6.7-8.8σ detection (Planck 42σ!)
- bias = 1.3-1.8, strongly model dependent



Holder, Viero, Zahn et al. (2013) arXiv:1304.0446

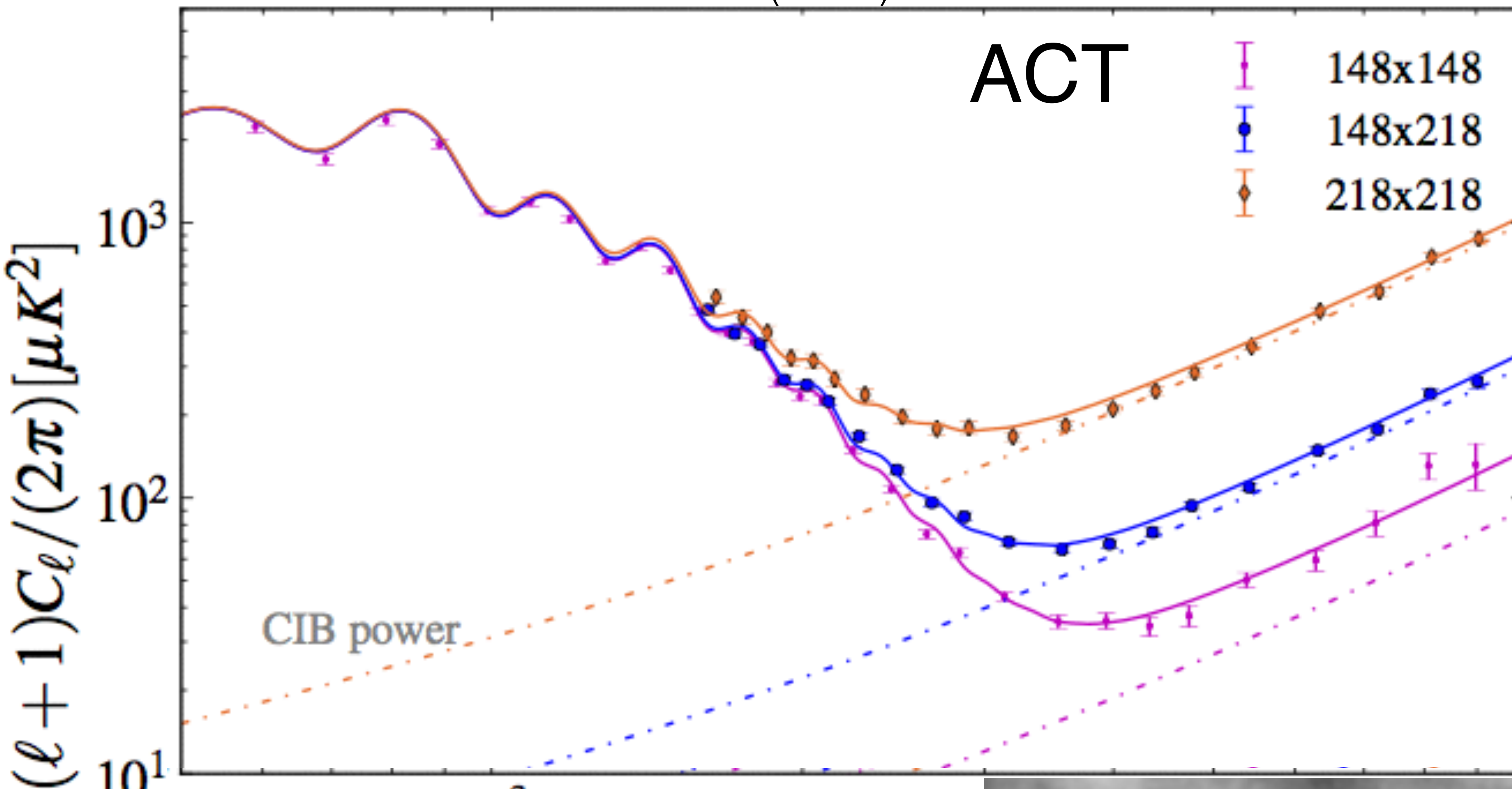
Measuring the CIB bias

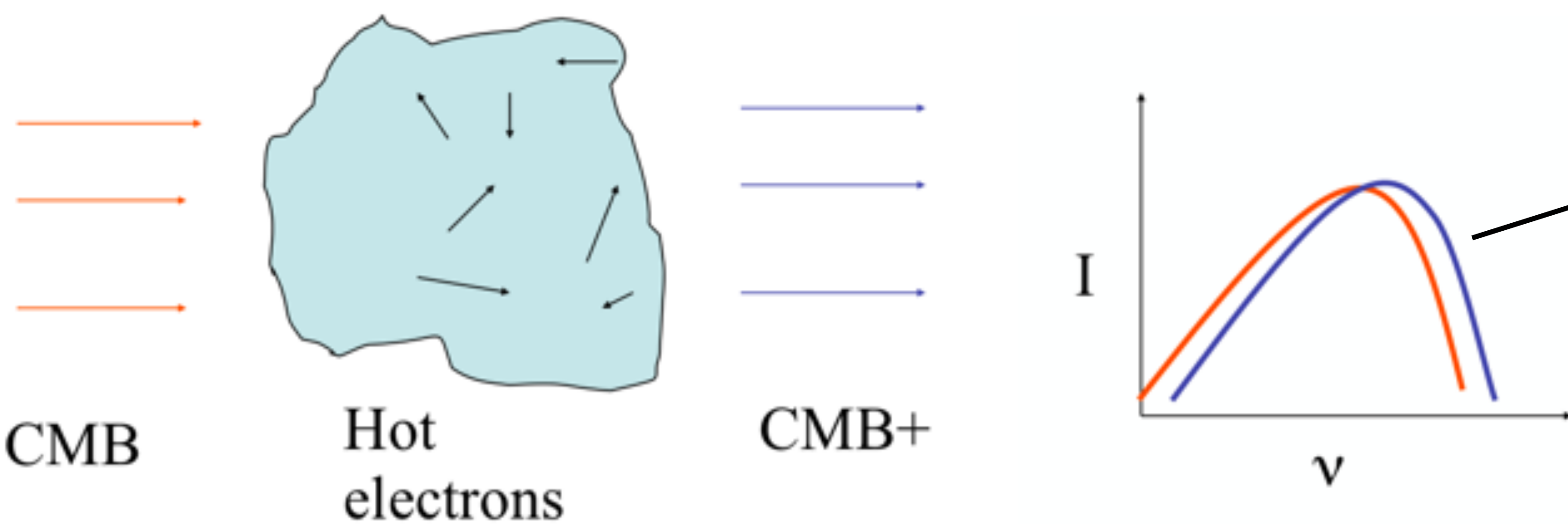
CIB as CMB Foreground

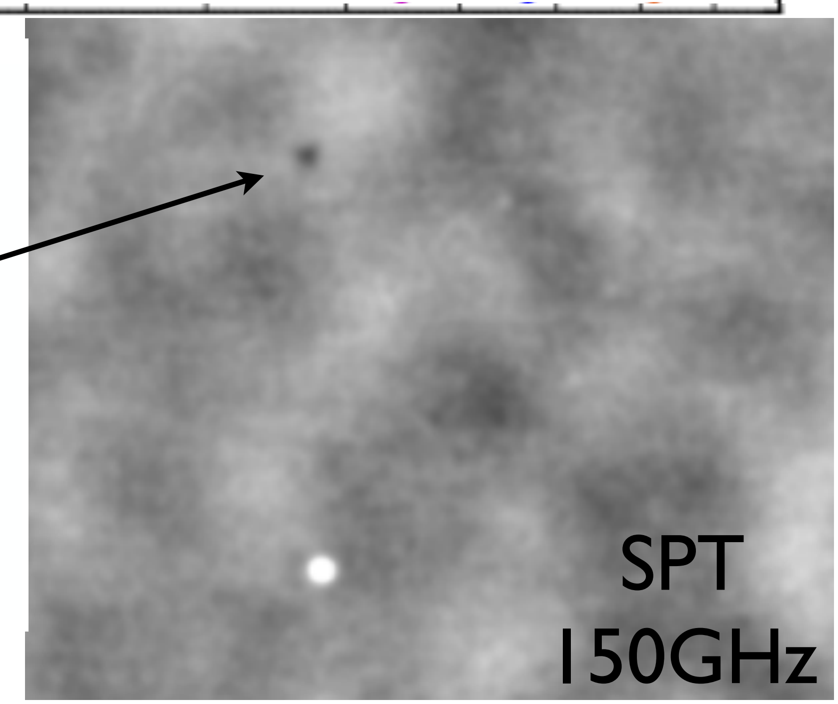
Sievers et al. (2013) arXiv: 1301.0824

Dusty Galaxies a significant contaminant at 150 and 220 GHz

SZ effect distortion of CMB by Compton scattering in massive clusters

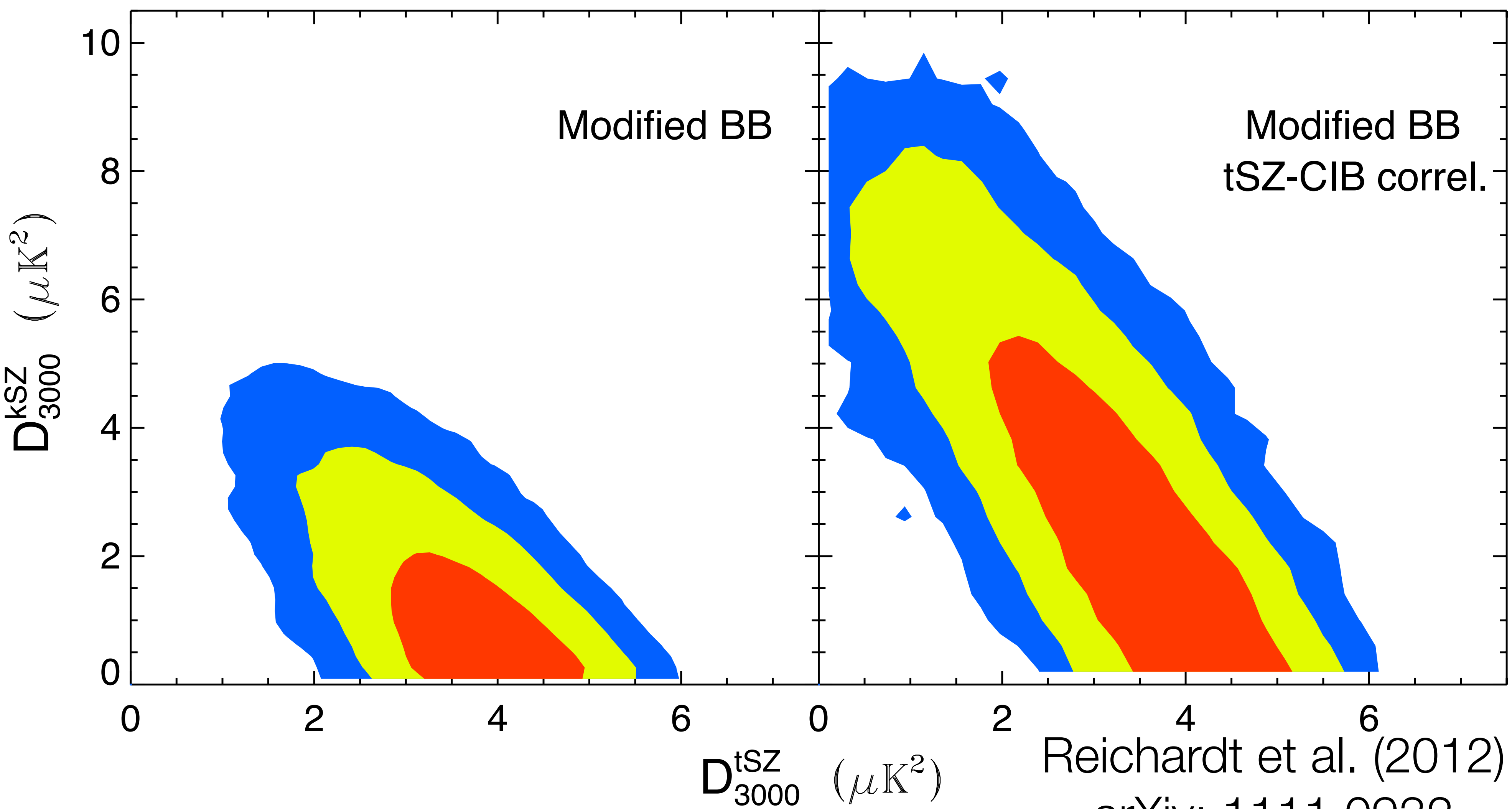




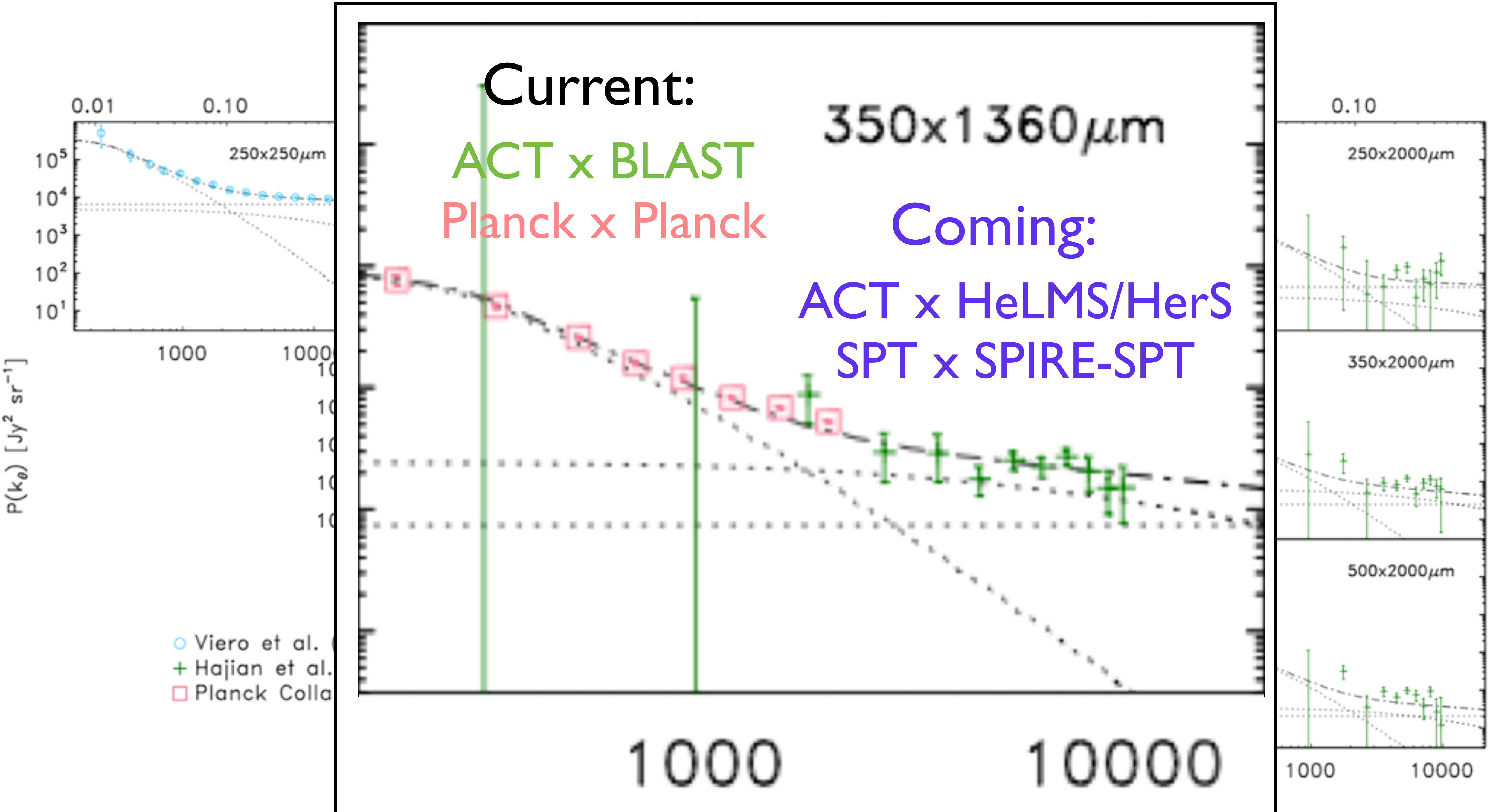


thermal SZ-CIB correlation?

- uncertain degree of tSZ and CIB correlation makes it very hard to separate components

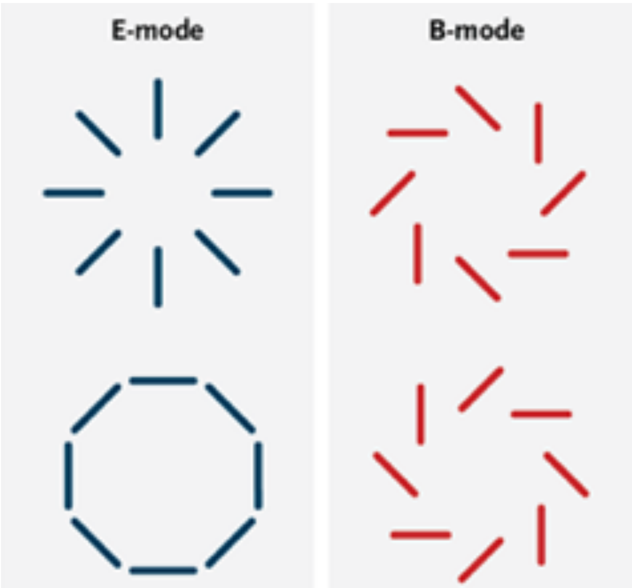


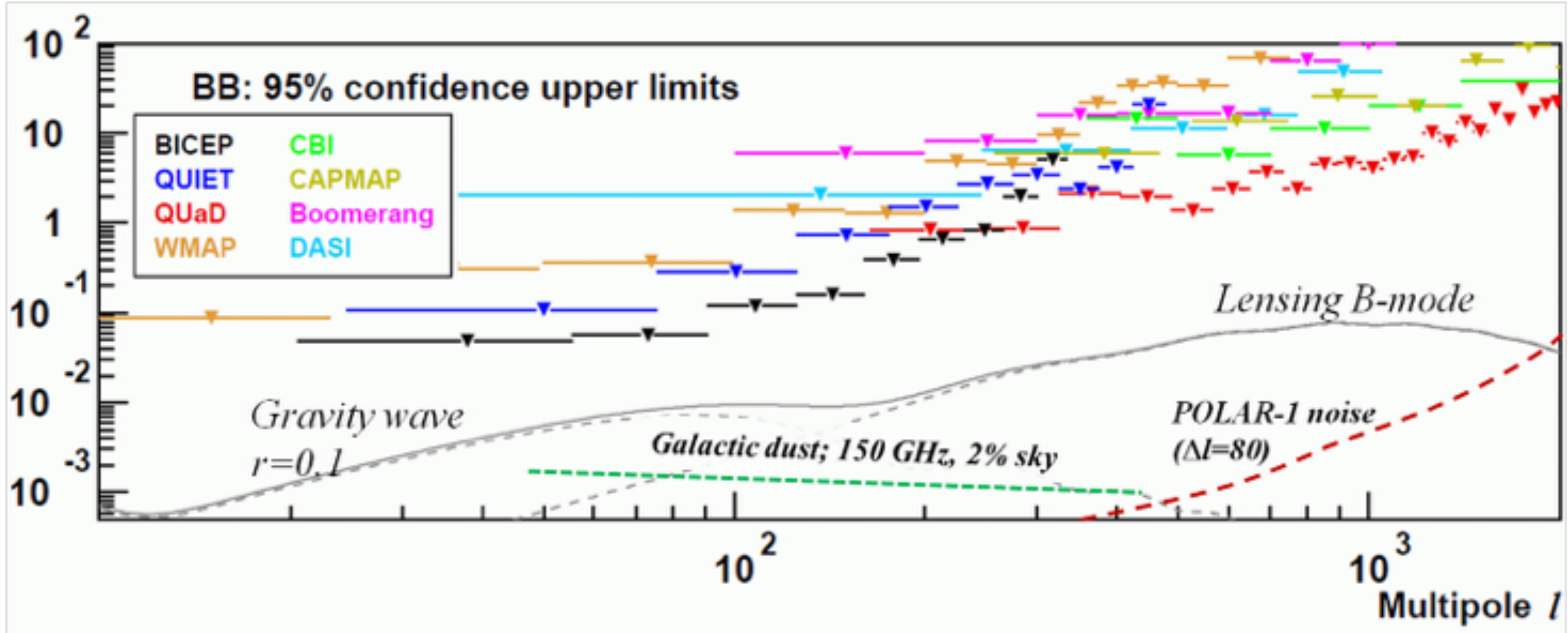
Reichardt et al. (2012)
arXiv: 1111.0932



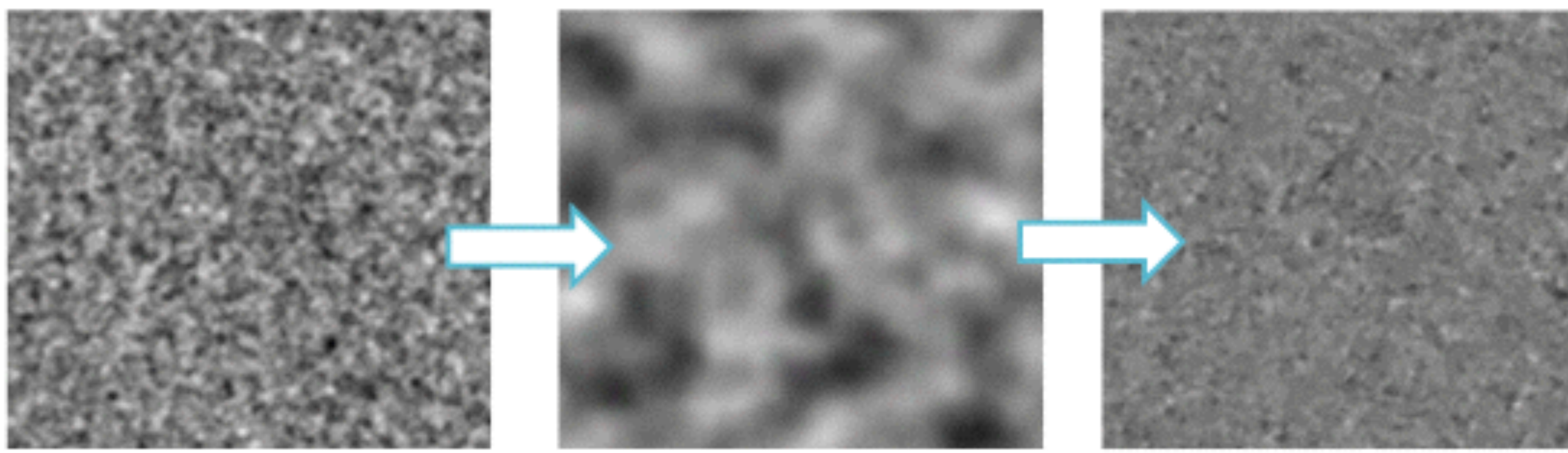
Green: Hajian, Viero et al. (2011)
Blue: Viero et al. (2013)
Red: Planck Collaboration (2013)

Cross-Correlating CIB and CMB





- Lensing mixes E-modes into B-modes



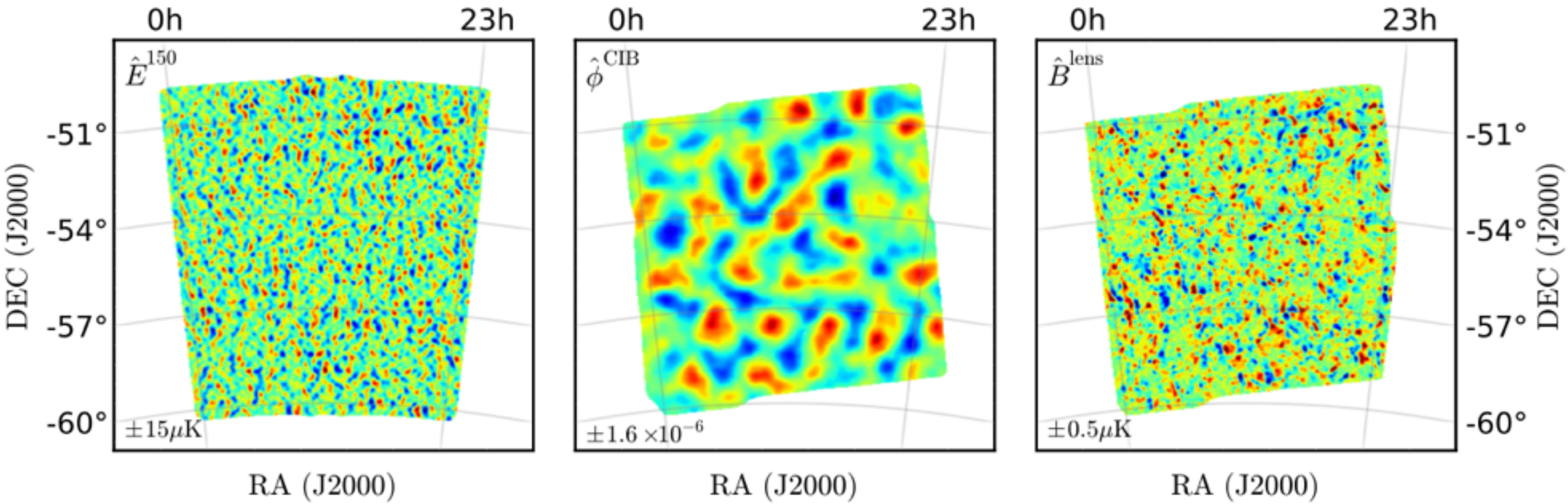
Gaussian E-mode background

Gravitational lens

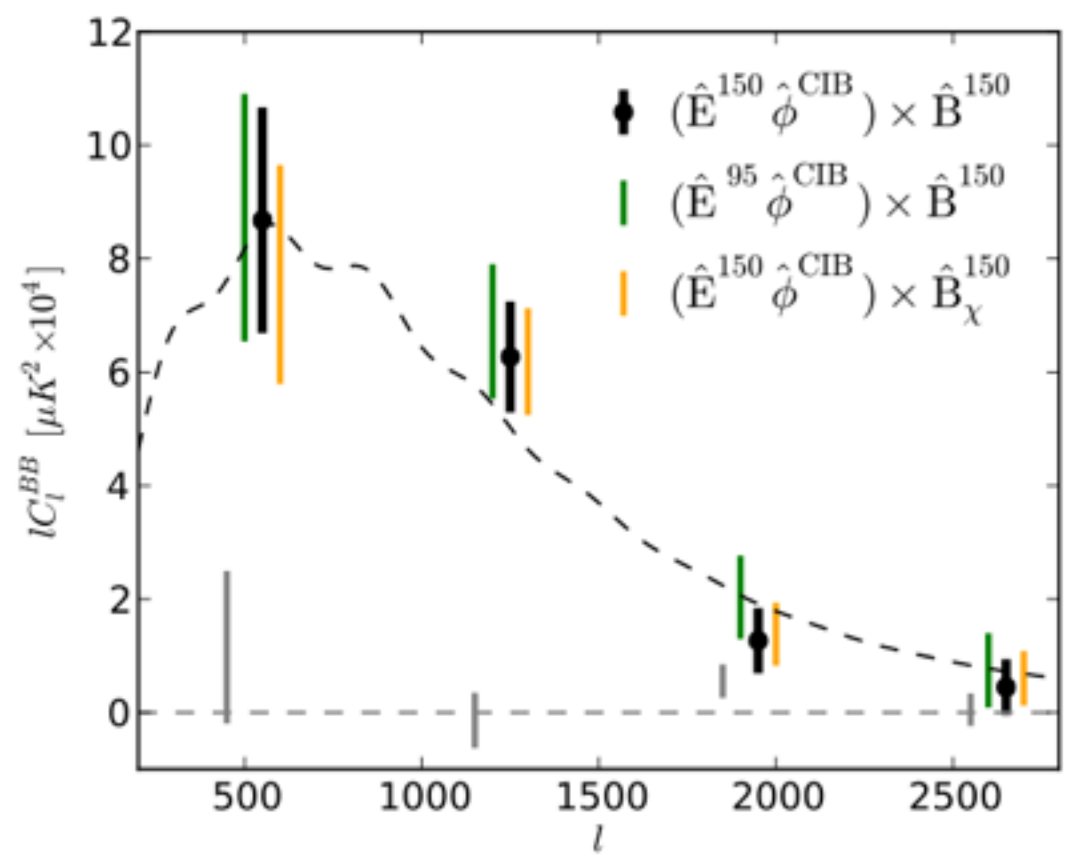
Lensing B-mode

Holder, Viero, Zahn et al. (2013)
arXiv:1304.0446

CMB Lensing B-modes



- 7.7σ detection of B-mode signal



CMB Lensing B-modes

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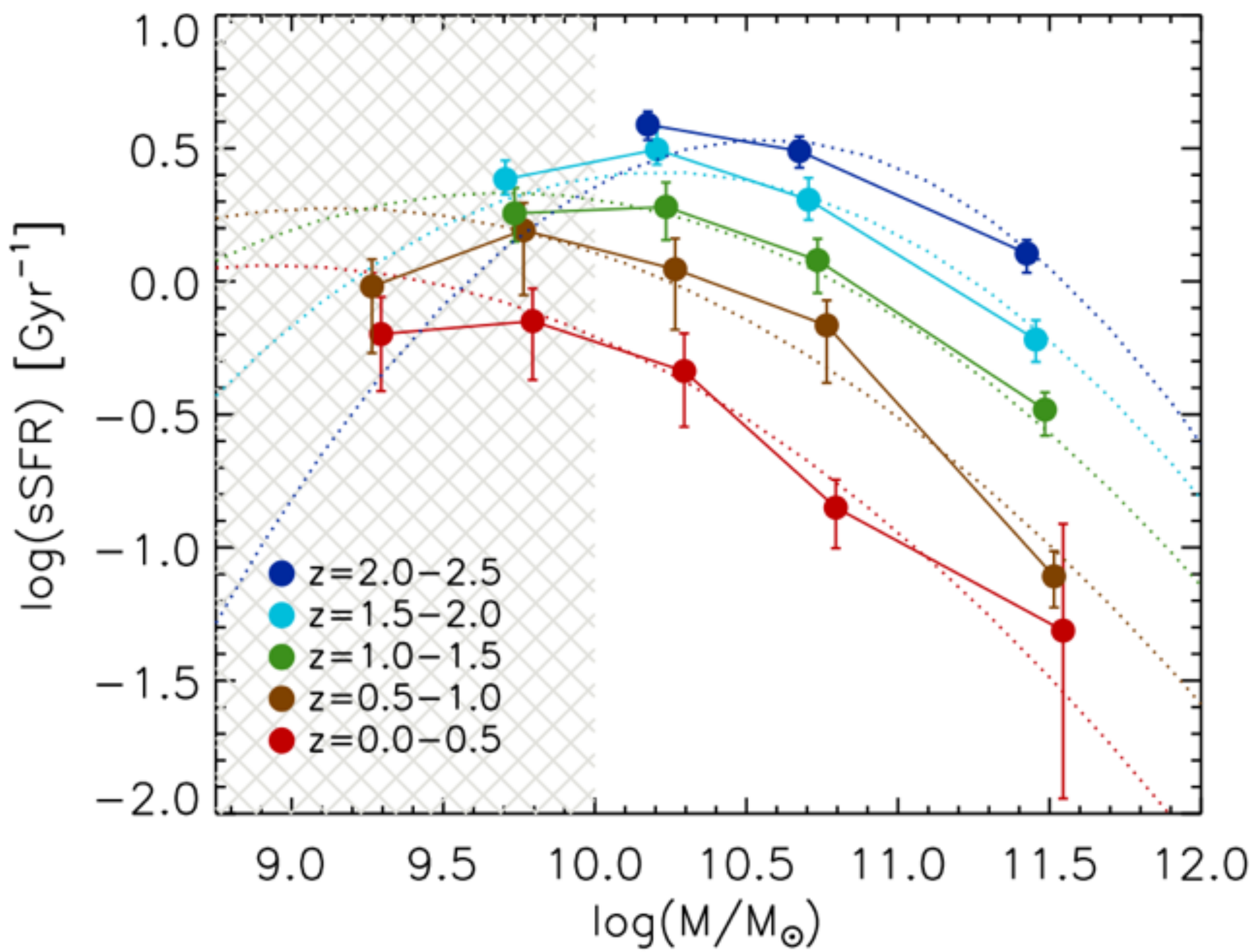
Moving Forward

Galaxy Evolution models critically fail to match low mass galaxies at intermediate redshifts (e.g., Guo+ 2011, Weinmann+ 2011,2012)

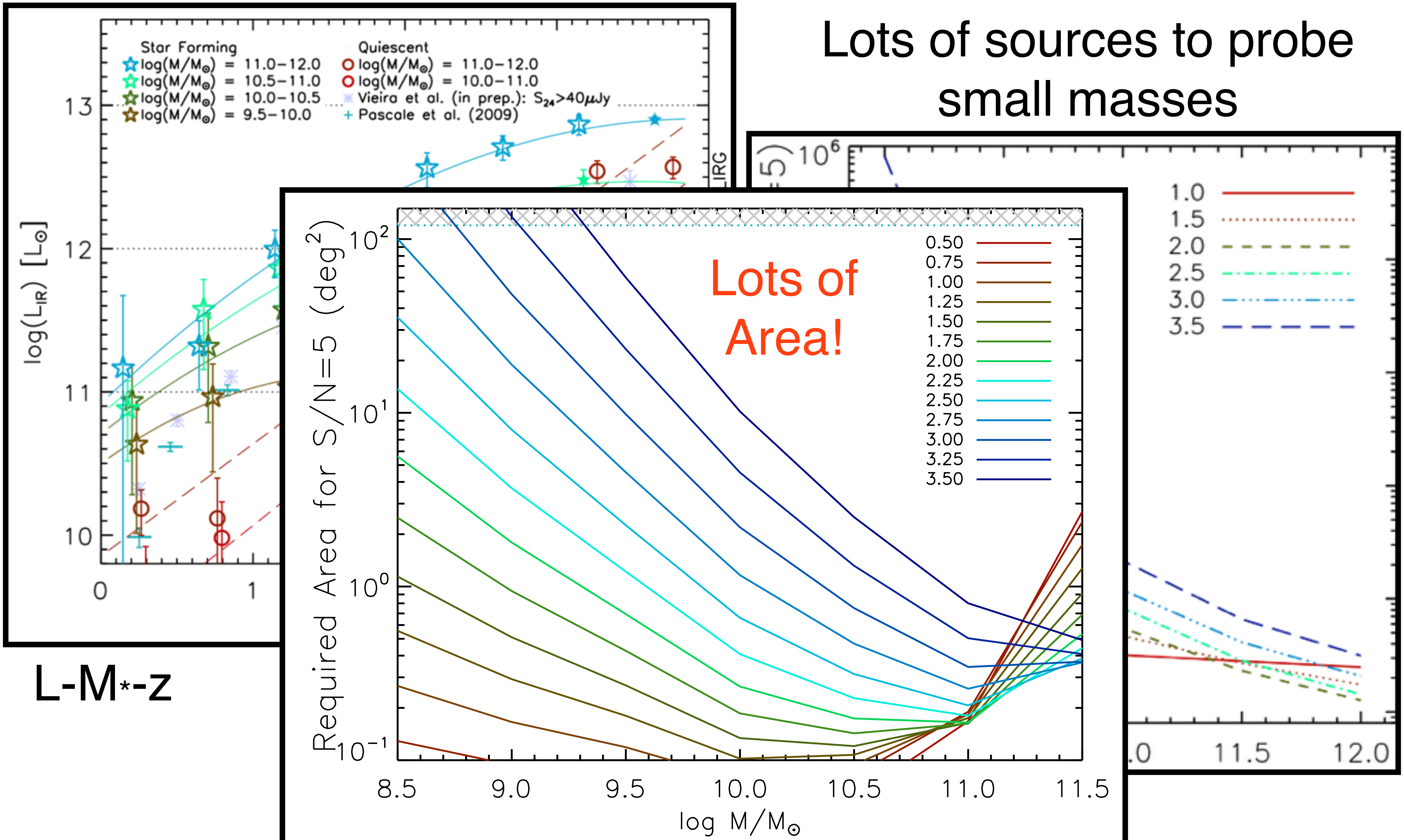
They require accurate LIRs/SFRs for this faint population, and that of their progenitors



Arumugam, Viero, Quadri et al. (in prep.)

Moving Forward

Lots of sources to probe small masses

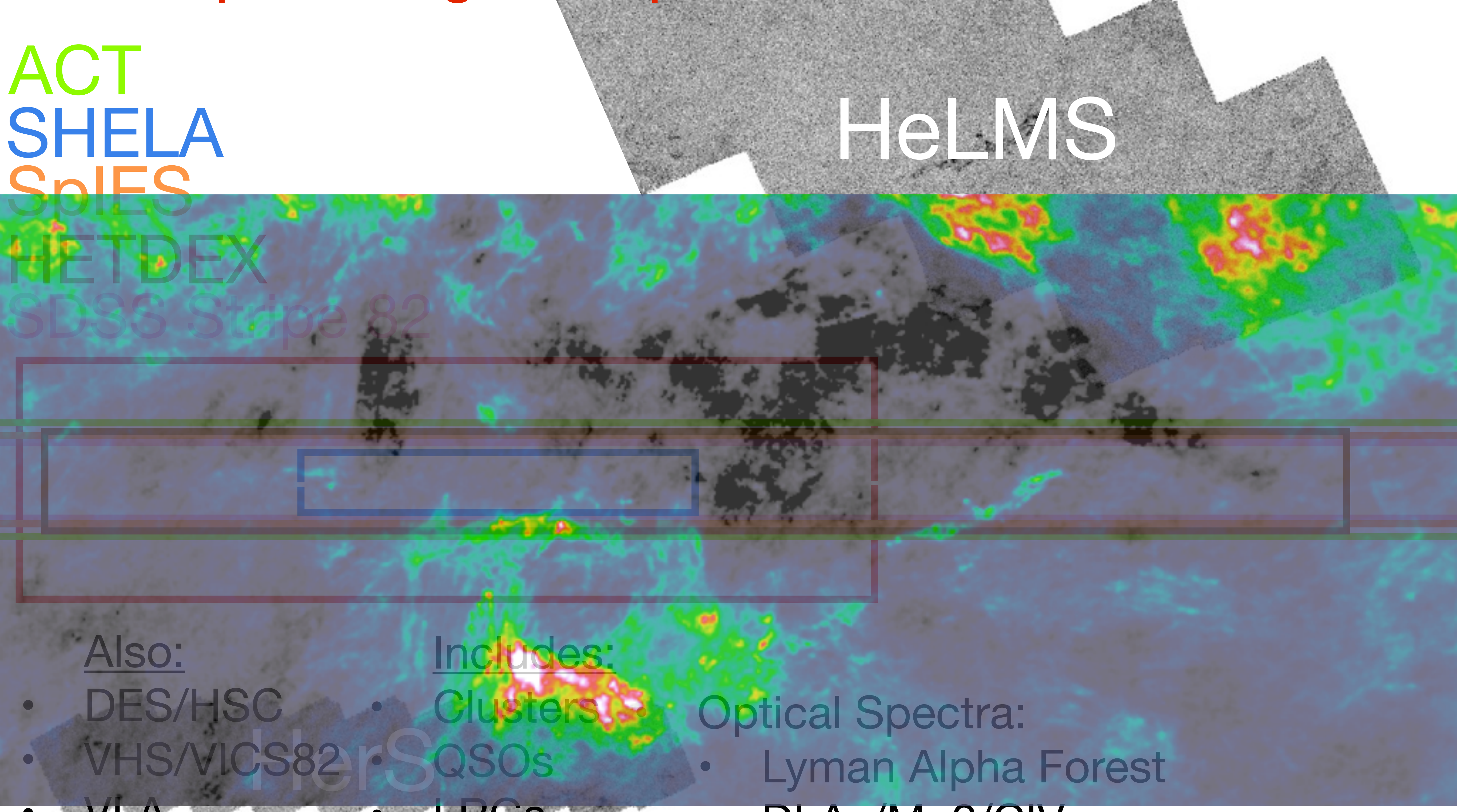


L-M*-z

estimated using mass function of Muzzin et al. 2013

Viero+ 2013, Herschel Stripe 82 Survey; arXiv:1308.4399

Find Maps/Catalogs at: http://www.astro.caltech.edu/hers



Also:

- DES/HSC
- VHS/VICS82
- VLA
- Wiggle-z
- LSST

Includes:

- Clusters
- QSOs
- LRGs
- maxBCGs
- HI

Optical Spectra:

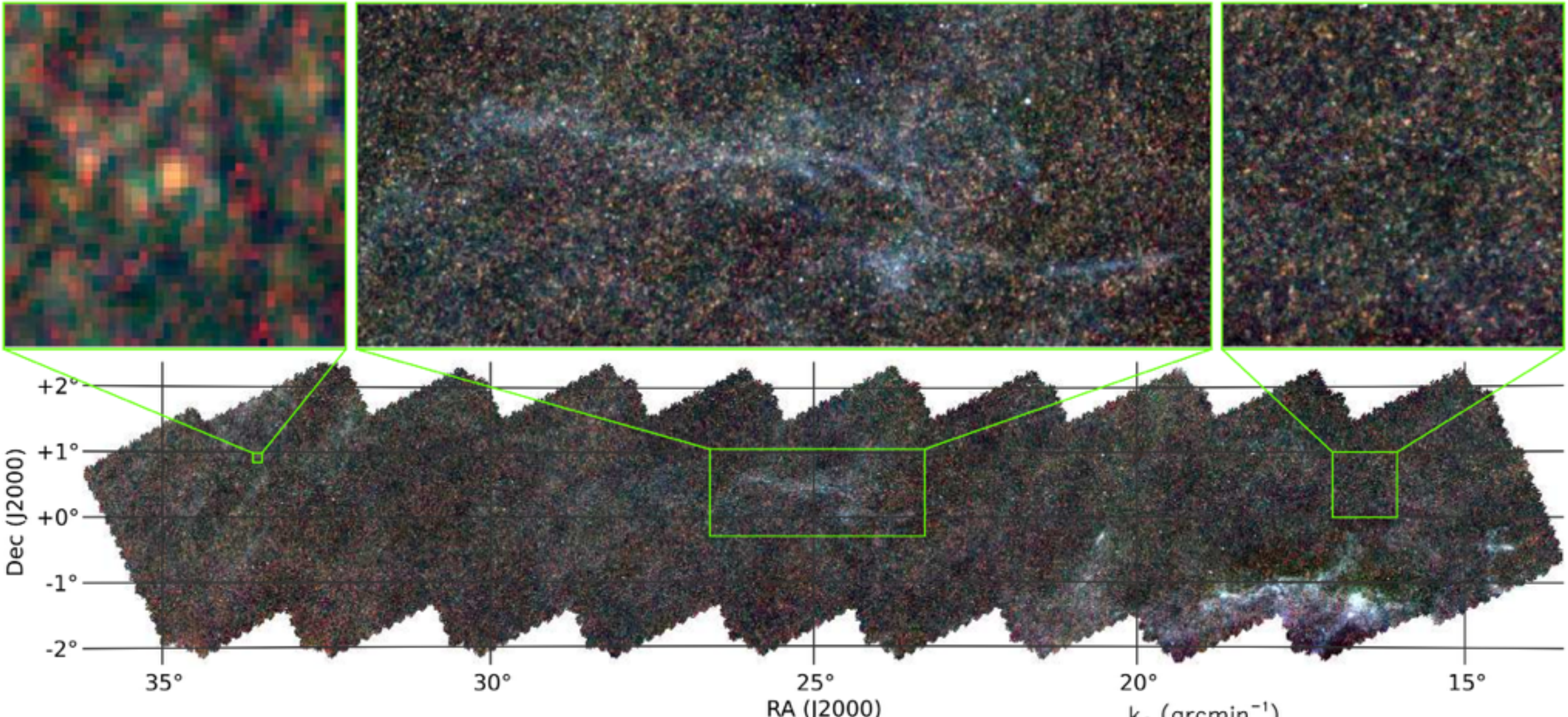
- Lyman Alpha Forest
- DLAs/Mg2/CIV

Viero+ 2013, Herschel Stripe 82 Survey; arXiv:1308.4399

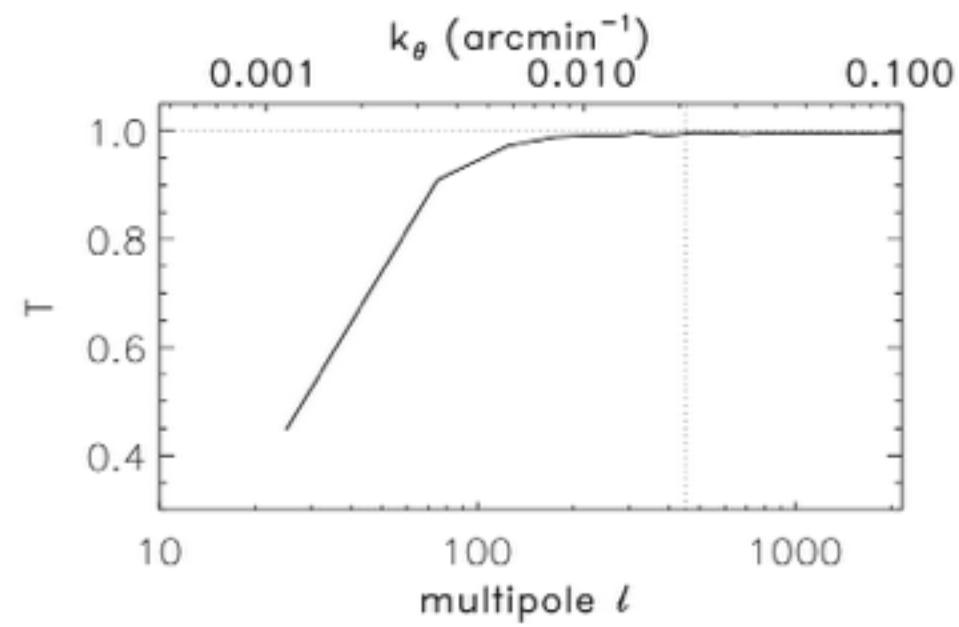
Find Maps/Catalogs at: http://www.astro.caltech.edu/hers

herschel stripe 82 survey

Brandt - Carrie Bridge - Ed Chapin - Caitlin Casey - Alex Conley - Erin Mentuch Cooper - Sudeep Das - Mark Devlin - Olivier Doré - Jo Dunkley - Duncan Farrah - Andreu Font-Ribera - Steven Finkelstein - Eric Gawiser - Karl Gebhardt - Amandeep Gill - Amir Hajian - Mark Halpern - Katie Harris - Brandon Hensley - Chardha Segee - Peter Kurczynski - Andrea Lapi - Gaelen Marsden - Lorenzo Moncelsi - Mattia Negrello - Seb Oliver - Lyman Page - Casey Papovich - Sara Petty - Ryan Quadri - Marie Rex - Isaac Roseboom - Nic Ross - Bernhard Schulz -Douglas Scott - Rachel Somerville - David Spergel - Joaquin Vieira - Marco Viero - Risa Wechsler - Rik Williams - Mike Zemcov



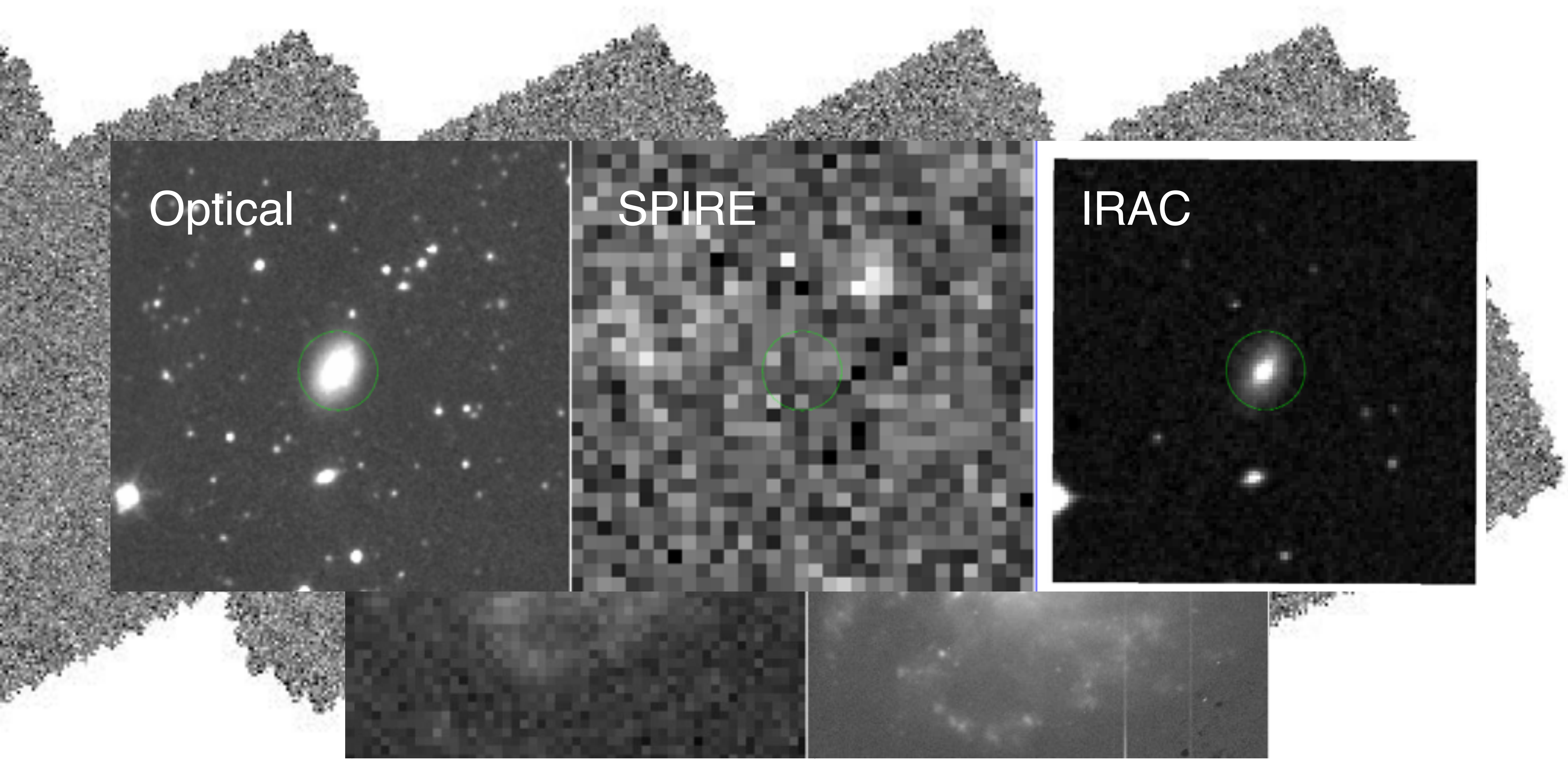
- 3.5 by 20 deg, or 70deg2
- Faithful to ~ 4 deg



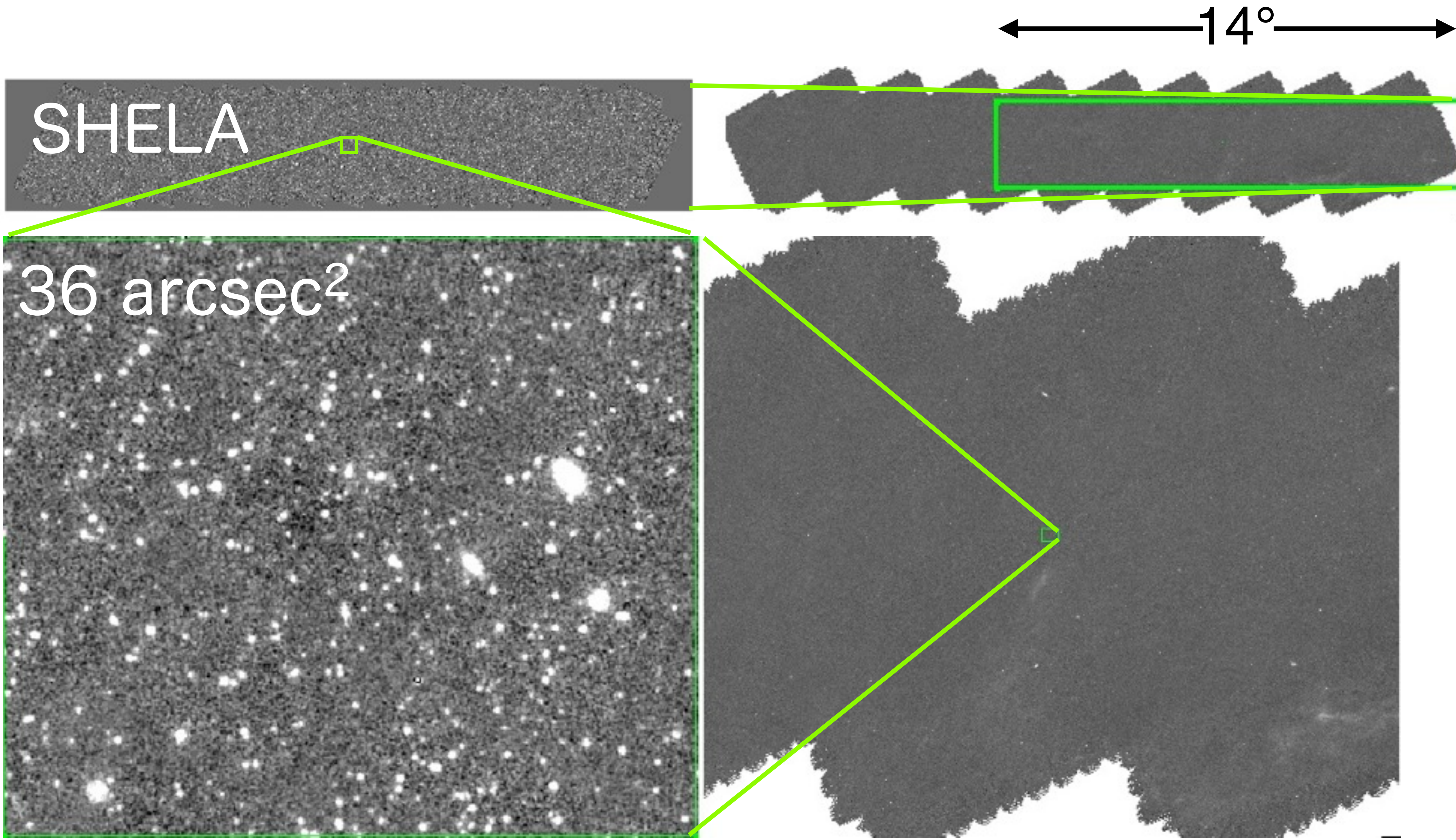
HerS

Made with SANEPIC by V. Asboth (UBC)

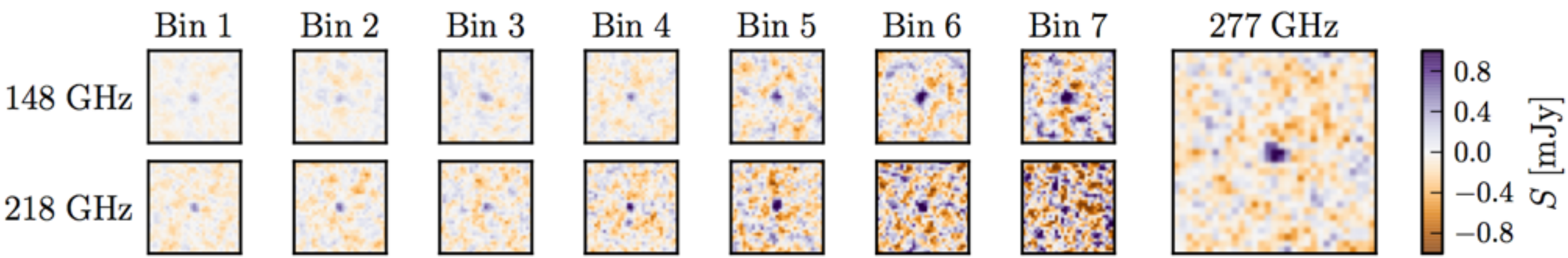
Local Starbursts



Specific Star-Formation Rates



HerS Submillimeter and ACT SZ detections in Radio Stacks



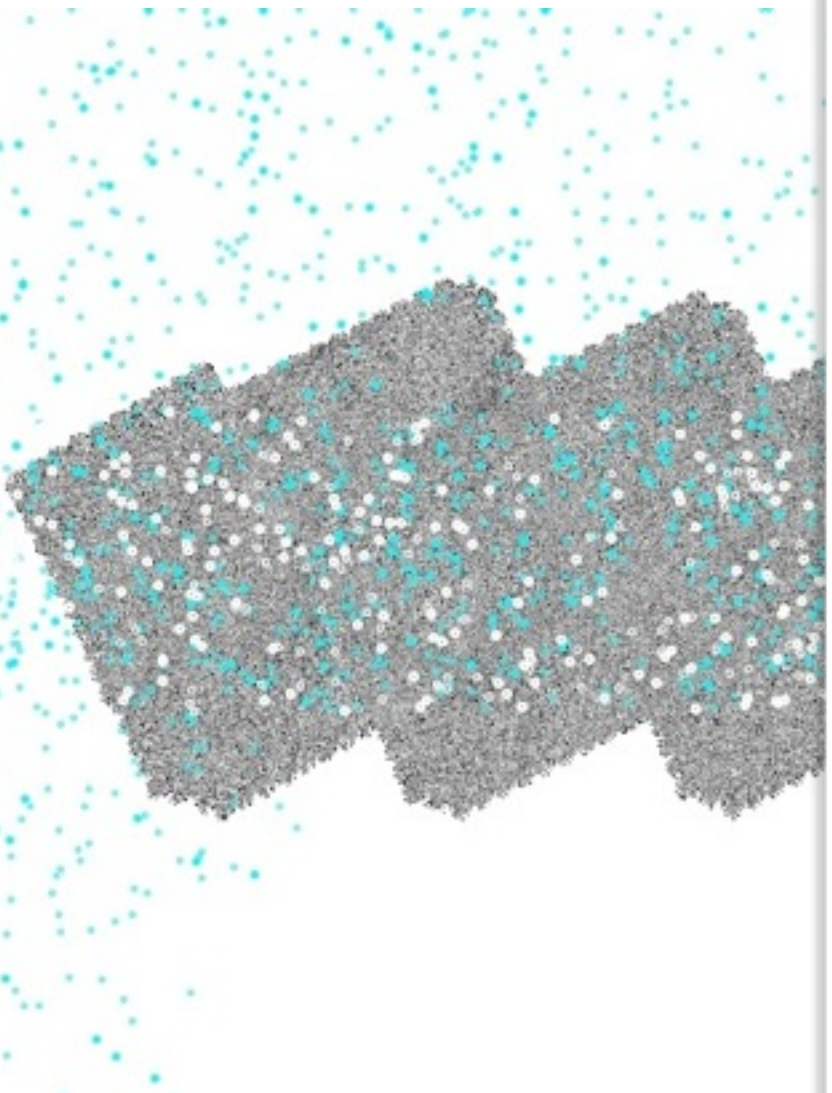
- Stacked ~4400 Radio galaxies in HerS/ACT
- Detection of SZ in $\log(M/M_\odot)\sim13$ halos

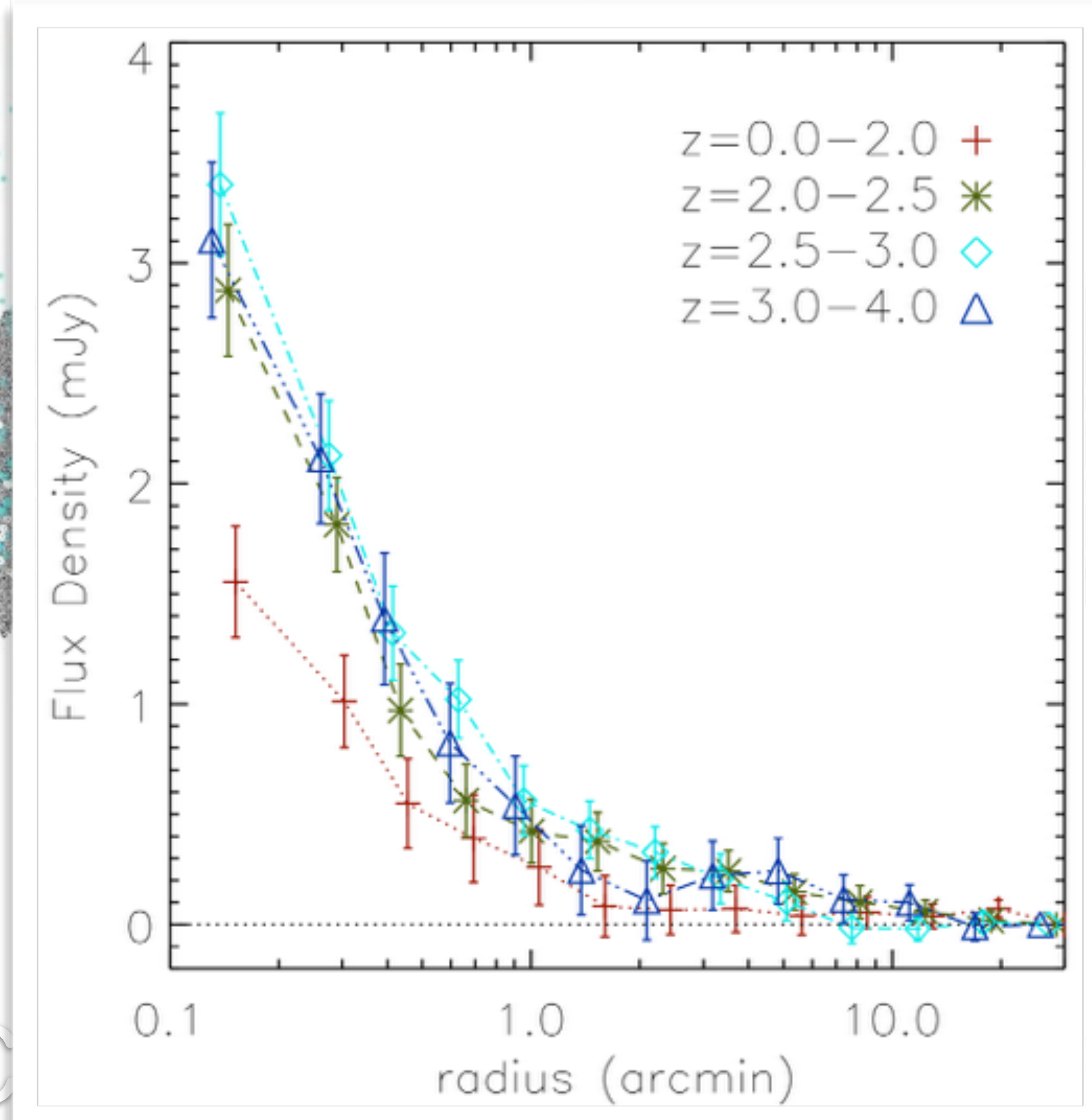
HerS

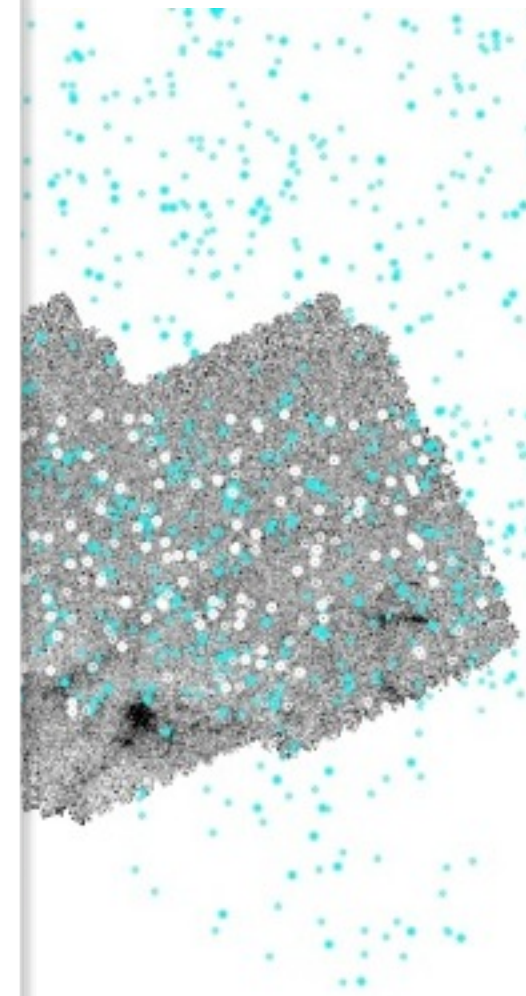
Gralla et al. 2013; arXiv:1310.8281

Viero+ 2013, Herschel Stripe 82 Survey; arXiv:1308.4399

Find Maps/Catalogs at: http://www.astro.caltech.edu/hers





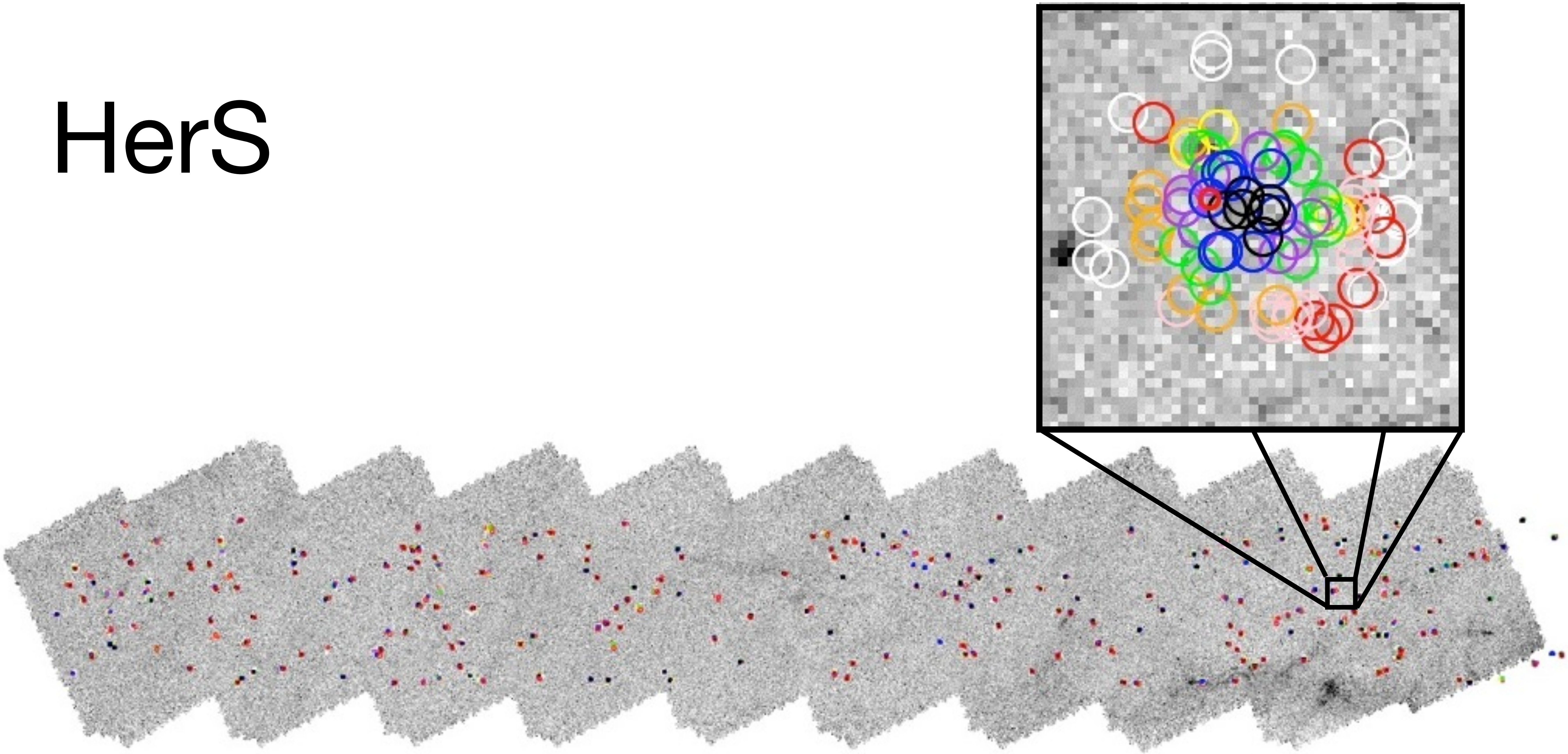


HerS

- C 012)
- BOSS quasars

Wang, Viero et al. (2013)
arXiv:1304.0446

HerS



- Cluster Members

Viero+ 2013, Herschel Stripe 82 Survey; arXiv:1308.4399

Find Maps/Catalogs at: http://www.astro.caltech.edu/hers

Future Work with Surveys

- Immediately: Cross-correlations with
  - CMB to quantify CIB - SZ correlation
  - Clusters and cluster members to study CIB-tSZ correlation, and infall radius, etc.
  - SDSS-identified QSOs and DLAs to study their dust properties and bias
  - IGM Scattered Starlight to measure dust grain sizes
  - SNa host star-formation properties
- Farther in future: Star Formation History of lower mass and higher redshift galaxies

Summary

- Dusty Star-forming FIR/submm Galaxies are biased tracers of Dark Matter
- The CIB is made up mostly of typical galaxies from optical/NIR surveys
- Cross-Correlating large data sets is a powerful tool for answering many questions in Galaxy Evolution and Cosmology
    - HerS data publicly available at: http://www.astro.caltech.edu/hers
    - SIMSTACK code publicly available at: http://www.astro.caltech.edu/~viero/viero_homepage/toolbox/