First Results from the Herschel Space Observatory

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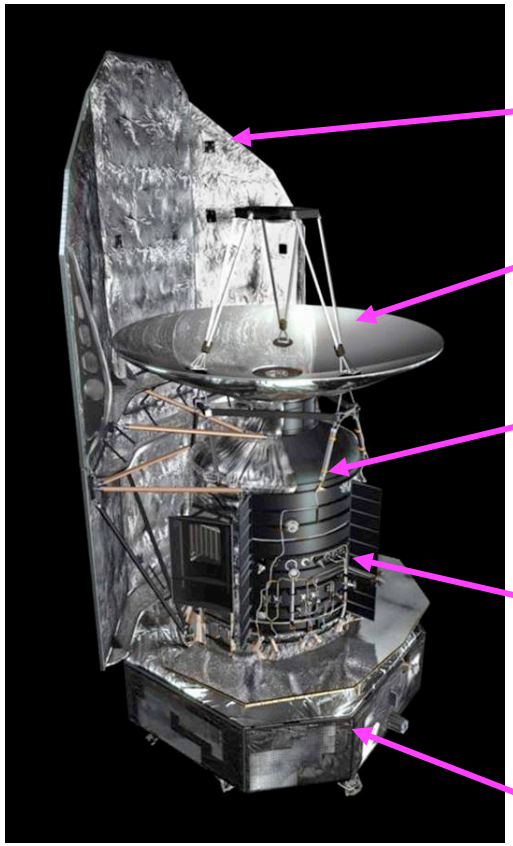
US (NASA) PI of Herschel-ATLAS (550 sq. deg)
LSS/high-z coordinator of HerMES (SPIRE GTO; 70 sq. deg.)
PI of the proposed Herschel-SPIRE Legacy Survey (4000 sq. deg)

The Herschel Spacecraft

7.2 m



3000kg **1500W**

Sunshield and solar array

3.5 m SiC Telescope (80 K)

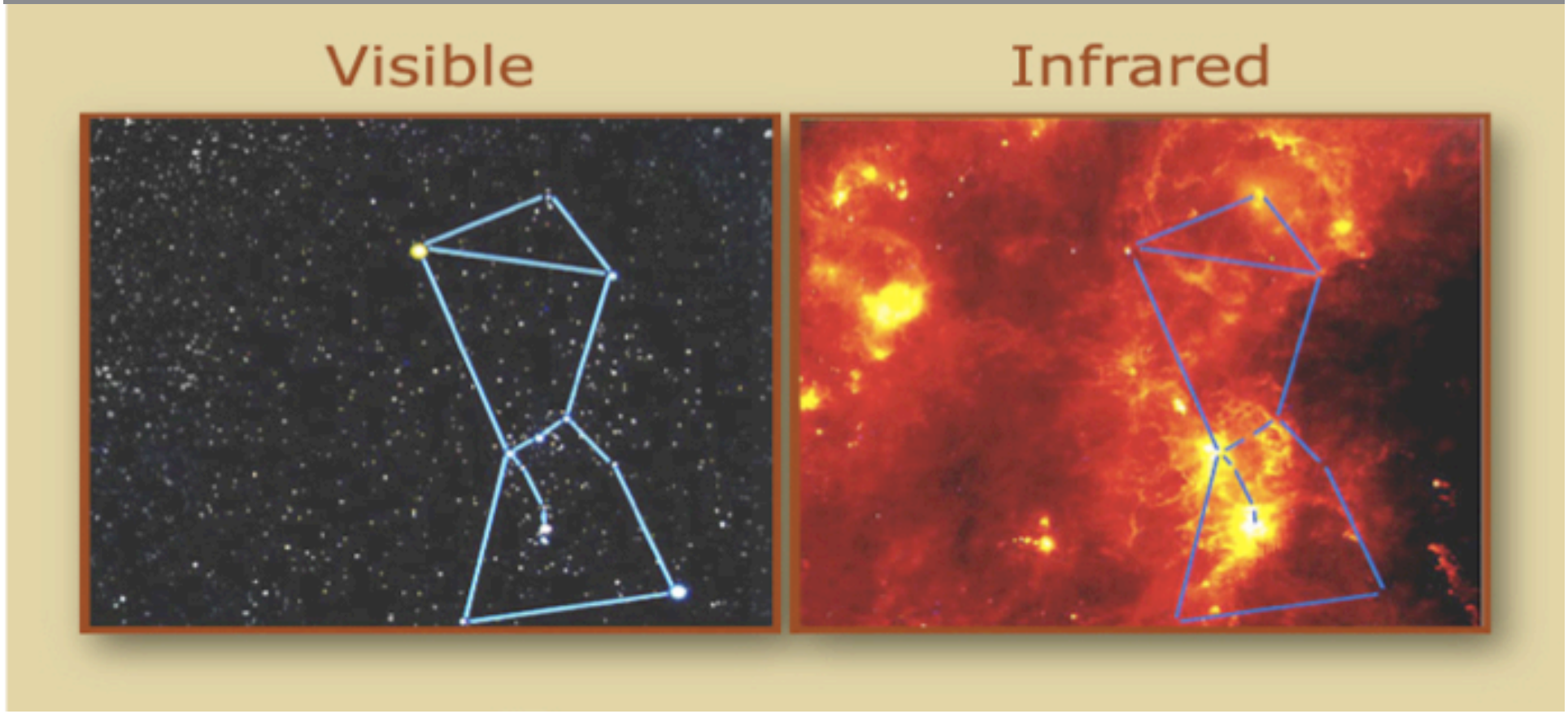
Instruments inside Cryostat (300mK)

He II Cryostat (~2460 liters)
(1.7 K)

Service Module (300 K)

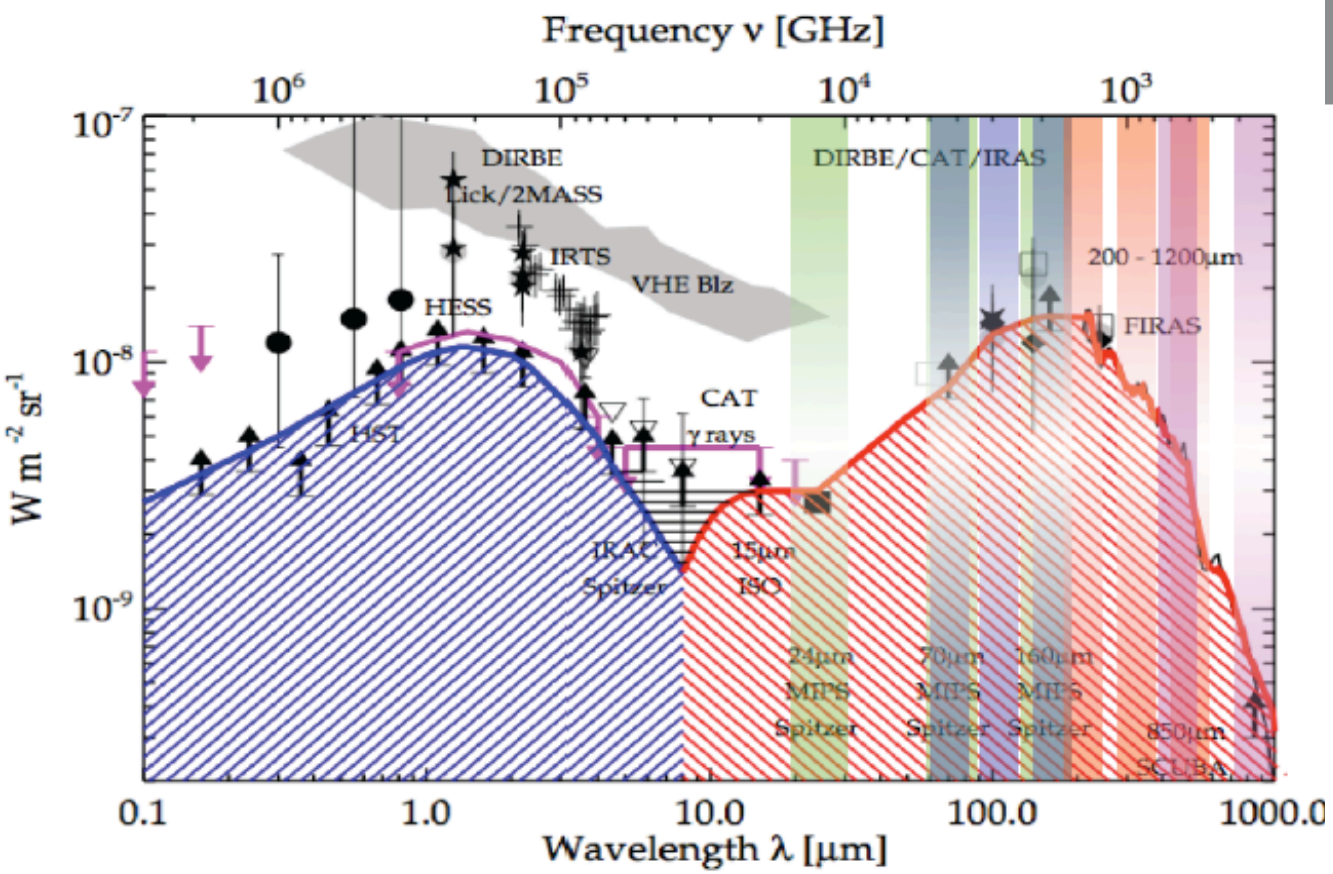
S/C units and Instrument electronics

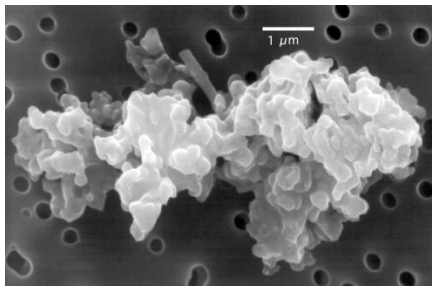
Infrared sky is active



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

Infrared sky is active





Dust

why do we care:
- 50% of the total bolometric luminosity in the Universe is absorbed by dust and re-radiated at far-infrared/sub-mm
- Dust plays a key role in lifecycle of stars
- Dust is responsible for extinction
- We are made of heavy elements that probably had the form of dust at some point

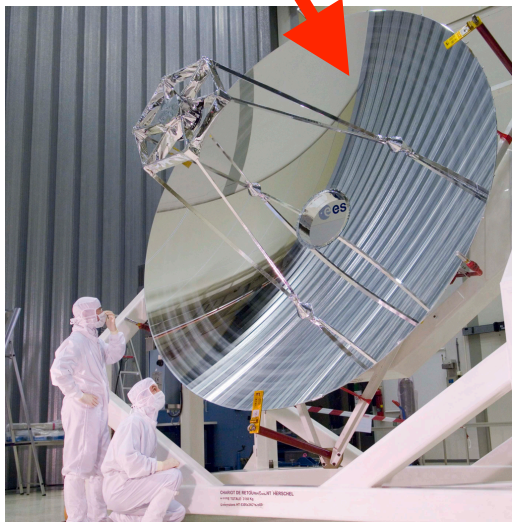
The Herschel Far-Infrared Observatory

Telescope Technology (ESA)

Silicon Carbide (SiC)

3.5 m diameter largest SiC structure ever made (and only one mirror made)

From SiC "dust" to a cryogenic fully formed 3.5 m diameter Telescope !



- **Process flow:**
  - **Powder mixing => Hydrostatic pressing in moulds => Assembly of segments => Grinding of mirror to precise shape with diamond tools => Polishing => Coating => Alignment testing and qualification (under space conditions) => Delivery for integration onto spacecraft.**

Telescope Technology (ESA)

Telescope Industrial facilities

Finland

OPTEON polishing installations

BOOSTEC

SiC facilities and ovens

France

Belgium

CSL Focal XXL

WFE facilities

Spain

CALAR-ALTO coating chamber

Herschel Basics

MISSION

ESA-Led Cornerstone
+ NASA Contributions

SPECIFICATIONS

3.5 m telescope (T ~ 80 K)
L2 Halo Orbit
3.5 year lifetime (boil-off ~May 2013)
Launched in May 2009

INSTRUMENTS

SPIRE (bolometers)

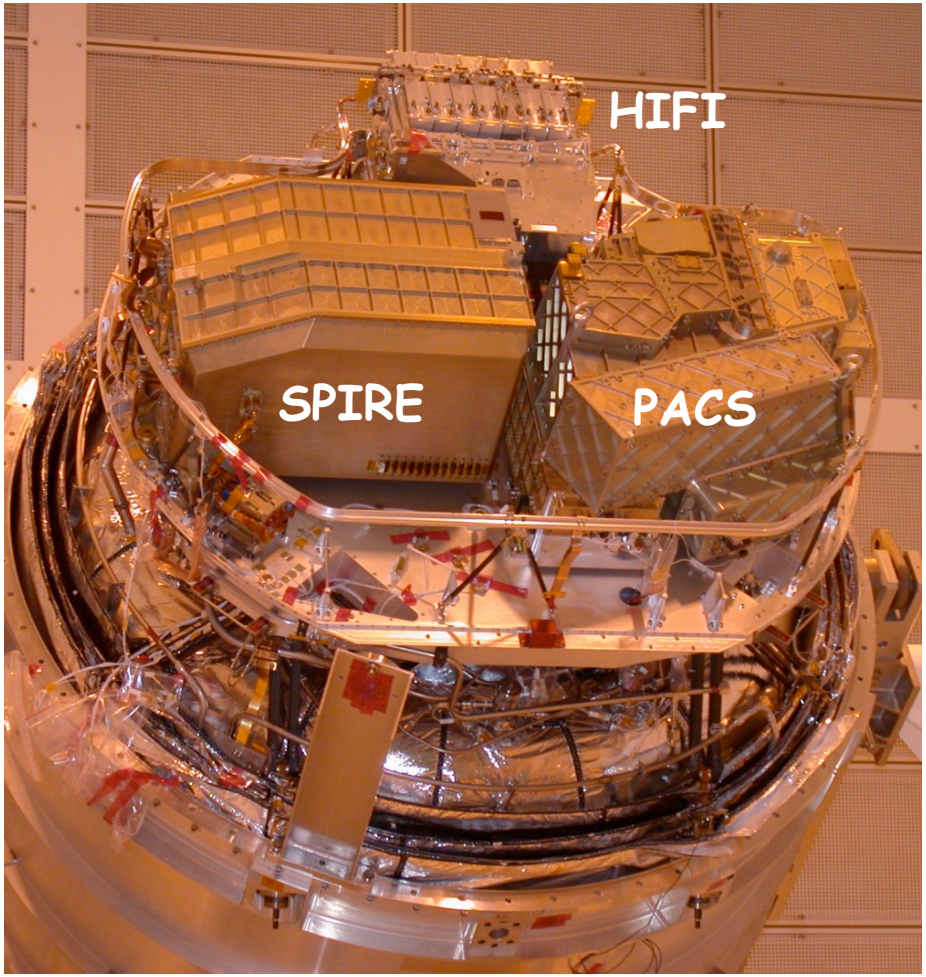
Photometer at 250, 350, 500 um
FT spectroscopy 200 – 350, 350 – 670 um

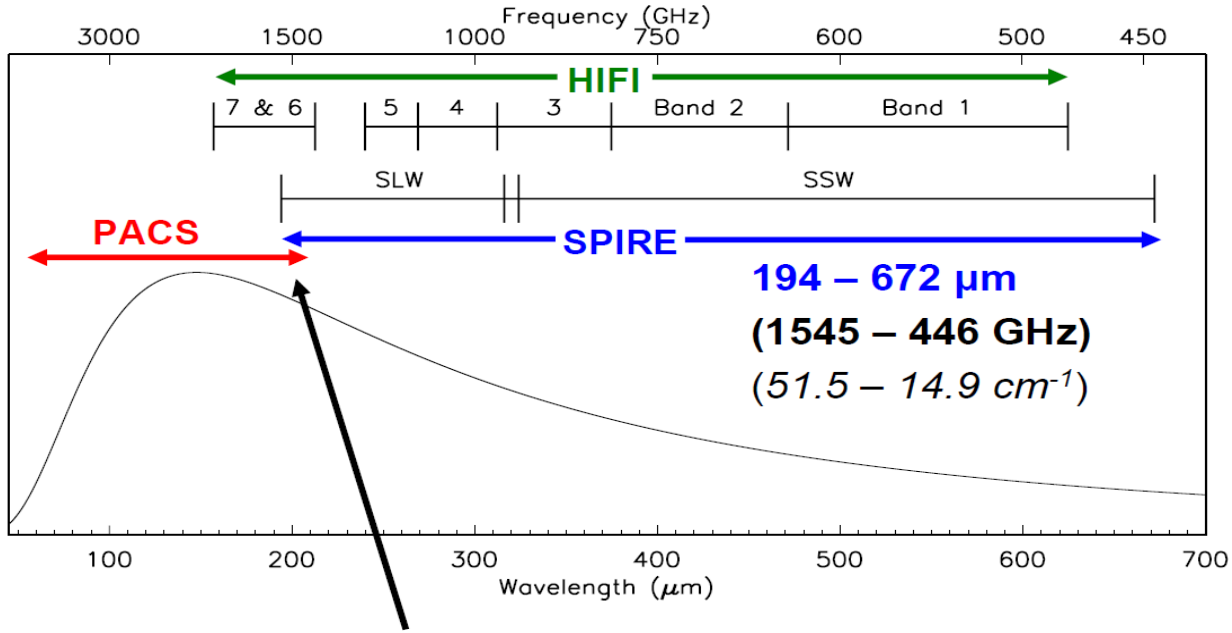
PACS (photoconductors & bolometers)

Imaging at 70/100, 160 um
Grating spectroscopy 60 – 210 um

HIFI (heterodyne)

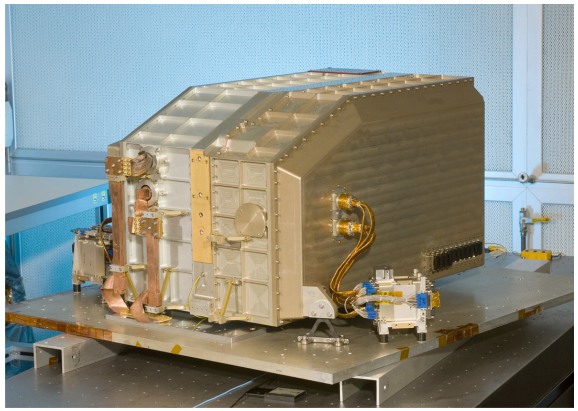
High-resolution spectroscopy 270 - 610 um



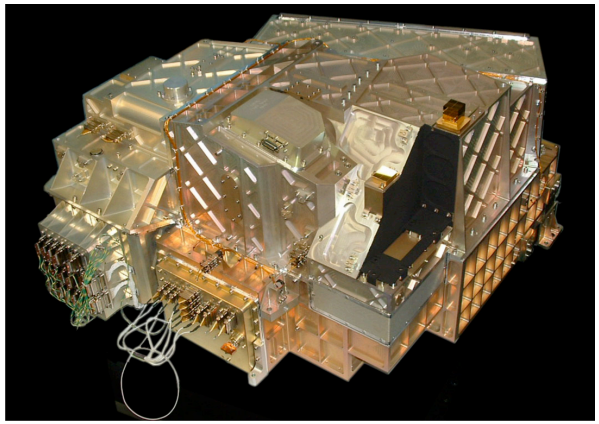


Good overlap with PACS (194 – 210 µm)

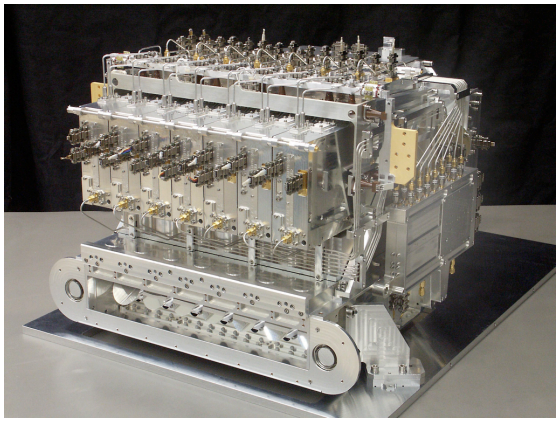
HIFI - Heterodyne receiver for spectral measurements (just like a radio)
PACS - 3-band imaging camera/spectrometer
SPIRE - 3-band imaging camera/Fourier Transform Spectrometer



SPIRE (UK)



PACS (Germany)



HIFI (Netherlands)

SPIRE

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

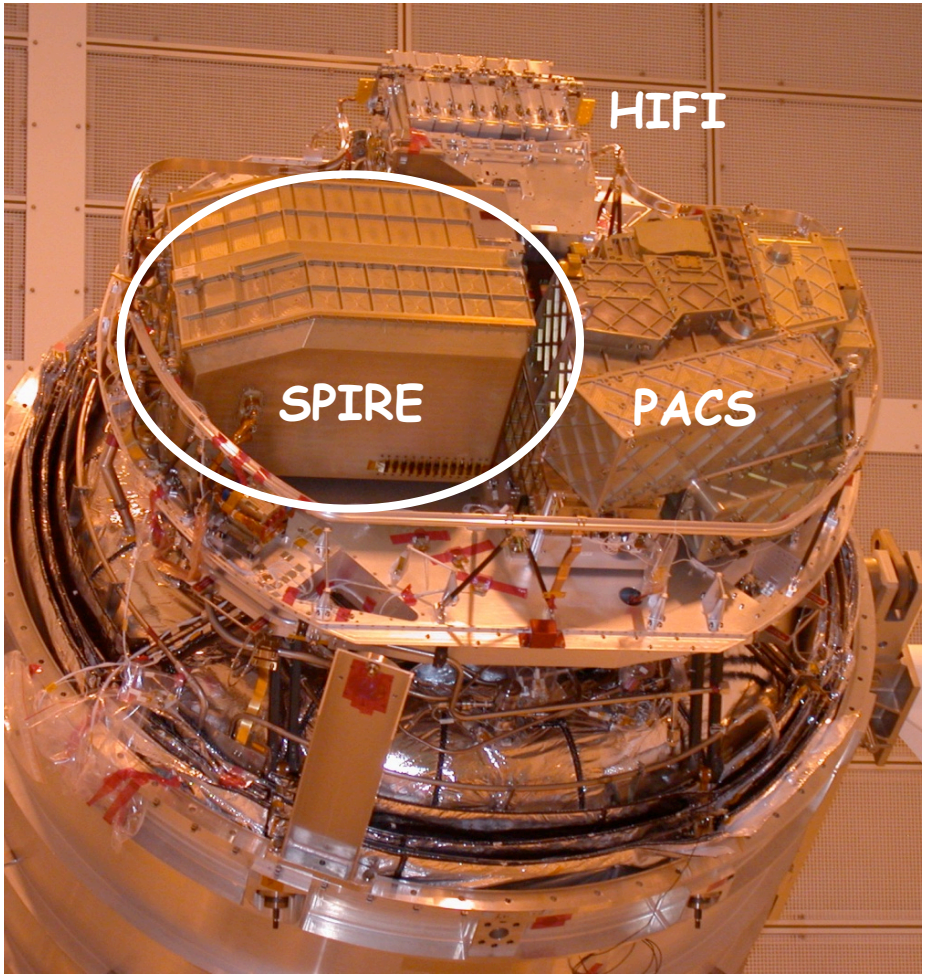
Imaging FTS

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

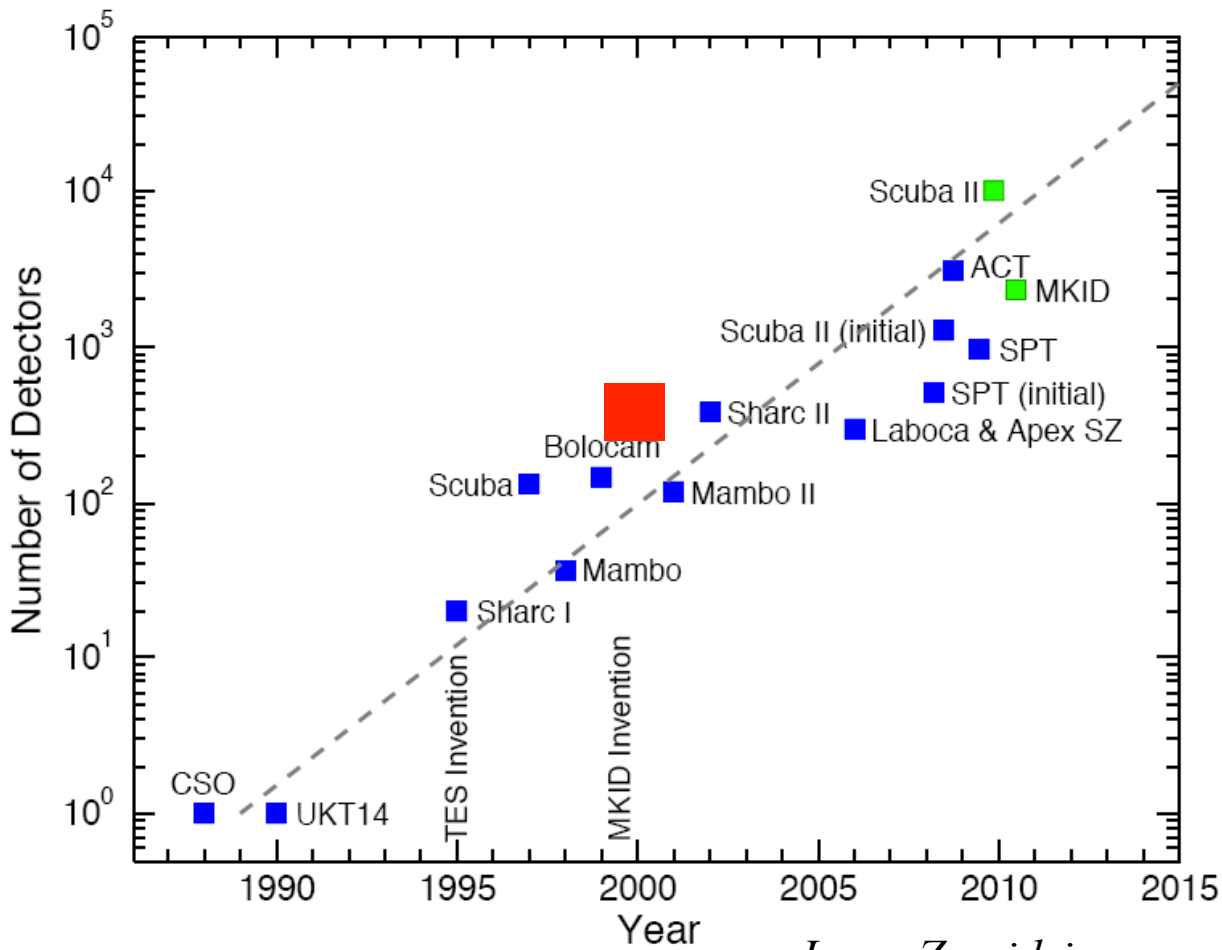
Wide instantaneous bandwidth, map making

Design Principles

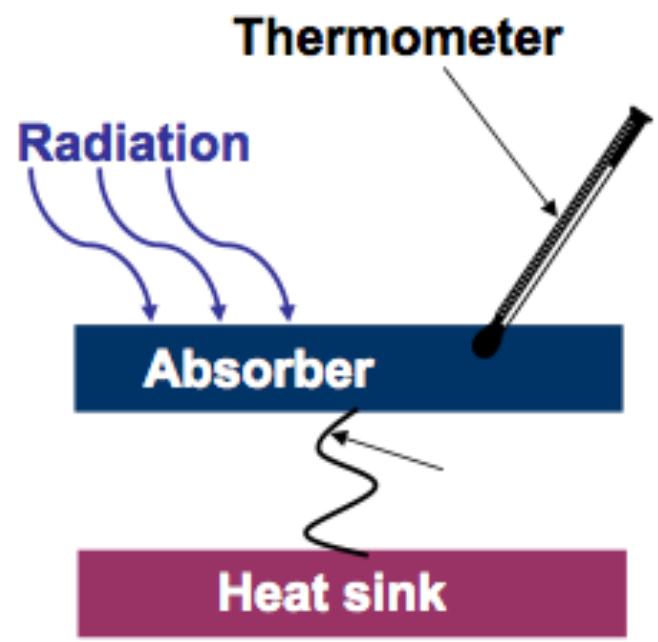
- Sensitivity limited by thermal emission from the telescope
- ^{3}He cooled detector arrays (0.3 K)
- Feedhorn-coupled spider-web bolometers
- Minimal use of mechanisms
  Beam steering mirror; FTS mirror drive
- Optimized for scan-mapped surveys



"Richards' Law" for Bolometers

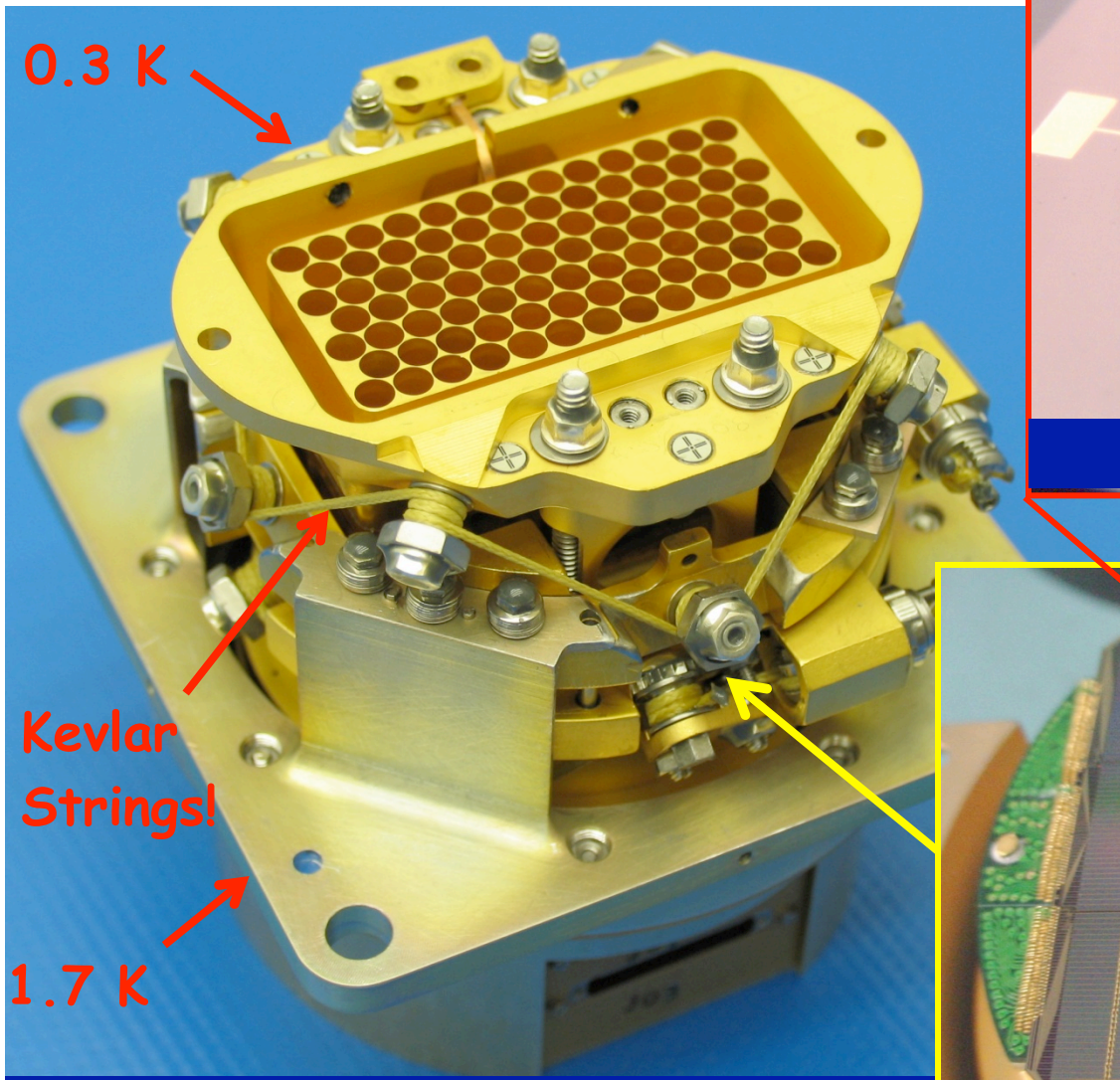


Jonas Zmuidzinas

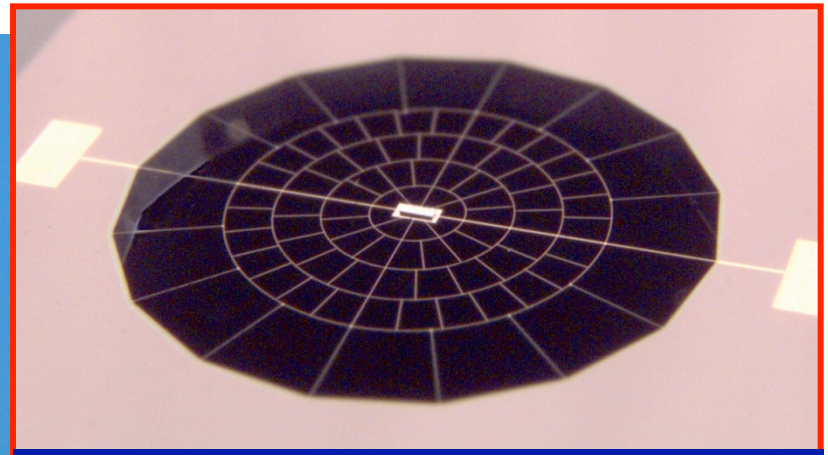


SPIRE technology downselect: 2000

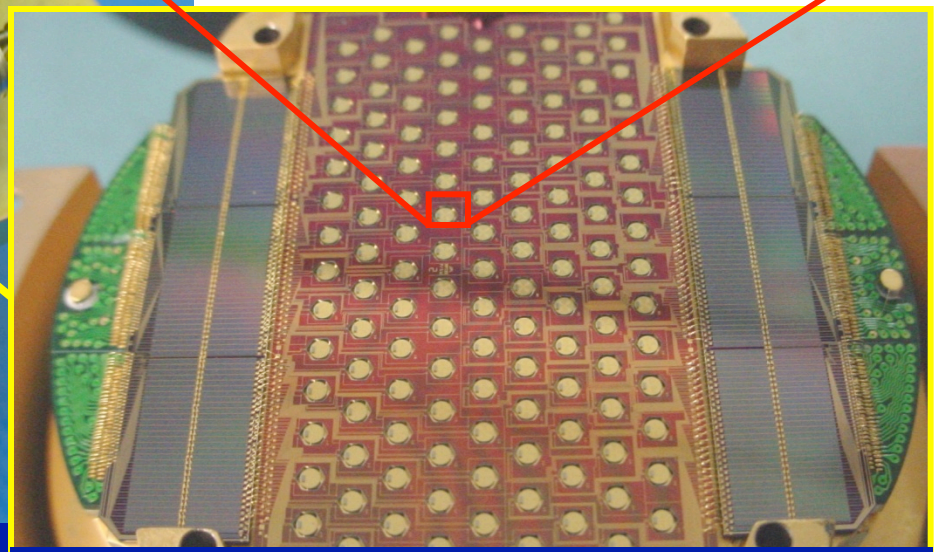
NASA Hardware Contributions



300 mK Detector Assembly



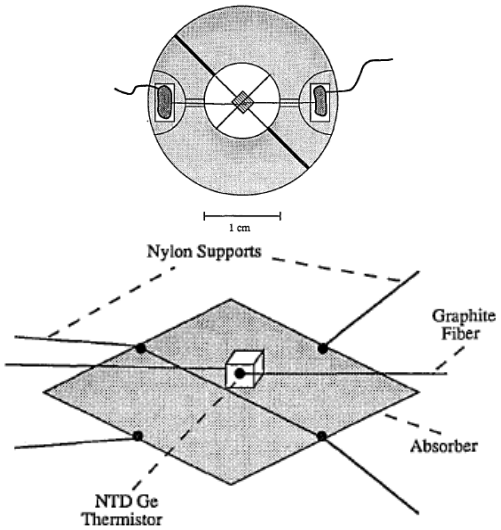
'Spider-Web' Bolometer



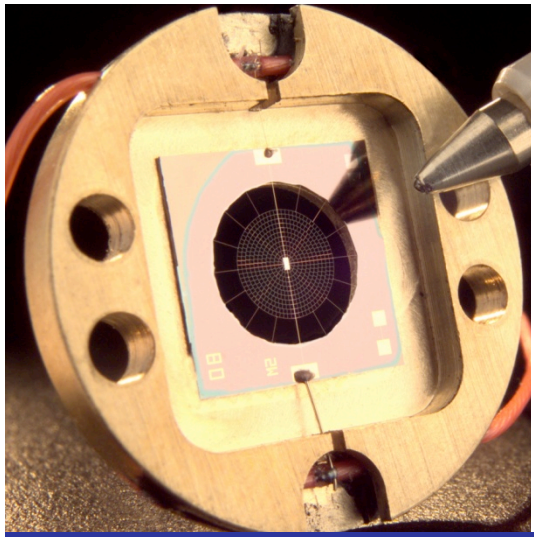
Focal Plane Array

Jamie Bock (Caltech/JPL; SPIRE US PI)

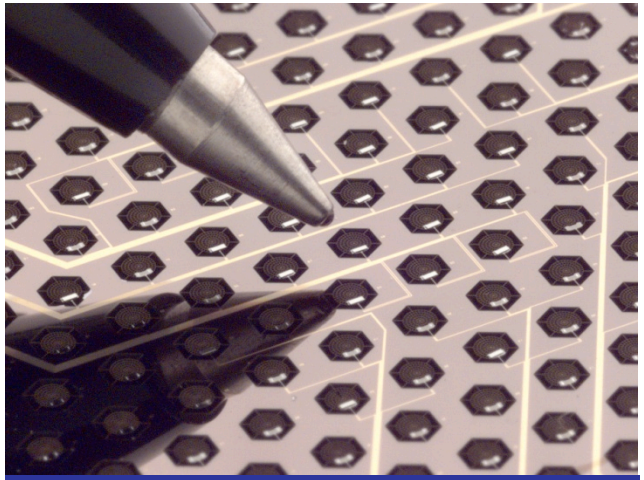
SPIRE Technology Pre-History



Composite bolometer



Spider-web bolometer

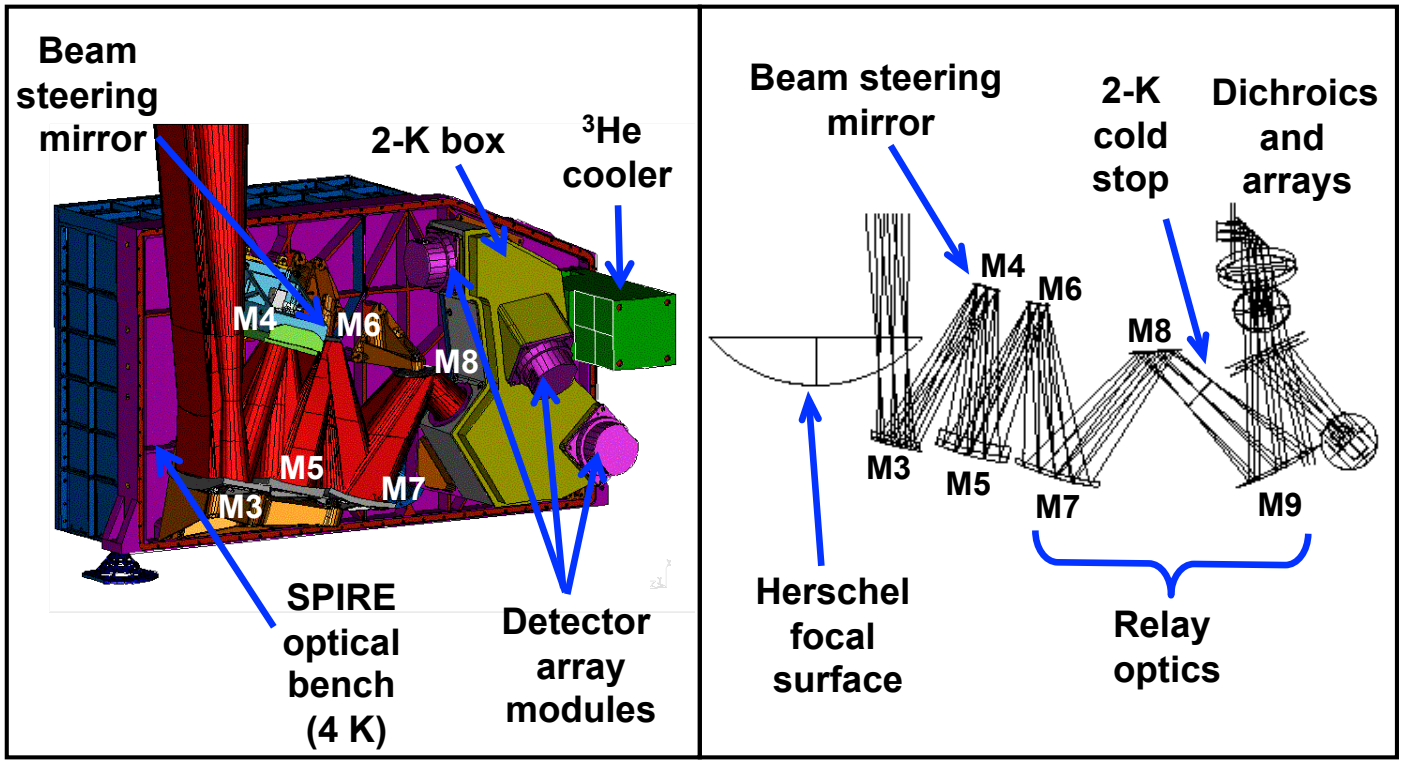


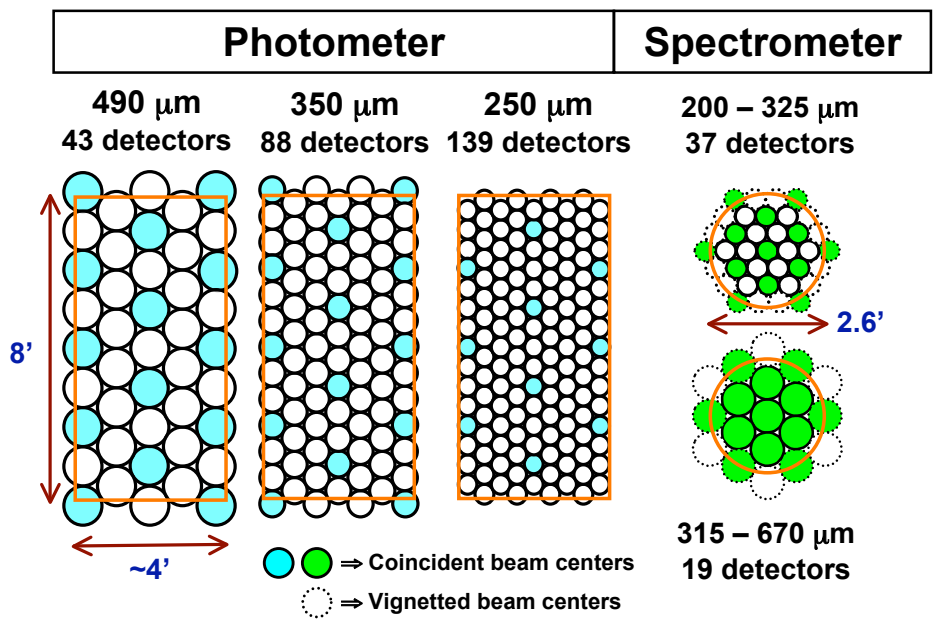
Spider-web bolometer array

IRTS 1995

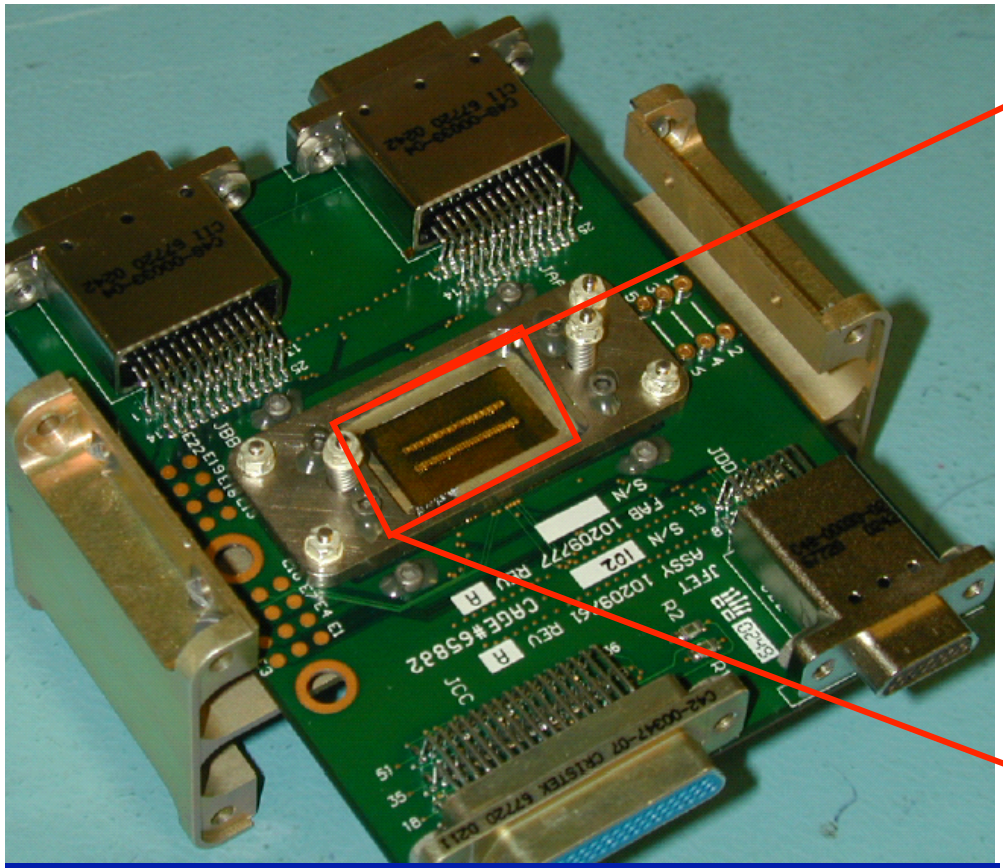
BOOMERanG 1998

BOLOCAM 2002

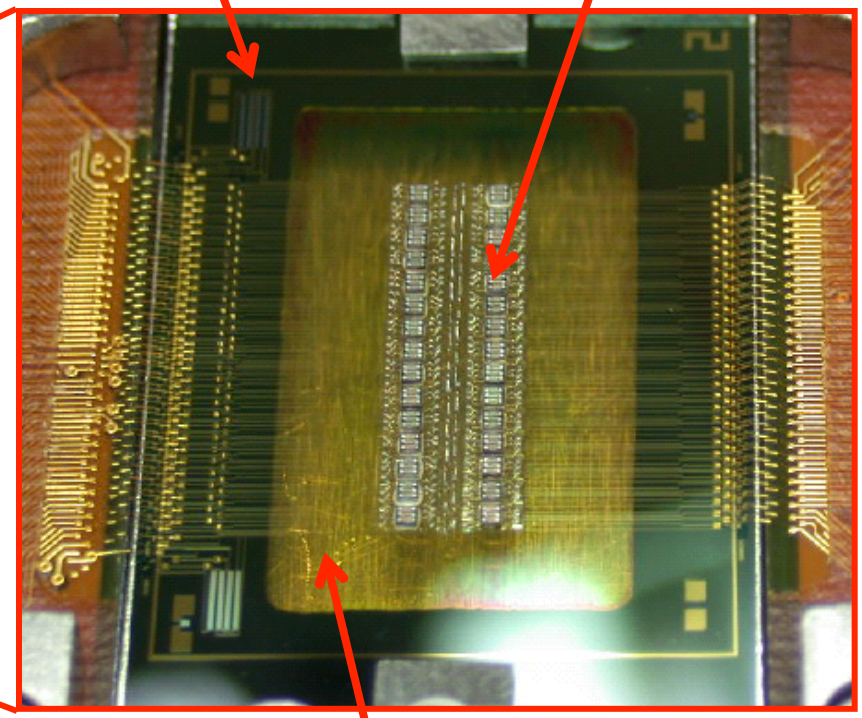

Beam steering mirror
2-K box
^{3}He cooler
M4
M6
M8
M5
M7
M3
SPIRE optical bench (4 K)
Detector array modules
Beam steering mirror
2-K cold stop
Dichroics and arrays
M4
M6
M8
M3
M5
M7
M9
Herschel focal surface
Relay optics


Photometer
Spectrometer
490 μm
43 detectors
350 μm
88 detectors
250 μm
139 detectors
200 – 325 μm
37 detectors
8'
~4'
2.6'
315 – 670 μm
19 detectors
⇒ Coincident beam centers
⇒ Vignetted beam centers

NASA Hardware Contributions

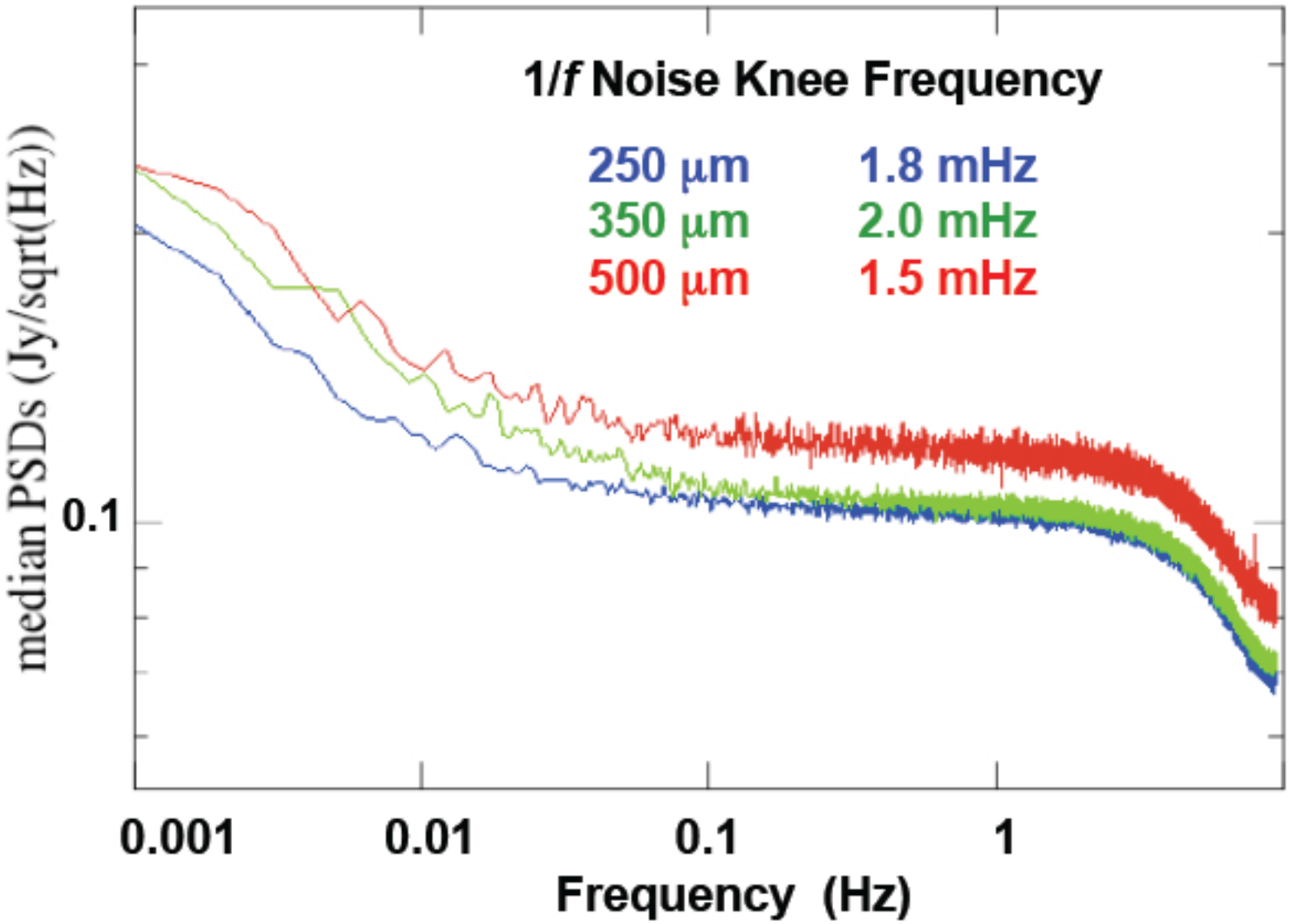


48-Channel JFET Amplifier Module



1 μm Silicon Nitride Film
Micro-Perforated!

Scan Mapping with SPIRE



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

Fairing integration on 10 May 2009

Two Spacecraft

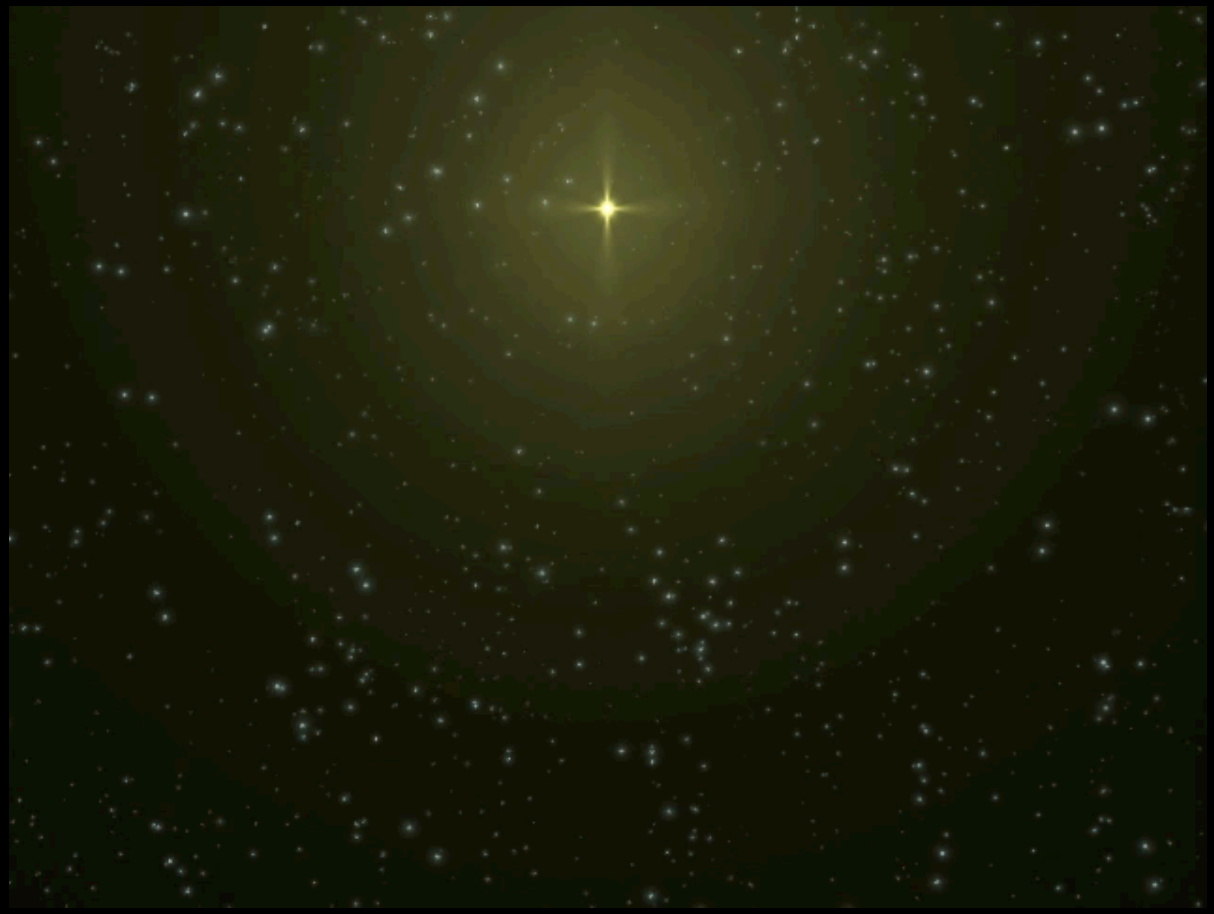
Herschel, three axis stabilised, **pointing** satellite

Planck, a low-spin-rate sky **scanning** satellite

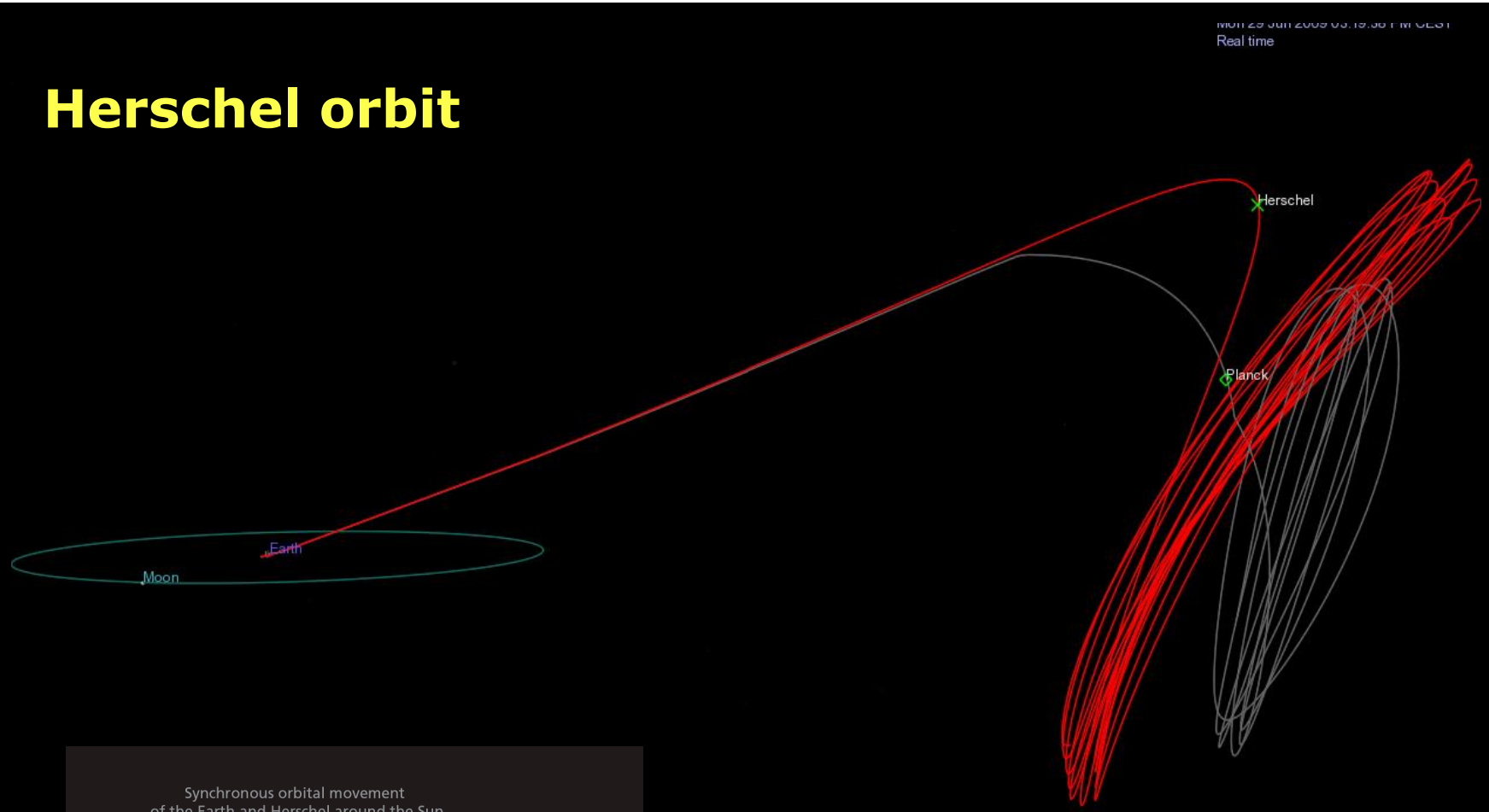
Rollout on May 13, 2009 Launch May 14, 2009

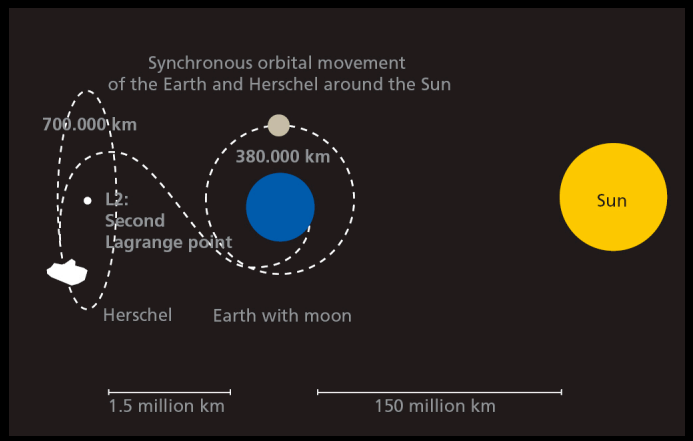
One Launcher

- **Ariane 5 ECA** with single launch for both Spacecraft



Herschel orbit

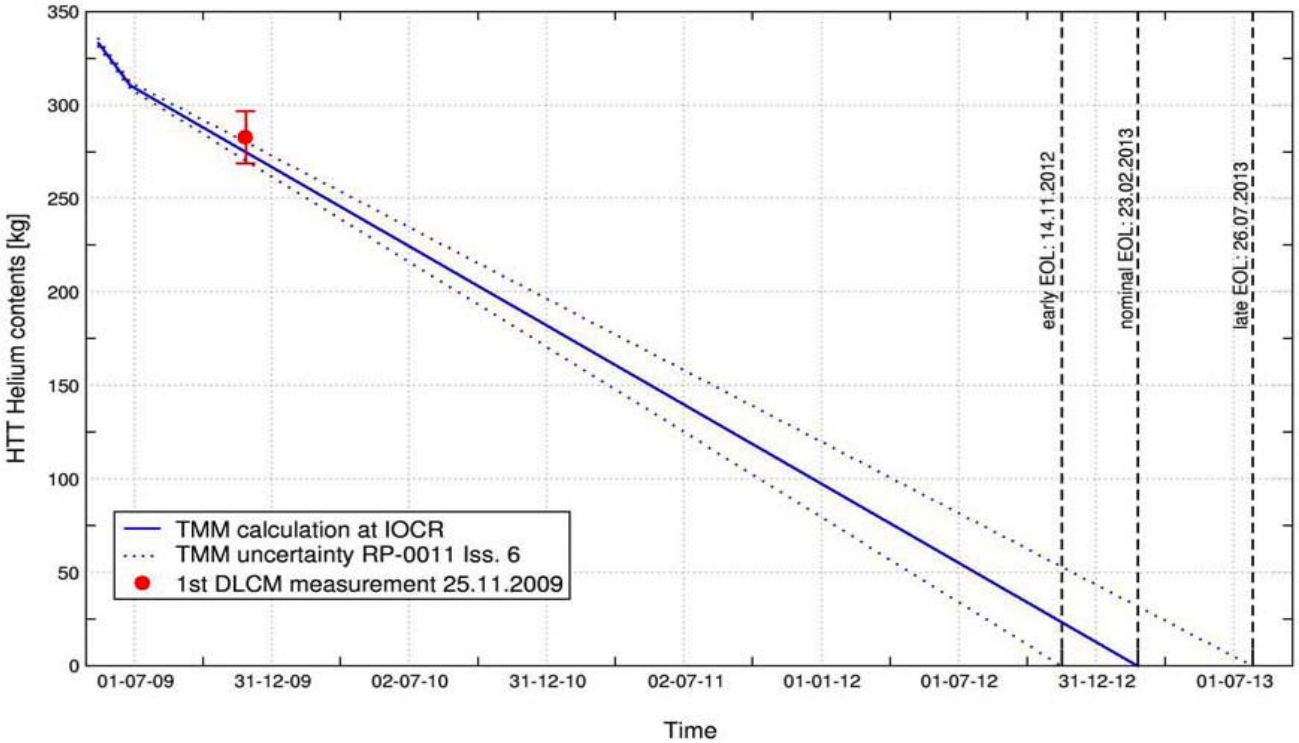




WMAP - ejected?
Herschel
Planck
JWST
LISA Pathfinder (L_1)
IXO (XEUS)
GAIA/EUCLID/PLATO/SPICA

Mission (cryostat) lifetime

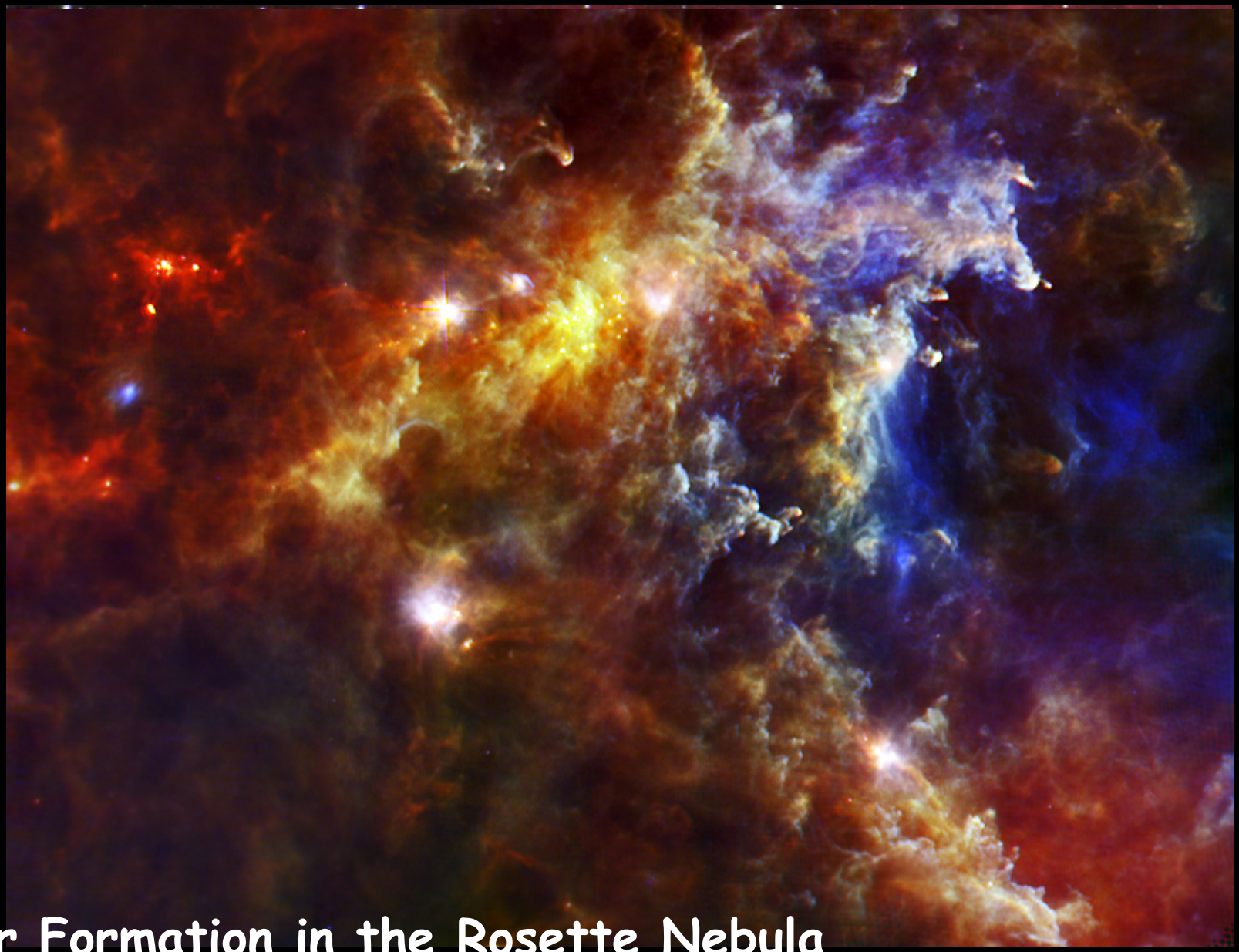
Large uncertainties remain, but confidence in ≥ 3.5 years



First DLCM on OD#195 (25 November 2009)

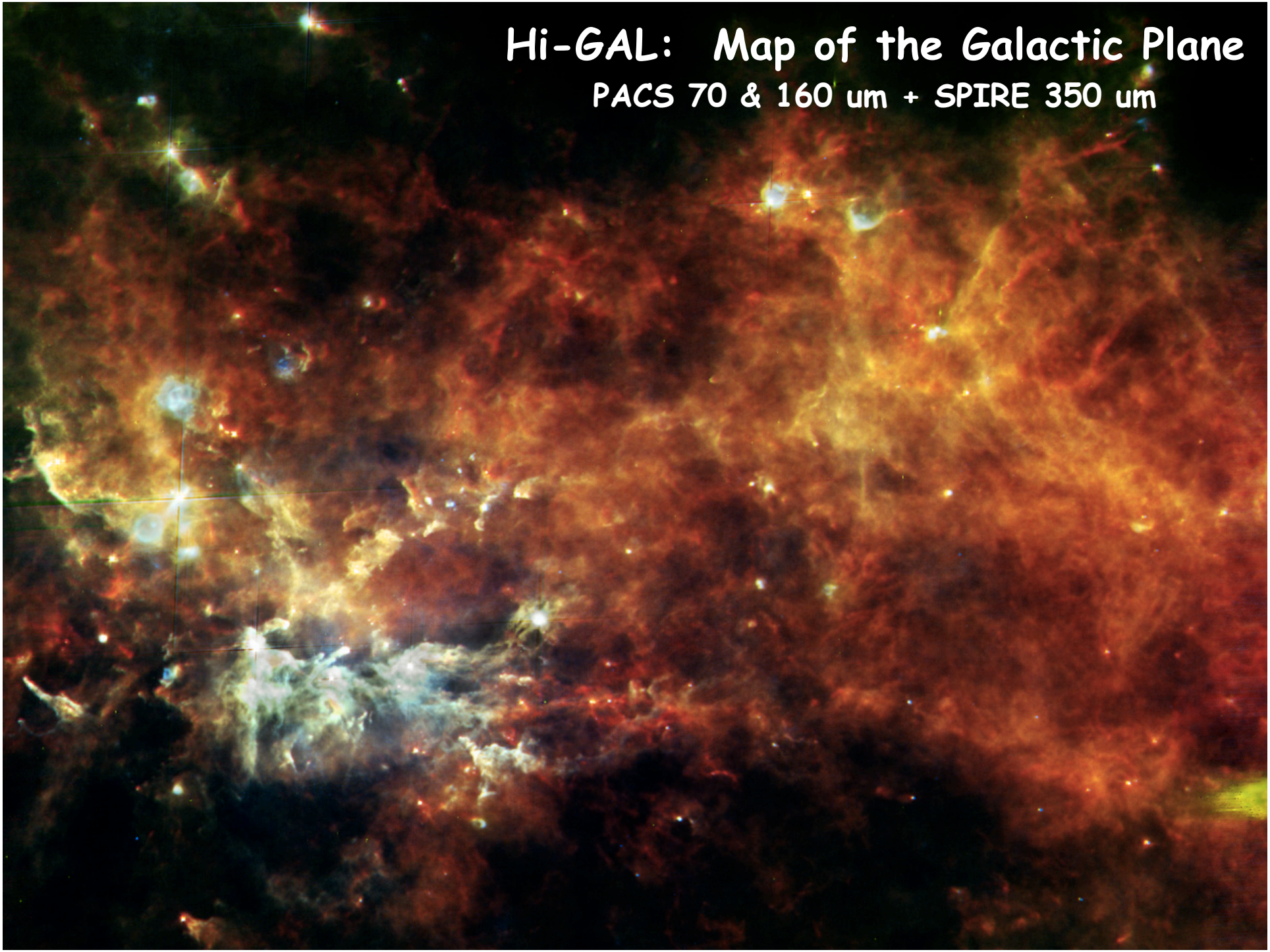
- Remaining amount He measured at 283 ± 14 kg (269-297 kg)
- Use 2.668 mg/s => 1228 ± 50 days (1168-1288 days)
- Compute total mission lifetime => 3.65-3.98 years
- Estimated amount of He was 275 kg (consistent)

⇒ Mission lifetime given as 3.8 years (end ~March 2013)

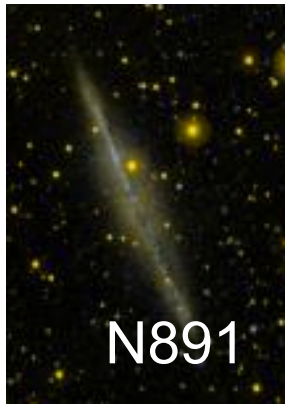


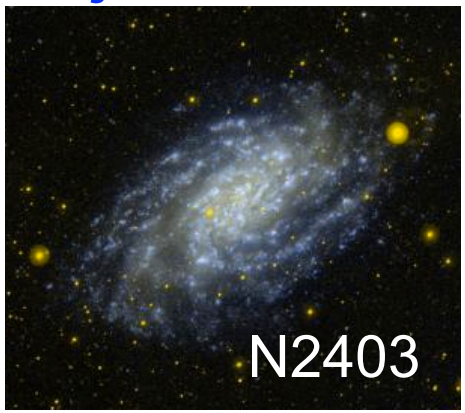
Star Formation in the Rosette Nebula

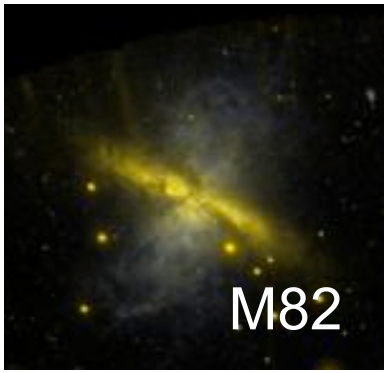
PACS 70 & 160 um + SPIRE 250 um

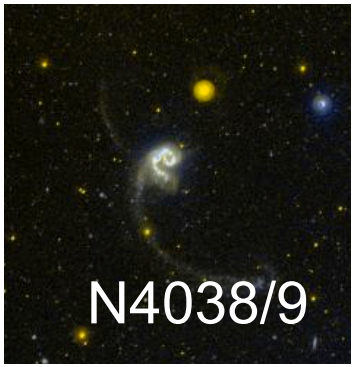

Hi-GAL: Map of the Galactic Plane
PACS 70 & 160 um + SPIRE 350 um

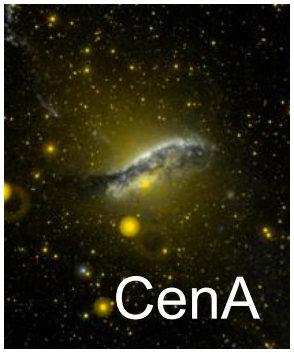
GALEX images of the VNGS target objects

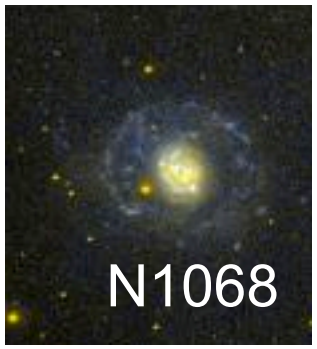


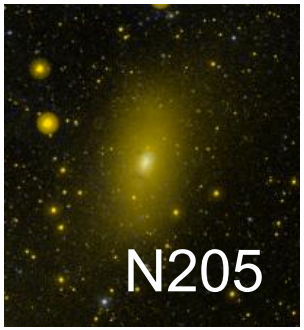




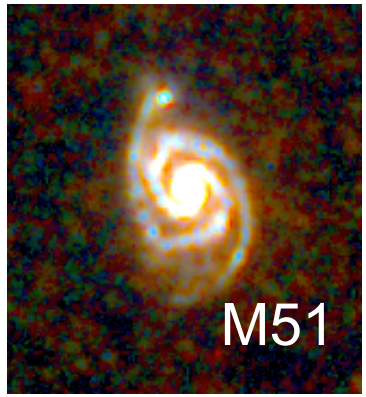


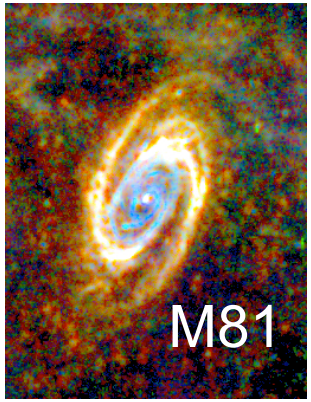


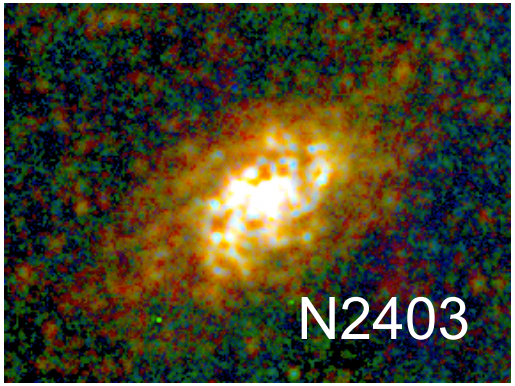


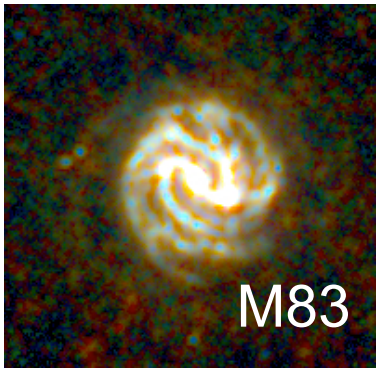


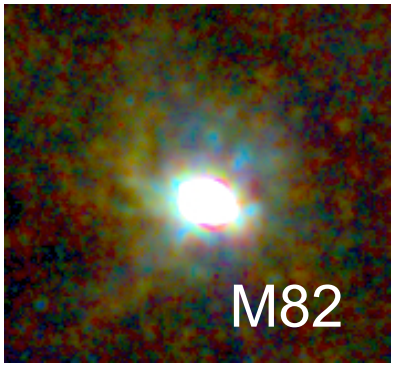
SPIRE images of the VNGS target objects

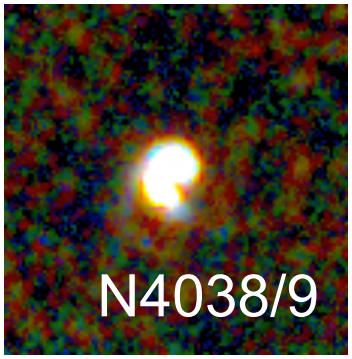


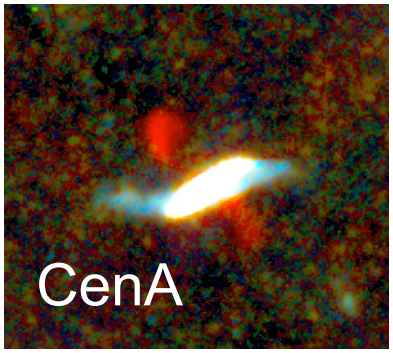


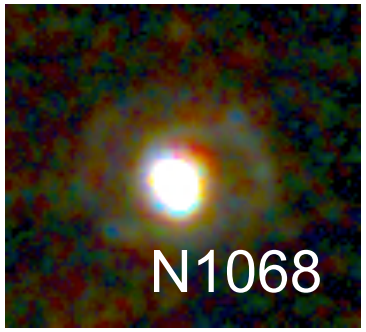


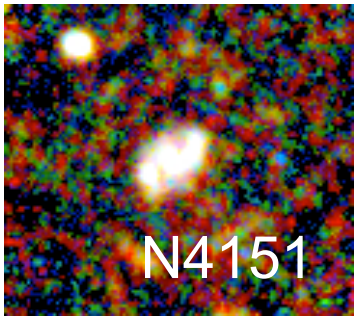


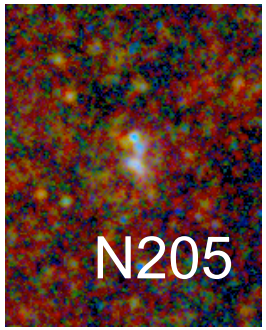


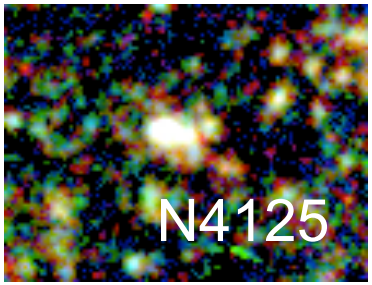




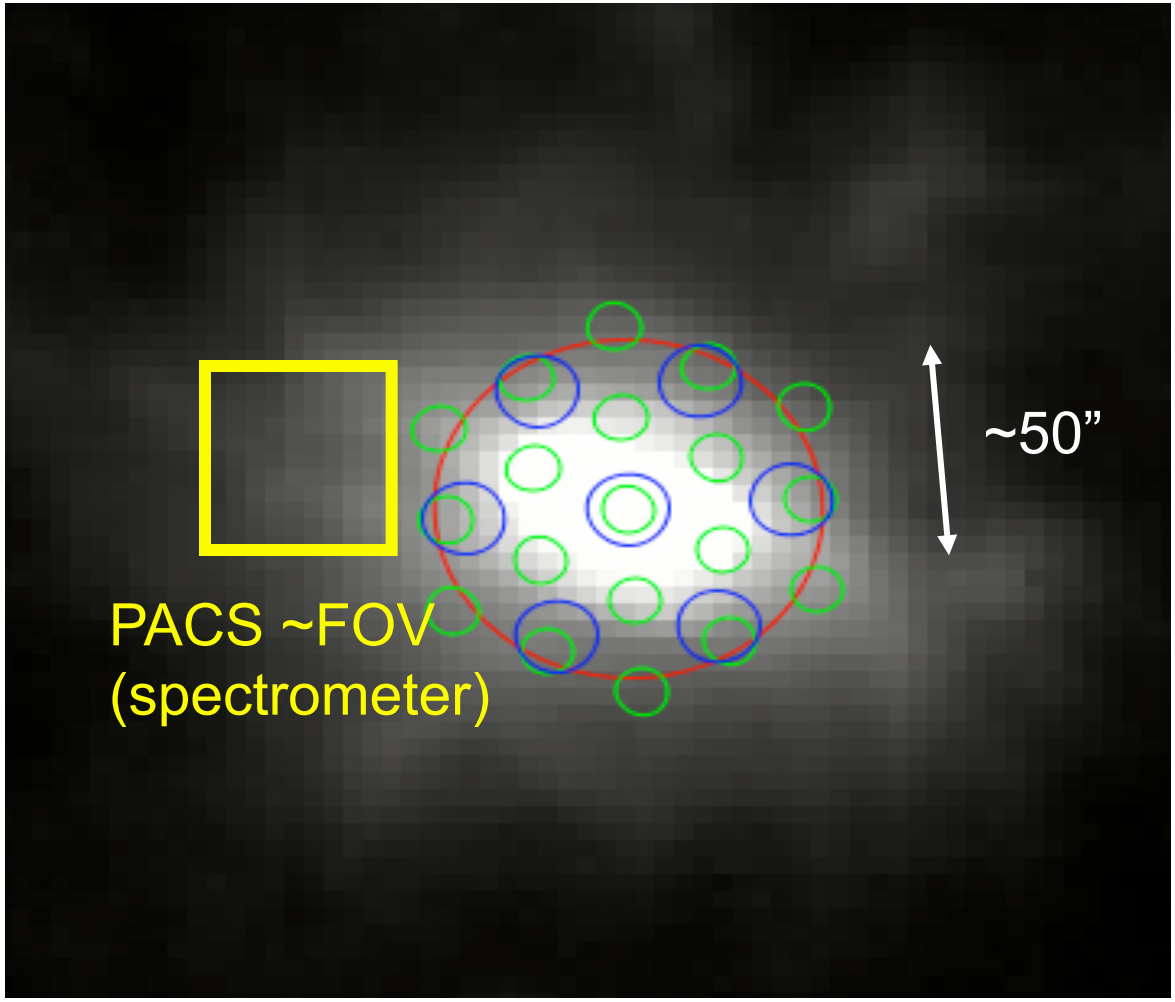








Imaging with the SPIRE FTS

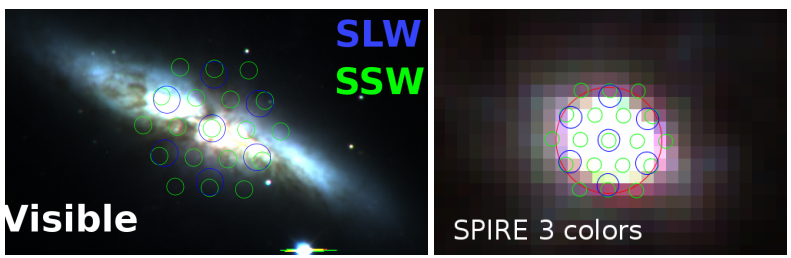


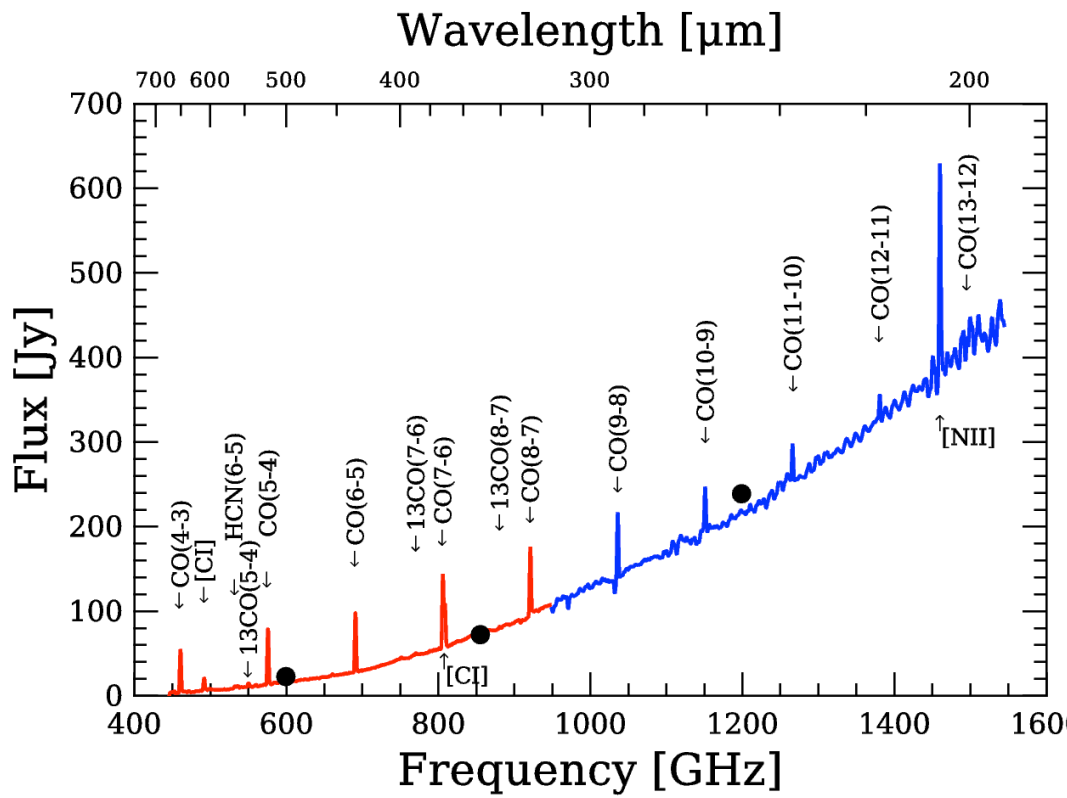
Background image: SPIRE 250 microns

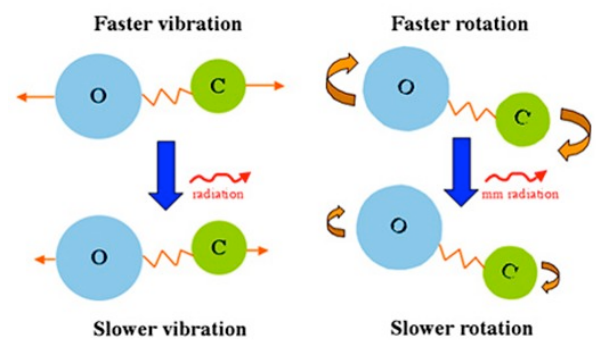
Probing the interstellar medium of M82

M82 SPIRE FTS observations

- M82 is the nearest (3.9Mpc) starburst (~10Msun/yr)
  - Brightest IRAS extragalactic source (1390Jy at 100μm)
  - Widely used in cosmology as starburst prototype
- Target of the *Very Nearby Galaxies Survey* (SAG2)
- M82 was observed as Performance Verification target
  - High resolution (FWHM=0.048 cm^{-1} R~1000)
  - 1332 seconds (10 repetitions)
  - Point source mode (single staring pointing)



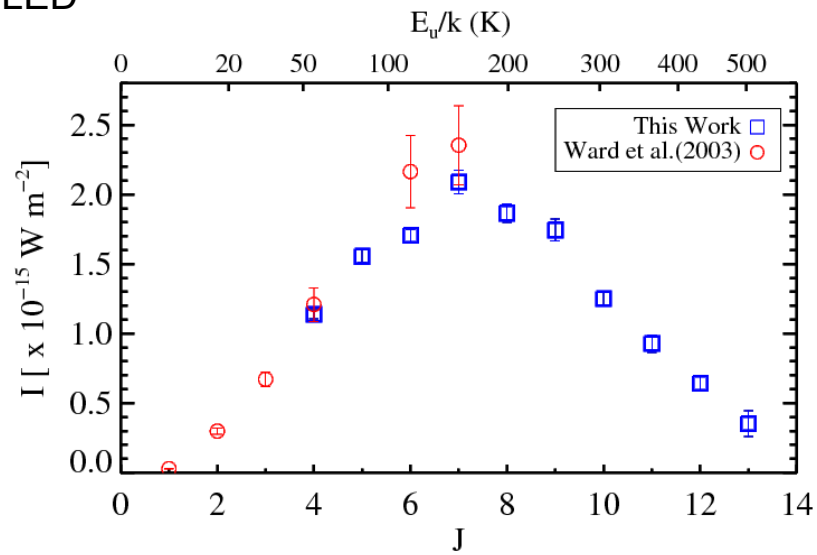


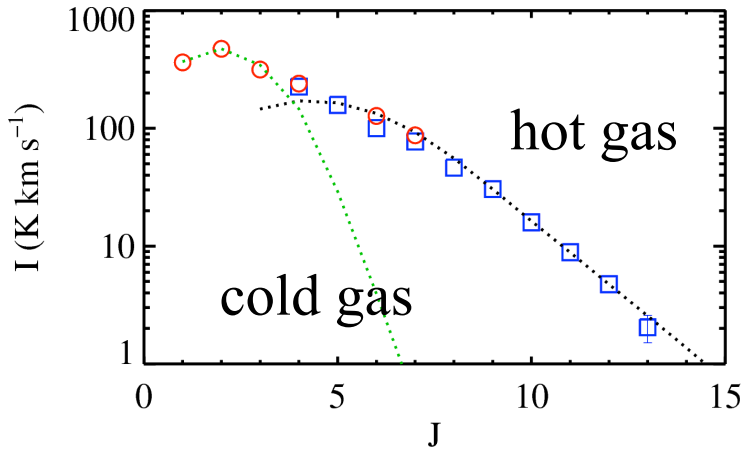


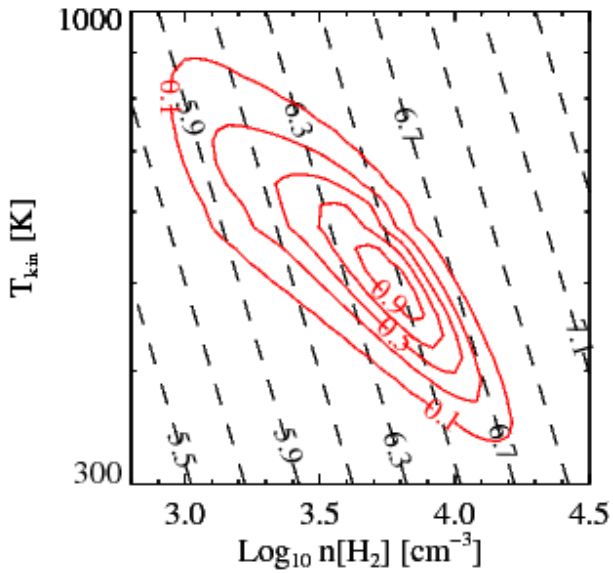
Probing the interstellar medium of M82

M82 ^{12}CO SLED

- The Spectral Line Emission Distribution (SLED) of ^{12}CO peaks at J=7-6
- Low J lines taken from Ward et al (2003) in a similar area
- Only with Herschel we can determine the peak of the SLED

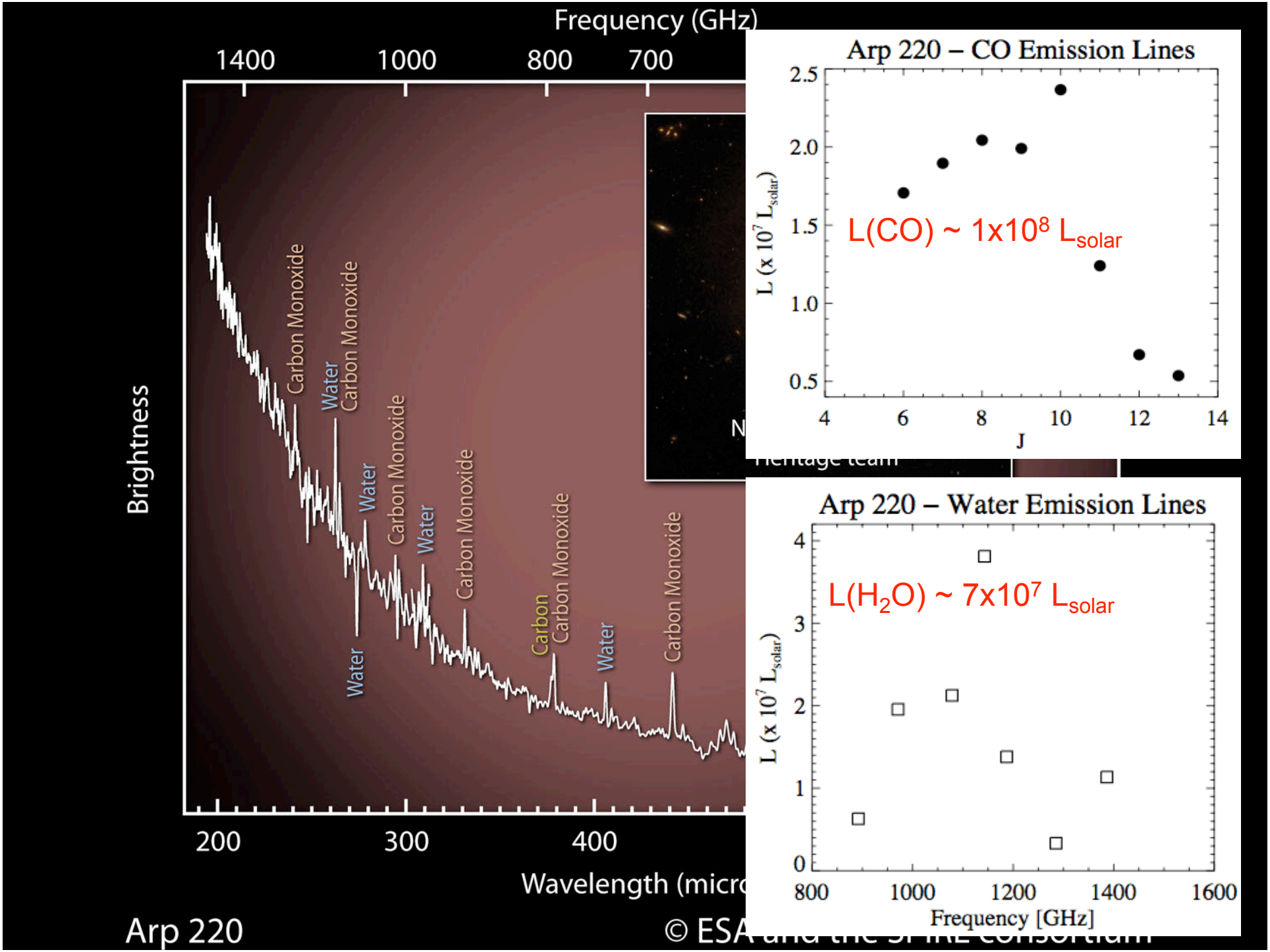






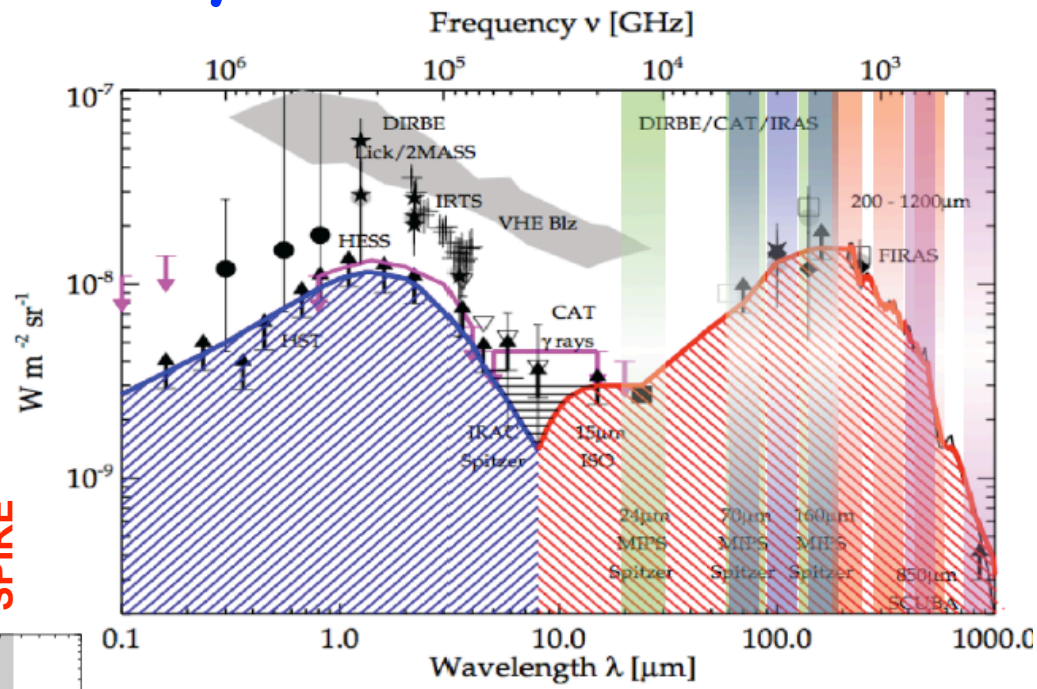
Best-fit model has T=545 K and 1.2x10^7 M_o of warm H_2 gas

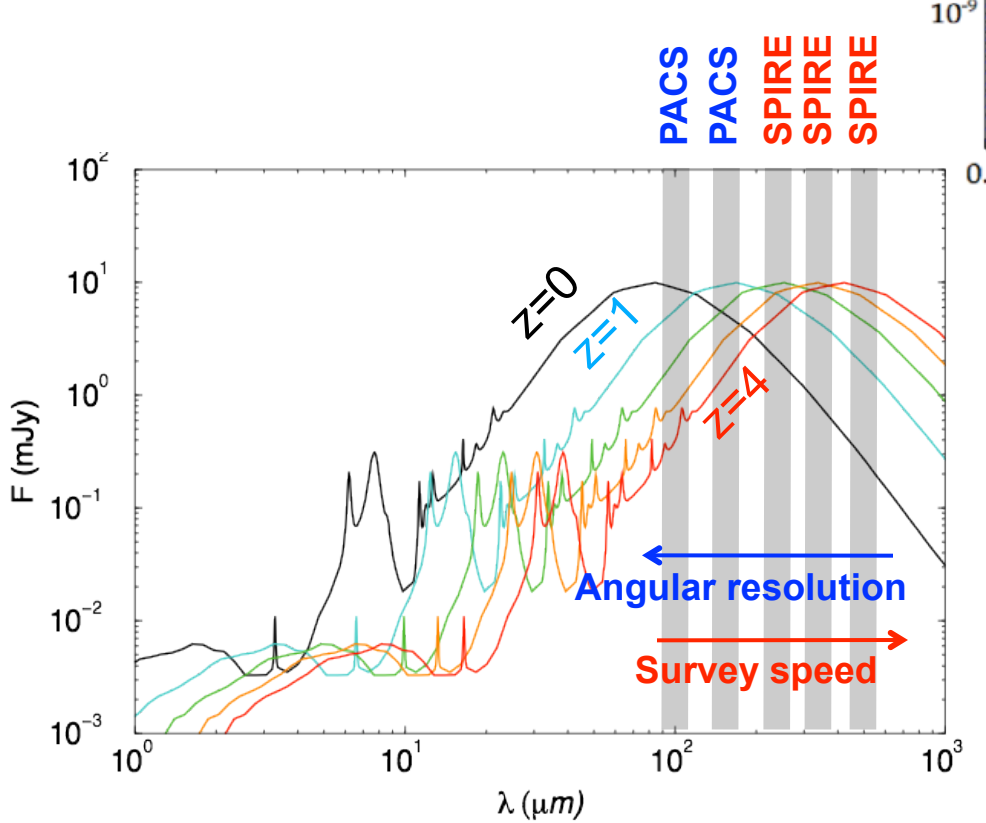
- **What heats gas to 545 K? turbulence, cosmic rays no evidence for an AGN in M82.**


Frequency (GHz)
1400
1000
800
700
Brightness
Carbon Monoxide
Water
Carbon Monoxide
Water
Carbon Monoxide
Water
Carbon Monoxide
Carbon
Carbon Monoxide
Water
Carbon Monoxide
200
300
400
Wavelength (micro
Arp 220
© ESA
Arp 220 – CO Emission Lines
L (x 10^7 L_solar)
L(CO) ~ 1x10^8 L_solar
J
Arp 220 – Water Emission Lines
L(H2O) ~ 7x10^7 L_solar
Frequency [GHz]

Cosmological Surveys with Herschel

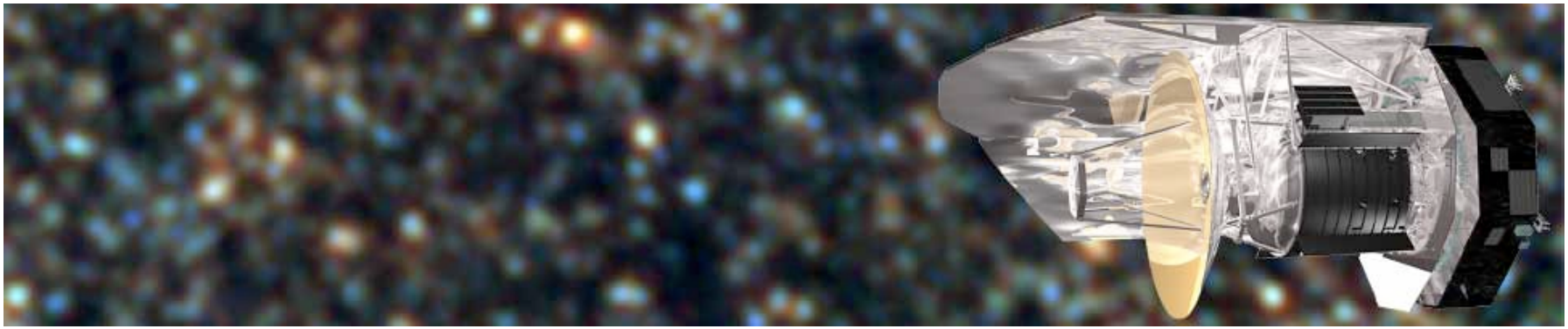
Far-Infrared Galaxy Formation
- History and evolution
- Populations
- Energetics
- Large scale structure





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

SPIRE Instrument team's Extragalactic survey



HERSCHEL MULTI-TIERED EXTRAGALACTIC SURVEY

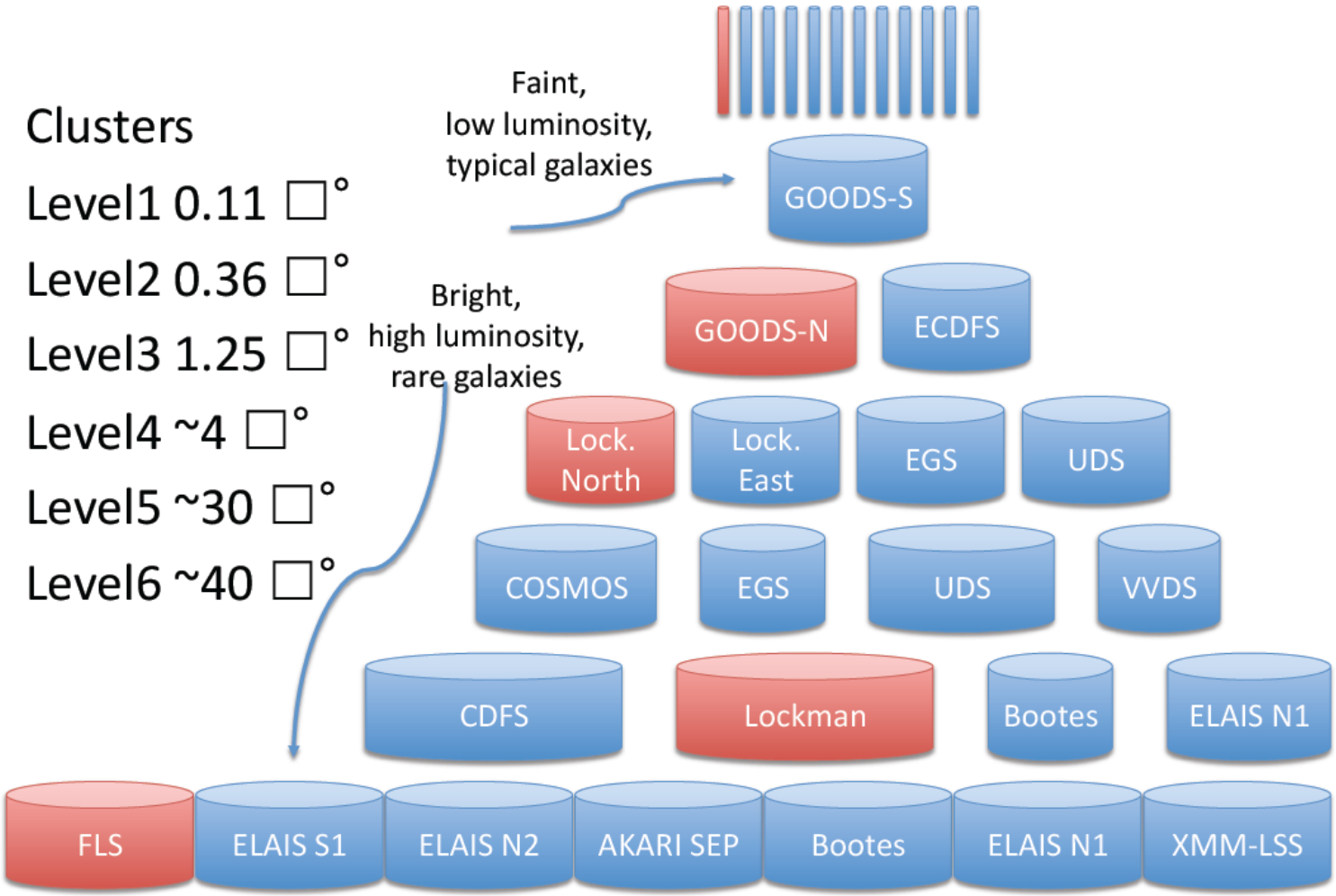
Primary US Institutions: Caltech/JPL; Colorado; UC Irvine

SPIRE GT Program

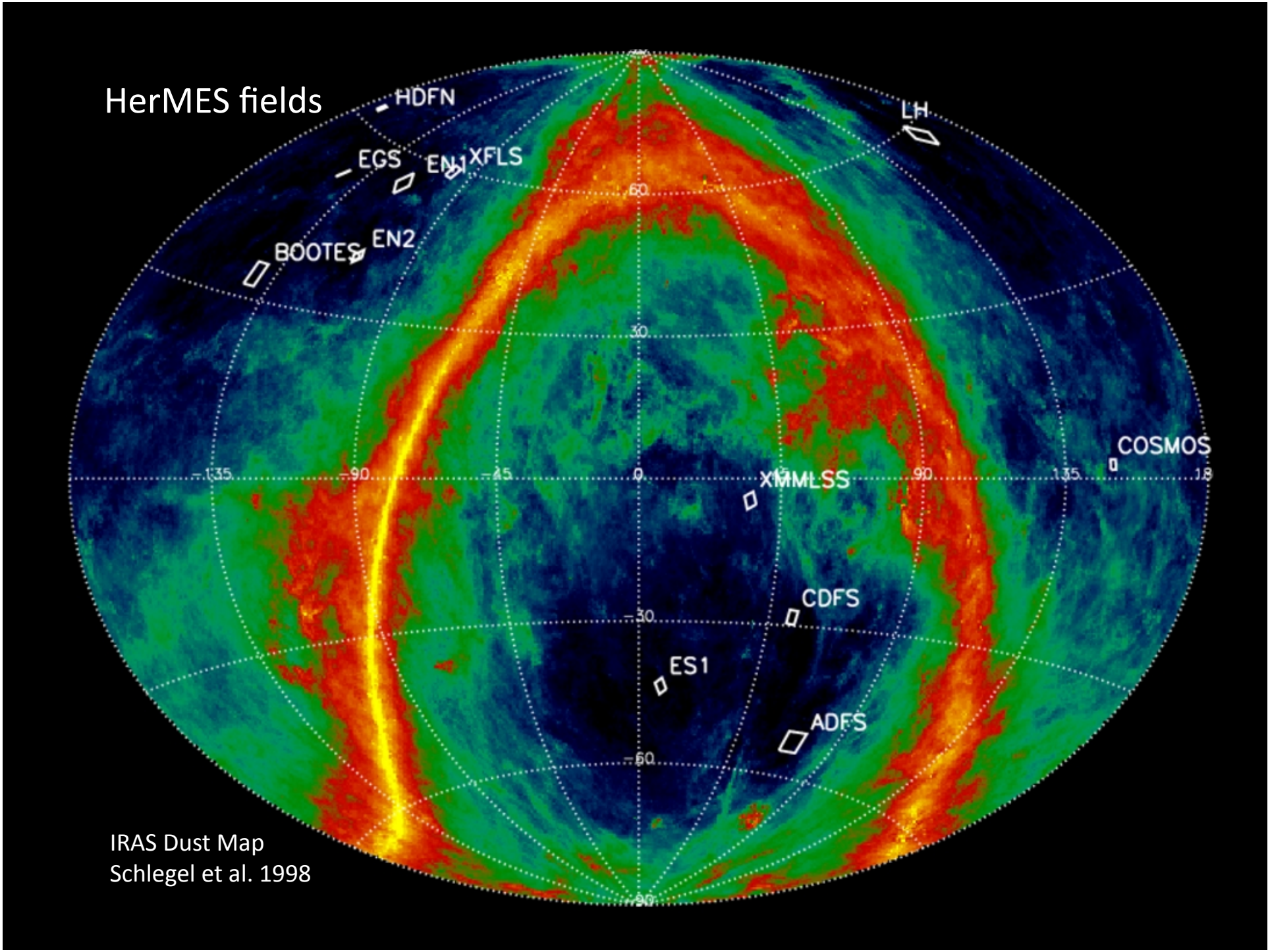
Bruno Altieri, **Alex Amblard,** Vinod Arumugam, Robbie Auld, Herve Aussel, Tom Babbedge, Alexandre Beelen, Matthieu Bethermin, **Andrew Blain, Jamie Bock,** Alessandro Boselli, **Carrie Bridge,** Drew Brisbin, Veroniquw Buat, Denis Burgarella, Nieves Castro-Rodriguez, Antonio Cava, Pierre Chanial, Ed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

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

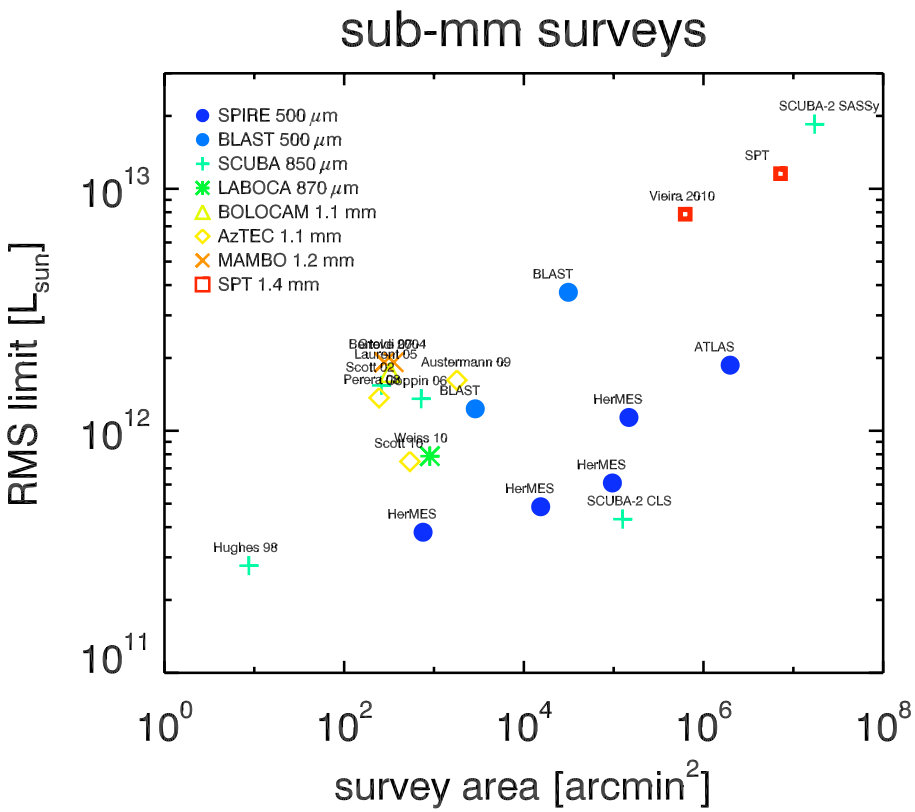
HERMES

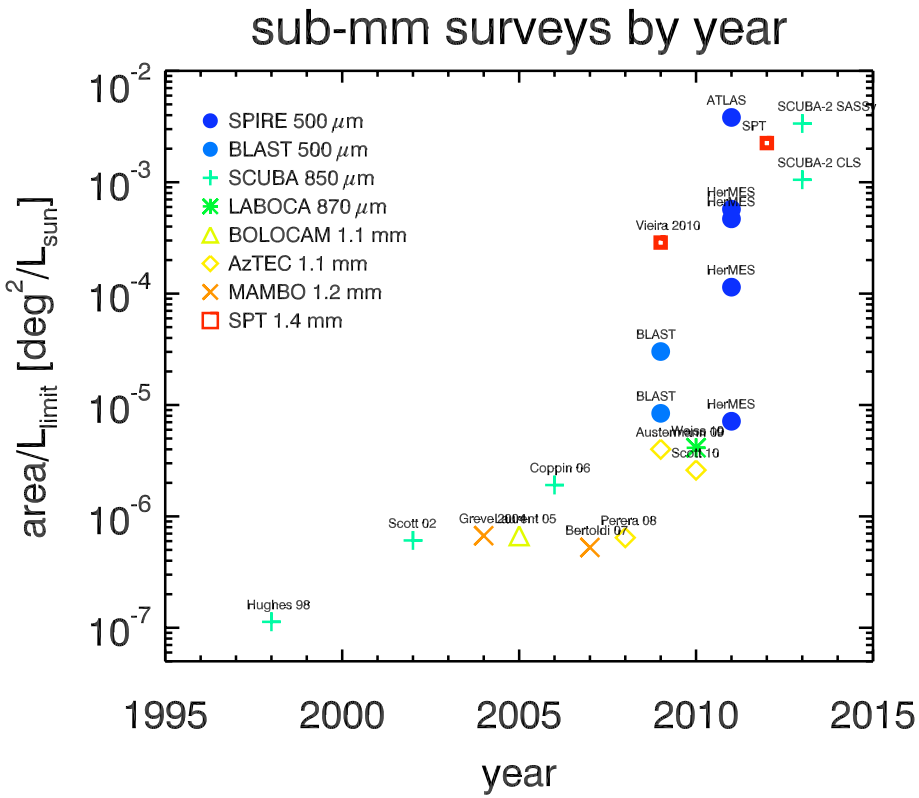


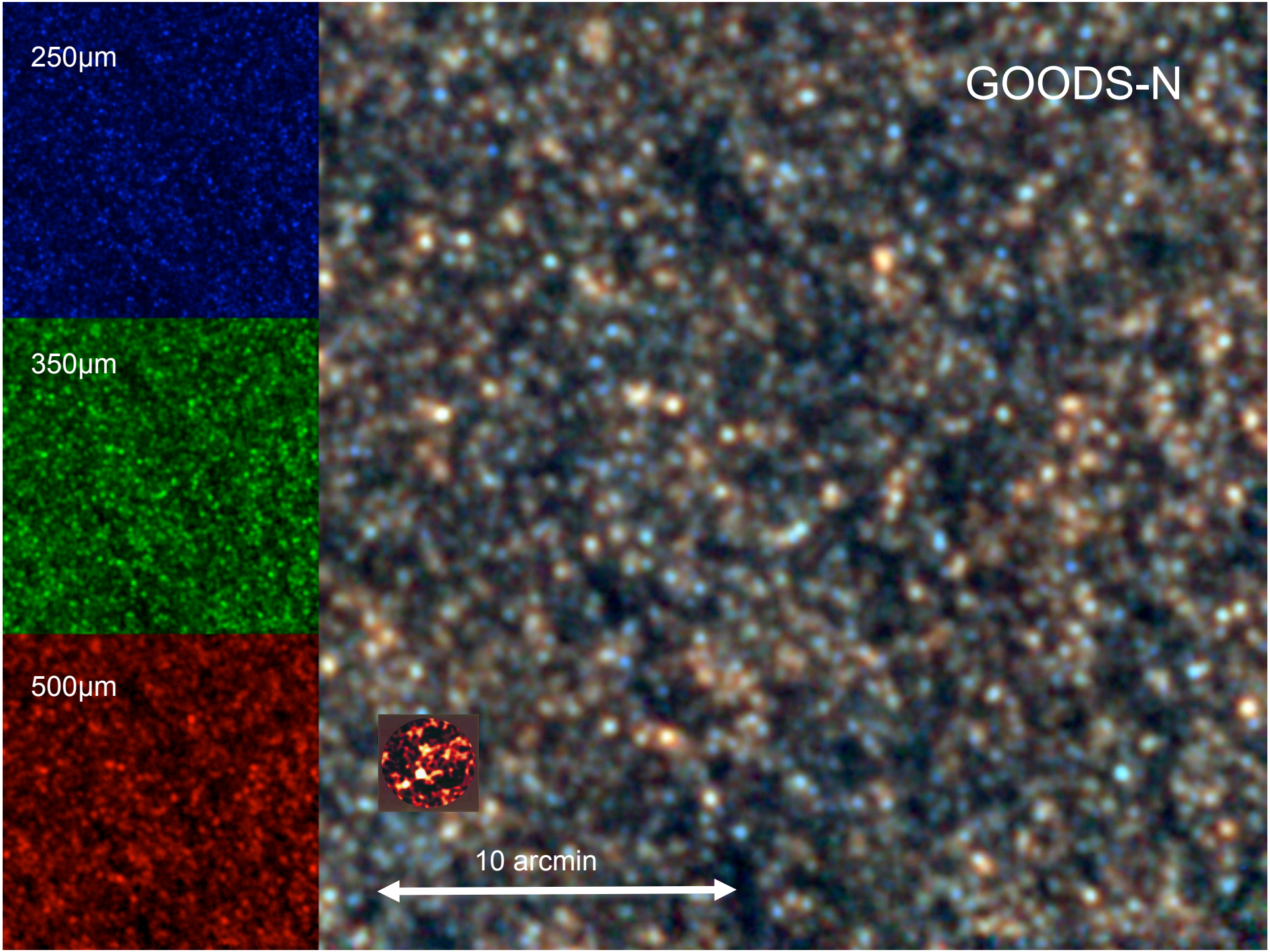
Science Demonstration Phase: 7 % of our total time
27,000 sources > 20 mJy @ 250 um
9 A&A papers + ~ 40 MNRAS papers in press/prep


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

Sub-mm Surveys

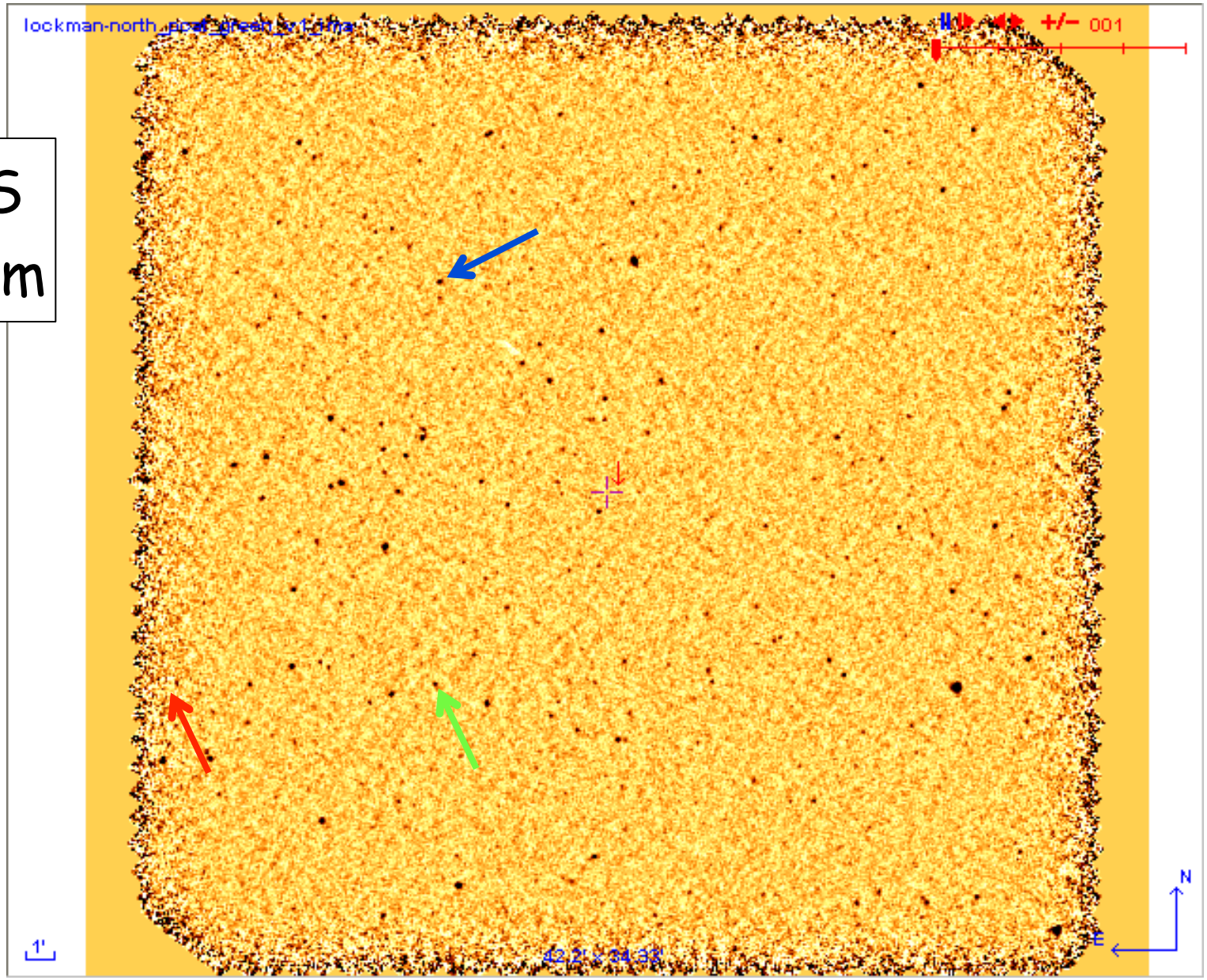





250μm
350μm
500μm
GOODS-N
10 arcmin

Finding Sources in Maps

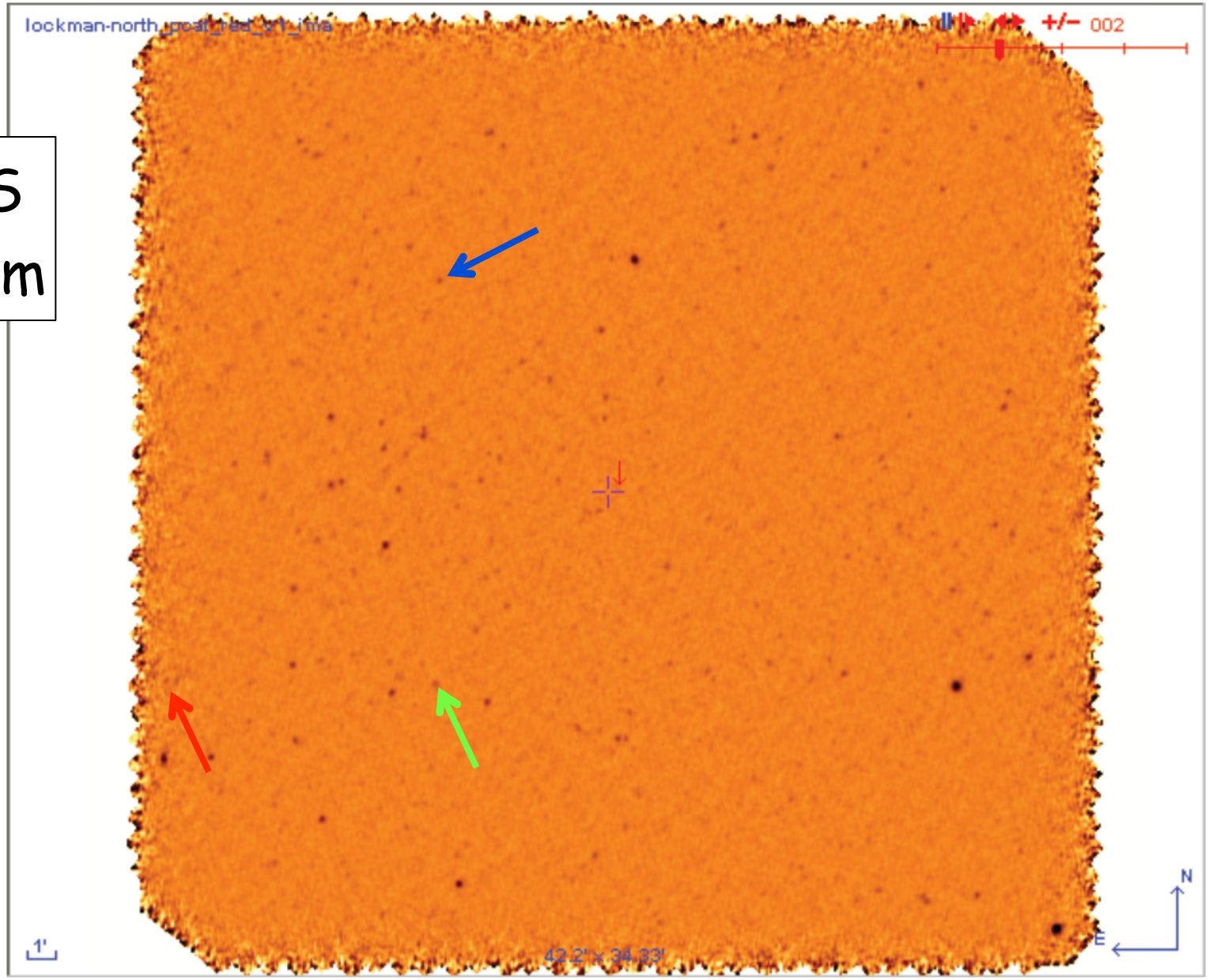
PACS
100 μm



I. Perez-Fournon

Finding Sources in Maps

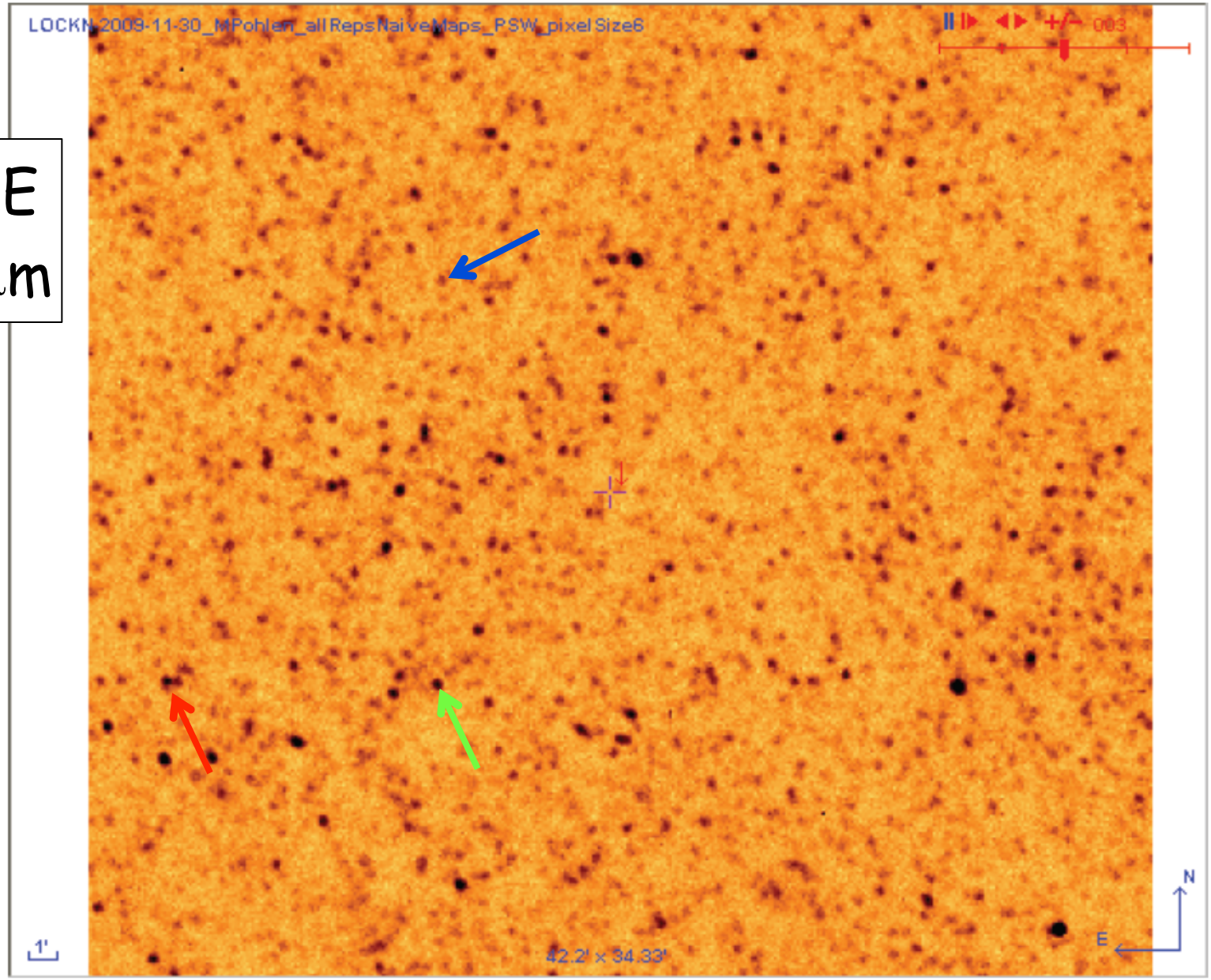
PACS
160 μm



I. Perez-Fournon

Finding Sources in Maps

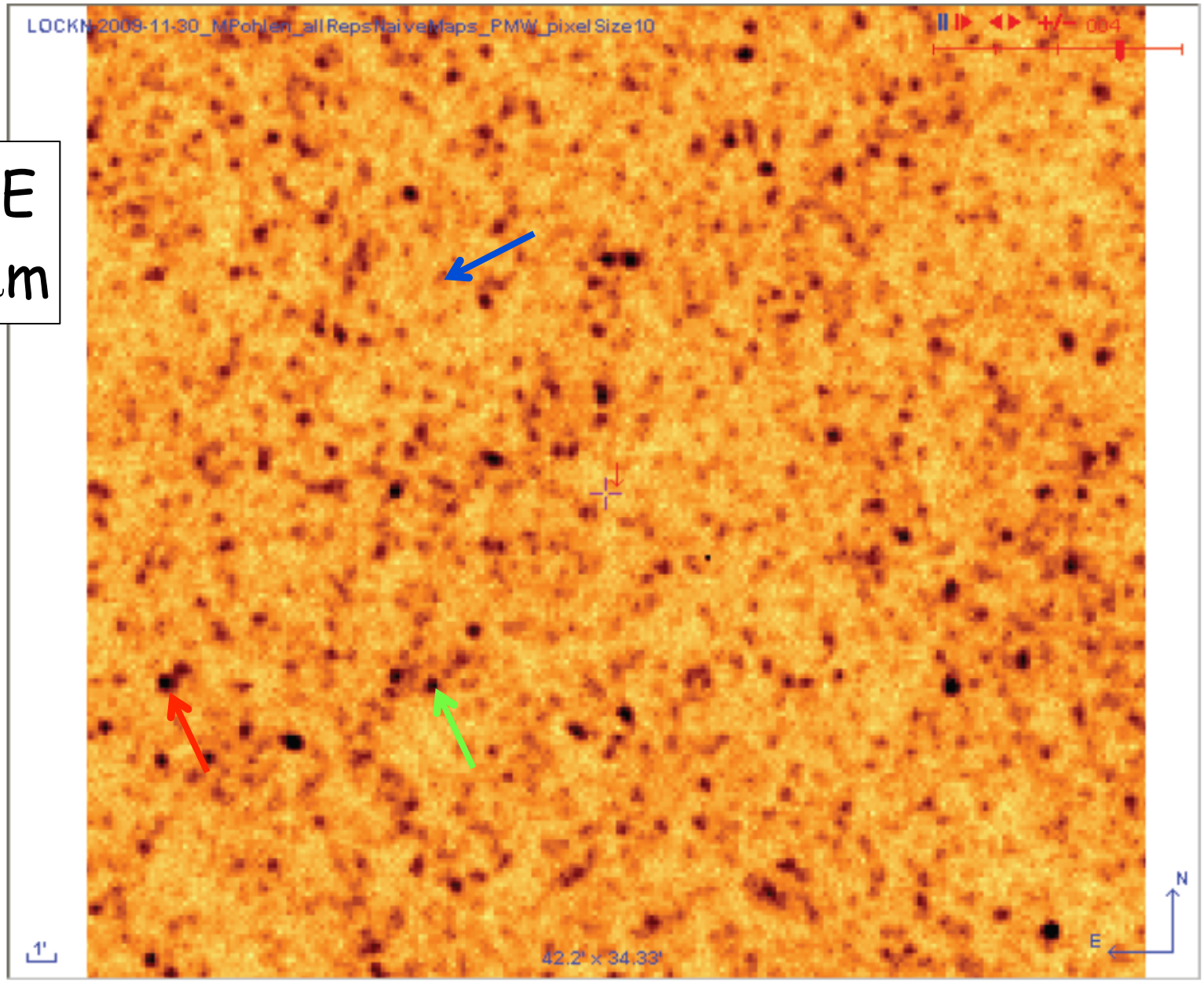
SPIRE
250 μm



I. Perez-Fournon

Finding Sources in Maps

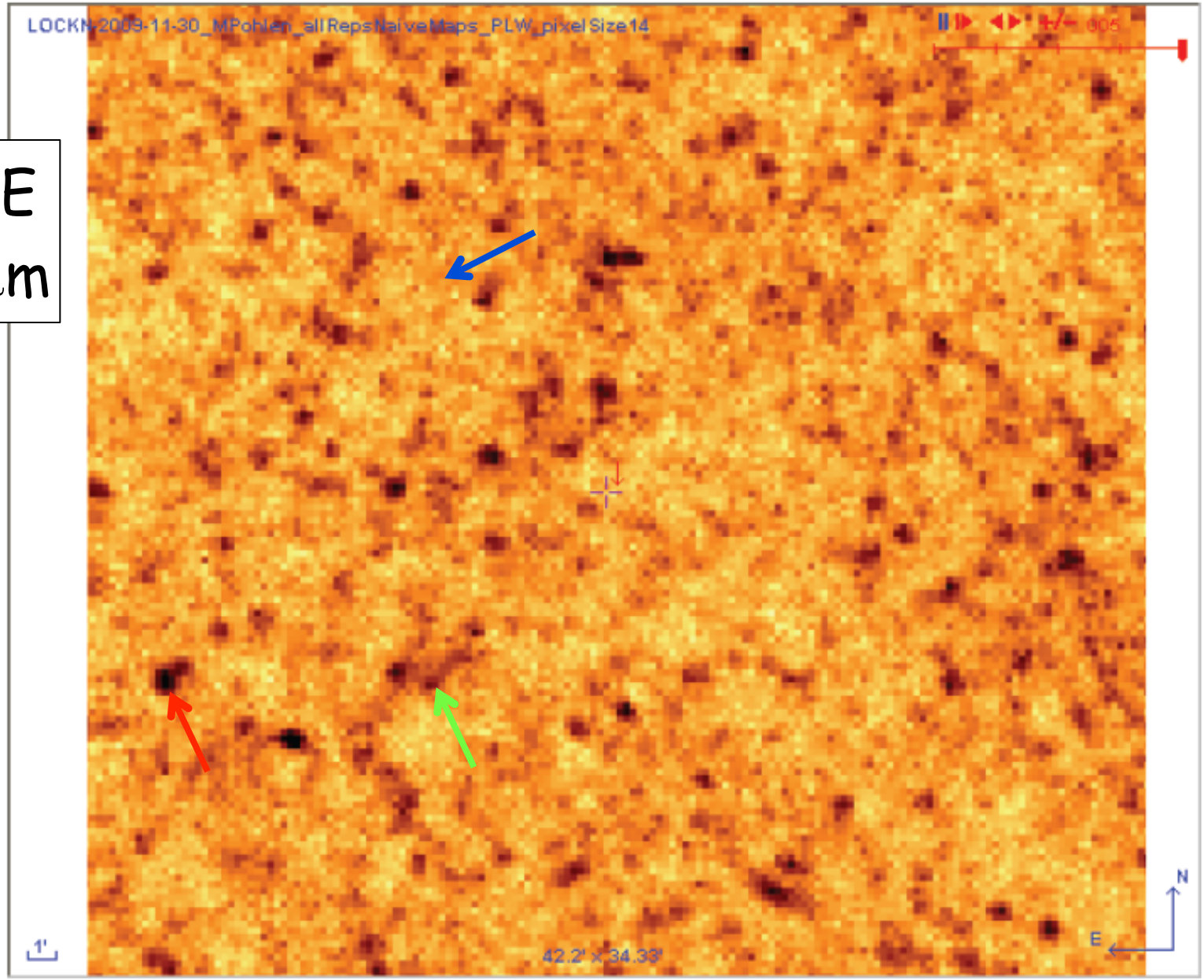
SPIRE
350 μm



I. Perez-Fournon

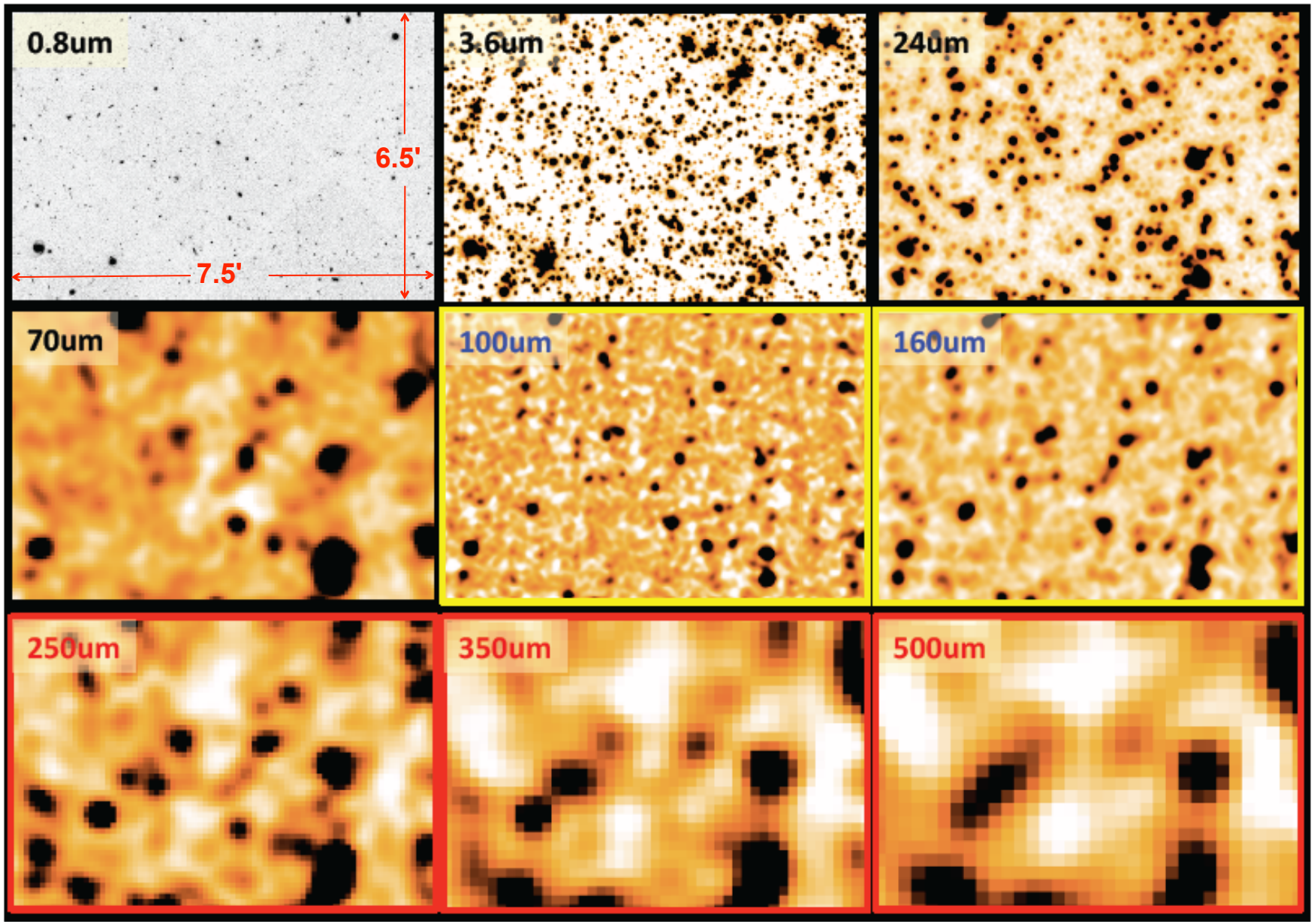
Finding Sources in Maps

SPIRE
500 μm

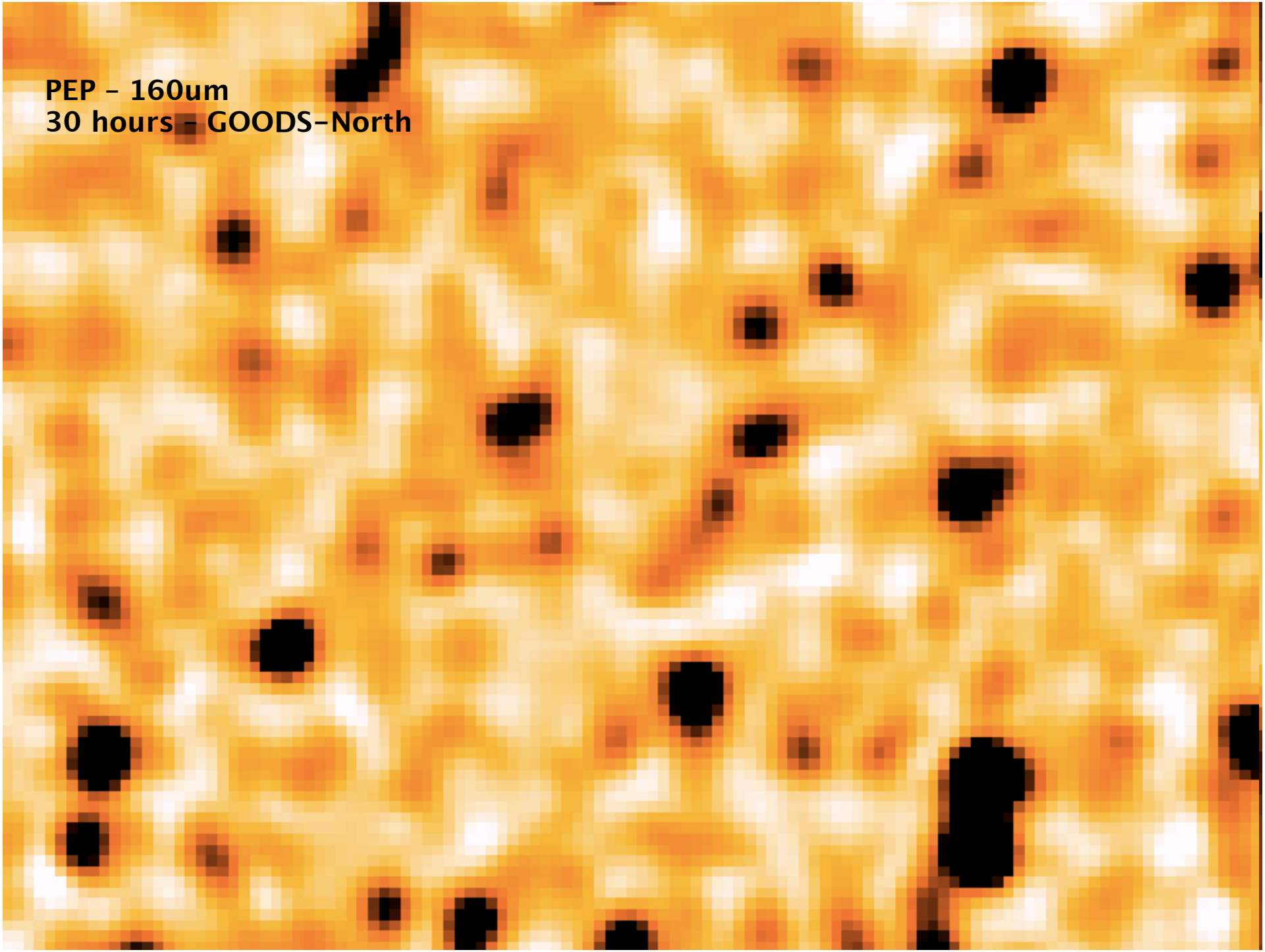


I. Perez-Fournon

The Confusion Challenge



D. Elbaz


PEP - 160um
30 hours - GOODS-North

Three Ways to Deal with Confusion

Herschel Source Photometry

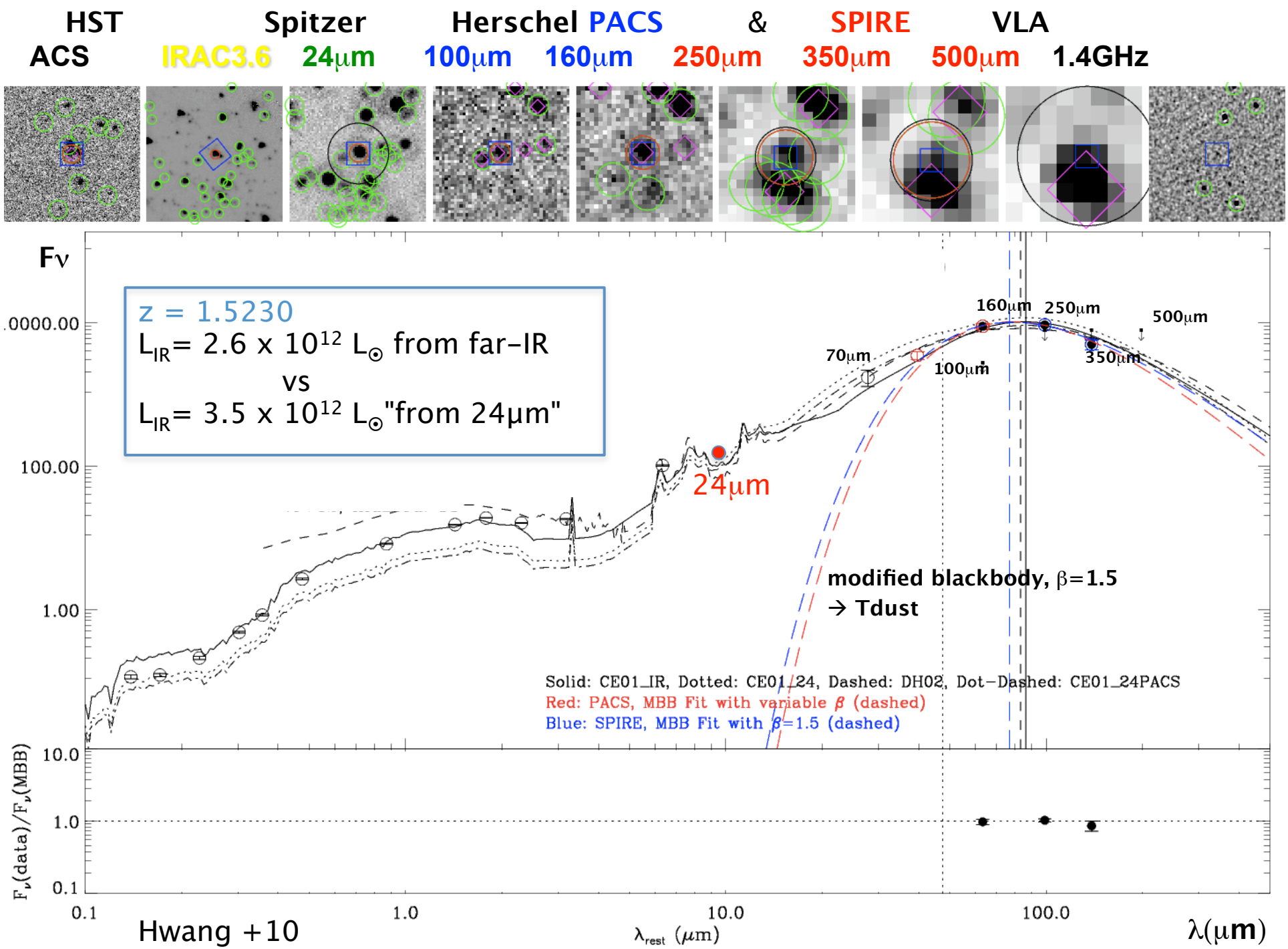
- Need to be careful about bias (sources on background peaks)
- Blending of multiple sources, especially at 500 um
- Blind follow-up in large beam is laborious (~SCUBA)
- However these are the most interesting source populations!

Pre-Existing Source Catalogs

- Assign source flux from Herschel maps
- Reliable to within confusion noise
- Choose fields with comprehensive ancillary coverage
- Follows bias inherent in finder catalog

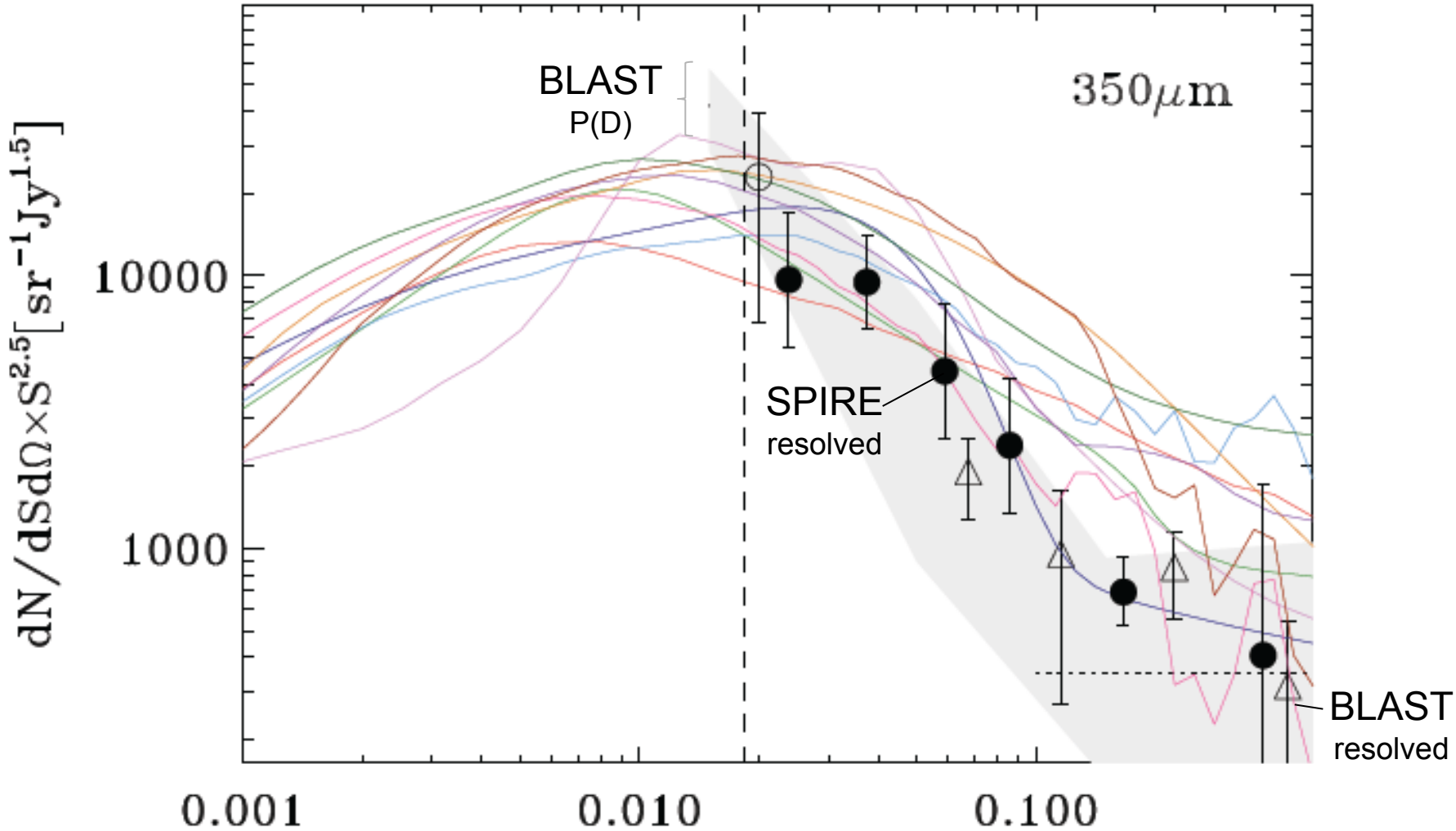
Map-Based Analysis

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


HST
ACS
Spitzer
IRAC3.6
24μm
Herschel PACS & SPIRE
100μm
160μm
250μm
350μm
500μm
VLA
1.4GHz
Fν
z = 1.5230
L_IR= 2.6 x 10^12 L_⊙ from far-IR
vs
L_IR= 3.5 x 10^12 L_⊙"from 24μm"
70μm
100μm
160μm
250μm
350μm
500μm
24μm
modified blackbody, β=1.5
→ Tdust
Solid: CE01_IR, Dotted: CE01_24, Dashed: DH02, Dot-Dashed: CE01_24PACS
Red: PACS, MBB Fit with variable β (dashed)
Blue: SPIRE, MBB Fit with β=1.5 (dashed)
F_ν(data)/F_ν(MBB)
λ_rest (μm)
λ(μm)

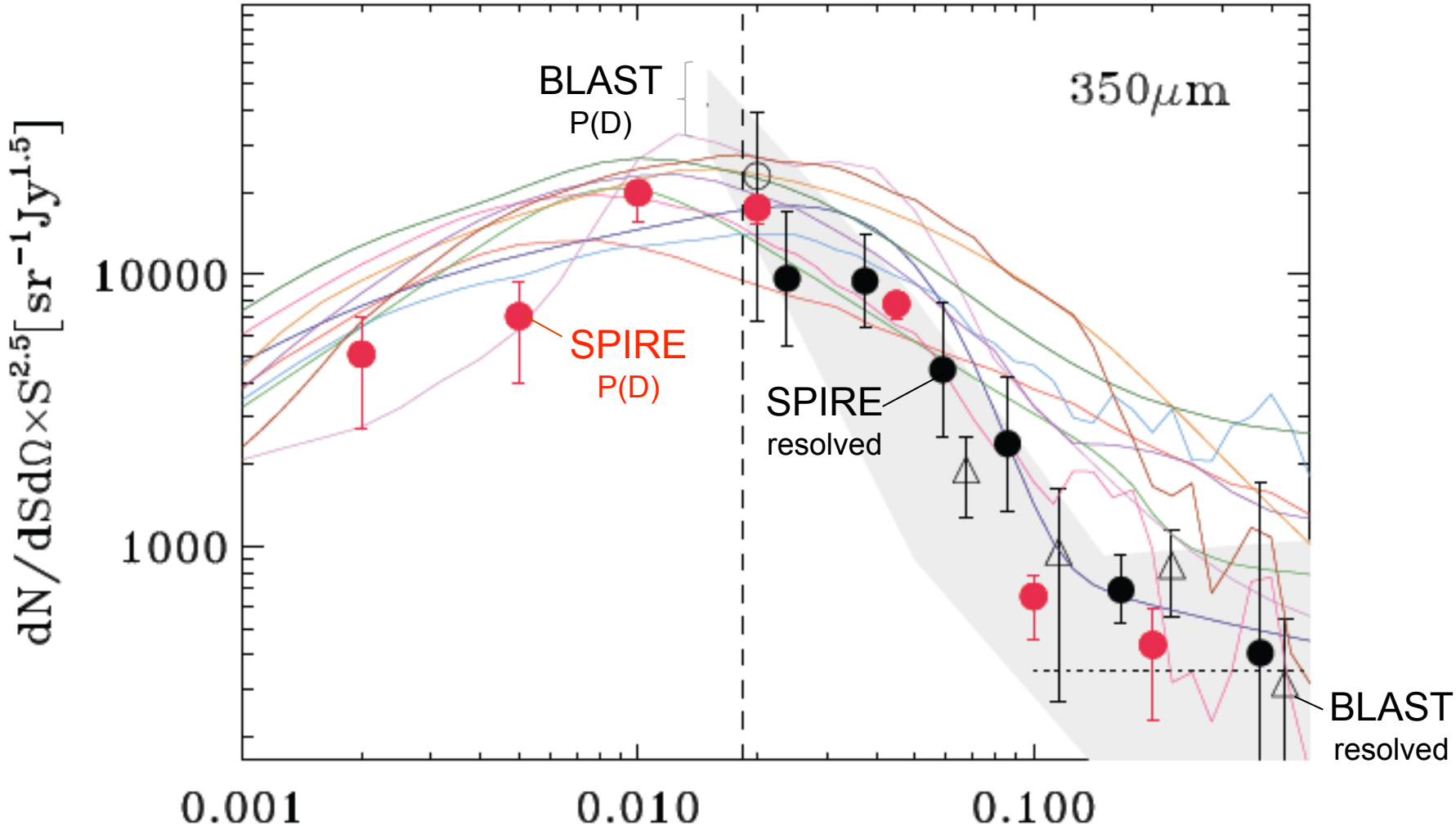
Hwang +10

SPIRE Source Counts



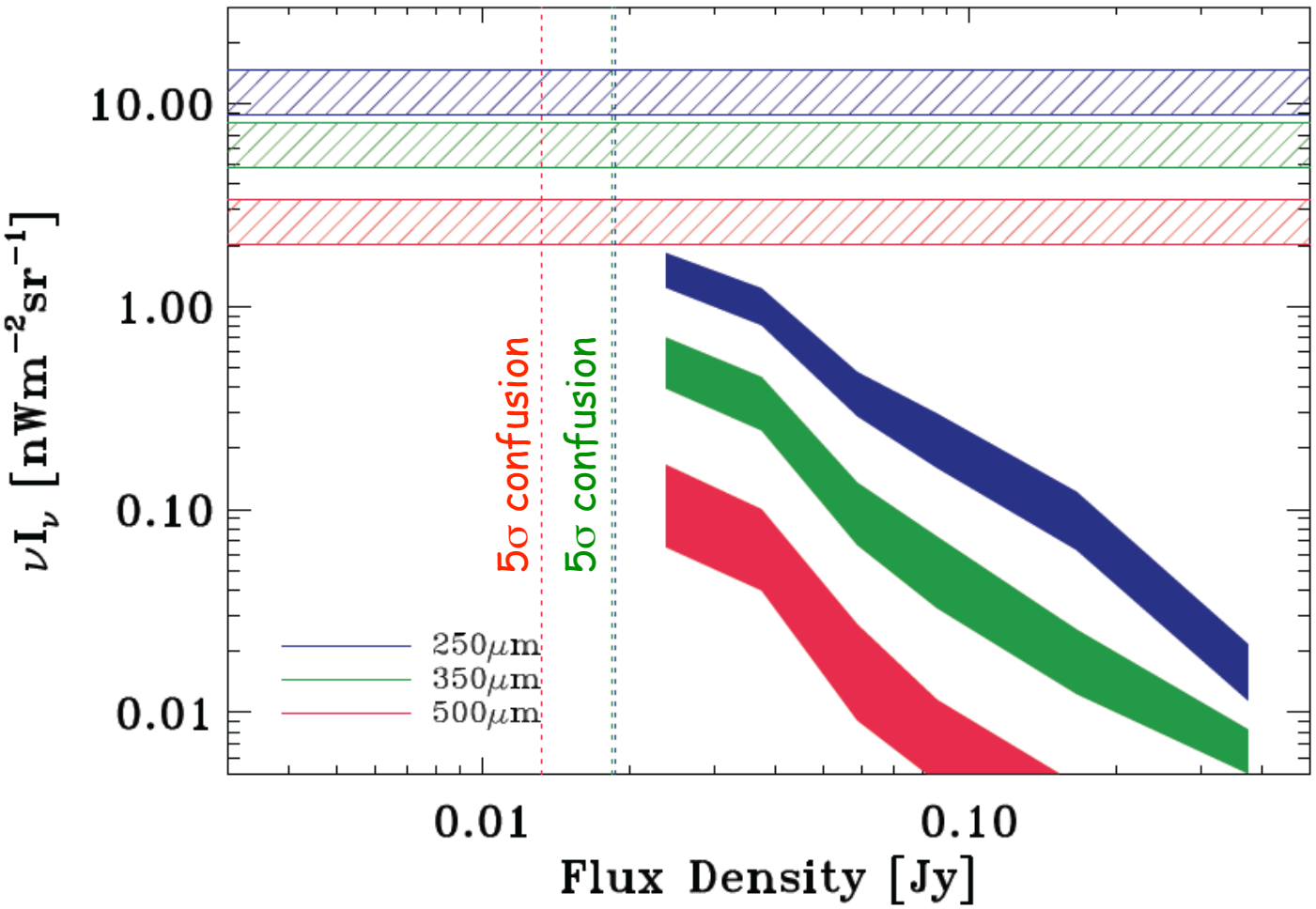
Oliver et al. 2010 A&A

SPIRE Source Counts



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

Resolving the FIR Background

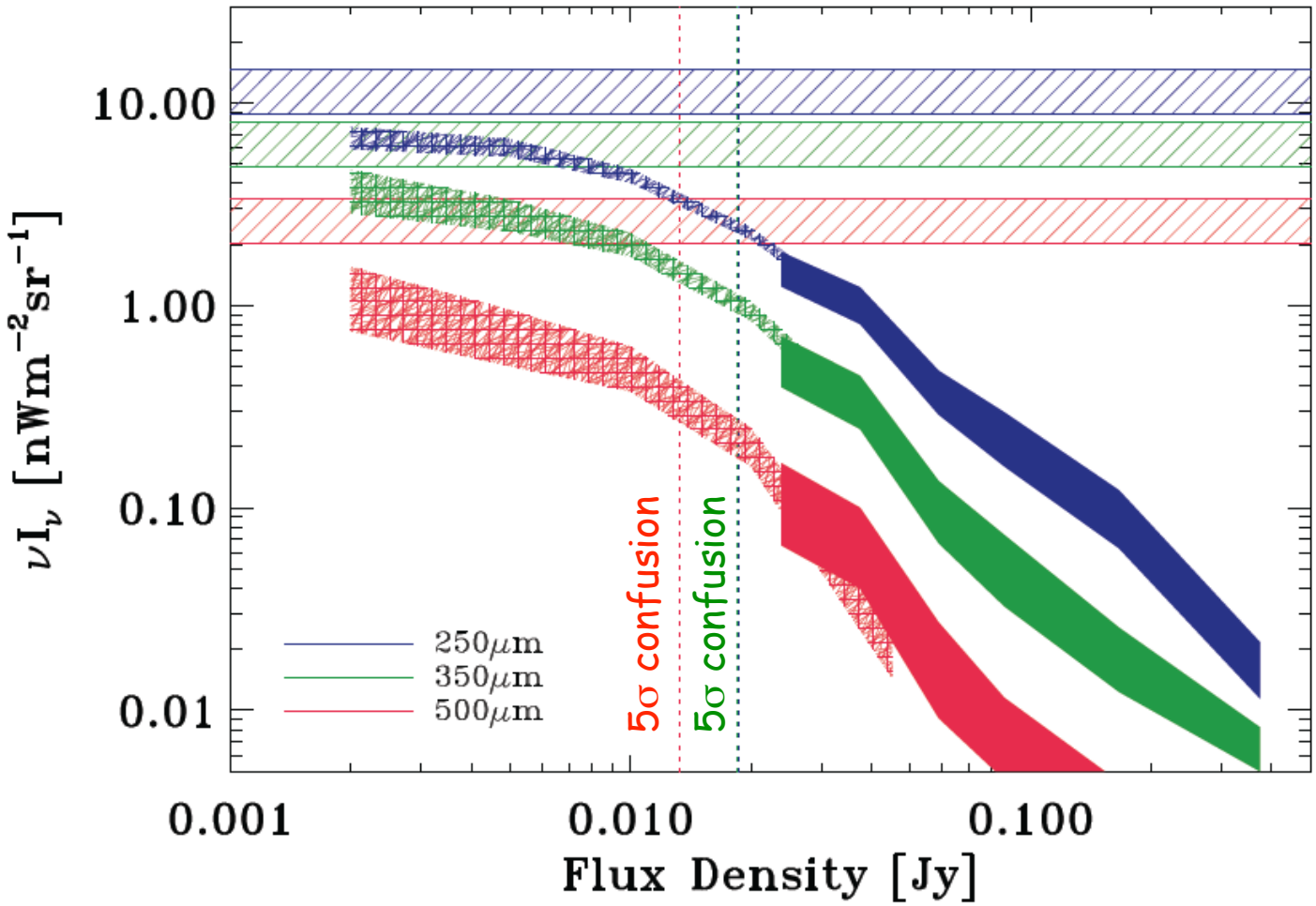


- **Source Counts**

250, 350, 500 μm

15%, 10%, 6%

Resolving the FIR Background

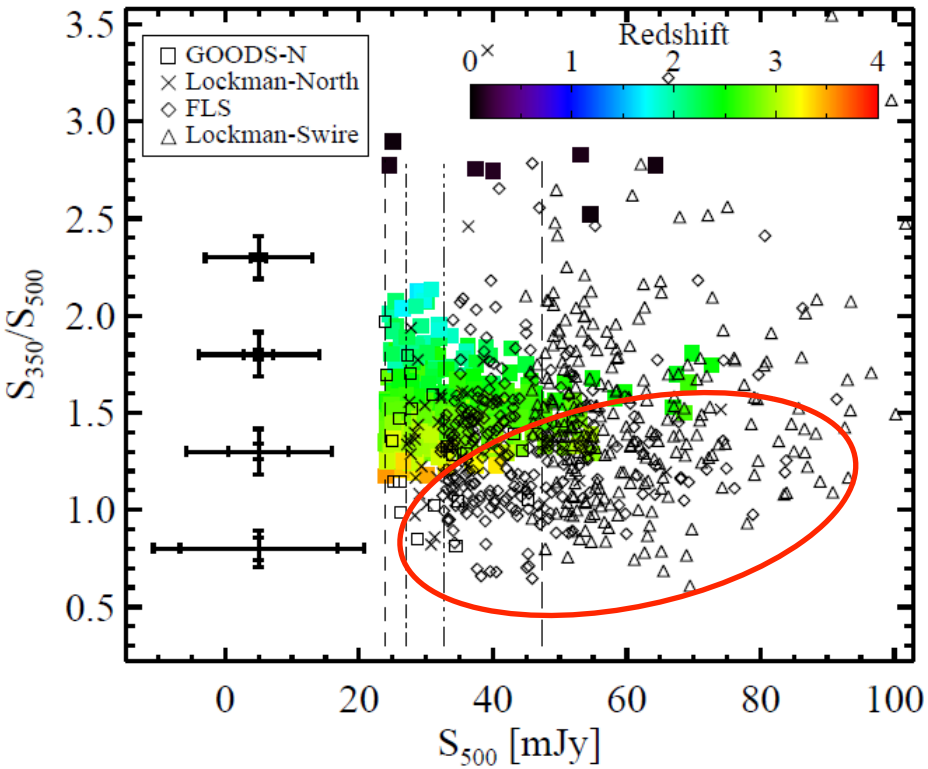


- **Source Counts**
  250, 350, 500 μm
  15%, 10%, 6%
- **P(D)**
  250, 350, 500 μm
  65%, 60%, 45%
- **Stacking**
  250, 350, 500 μm
  80%, 80%, 85%

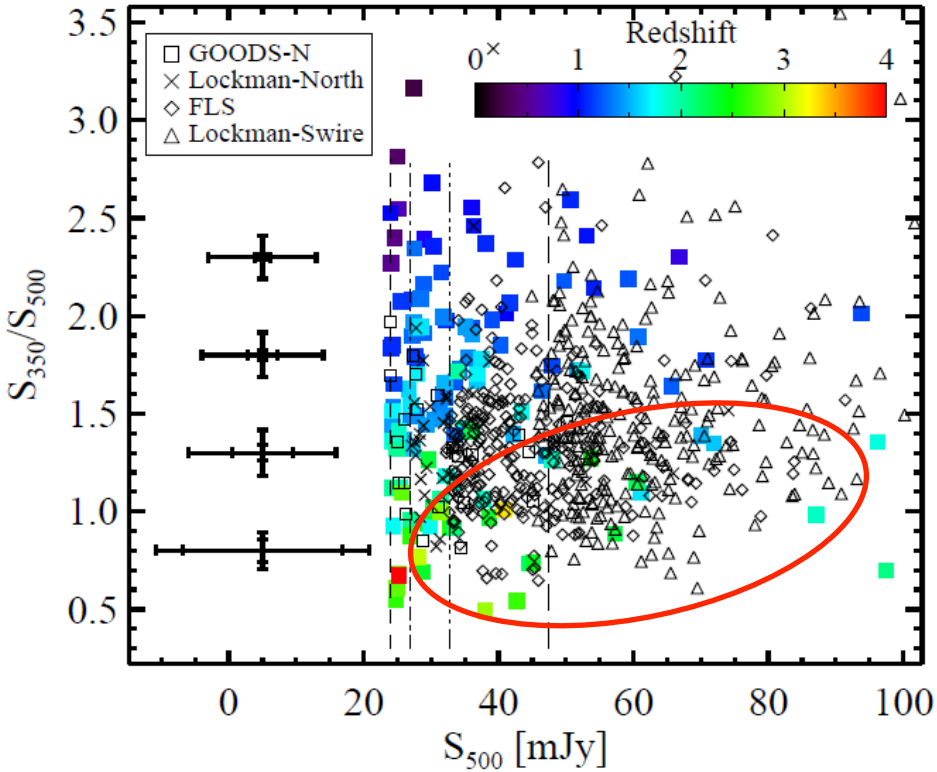
<u>Of course</u>: The remainder may be the most interesting sources!
E.g. the z > 3 galaxy population.

SPIRE Galaxy Colors

Results Compared to Pearson Model



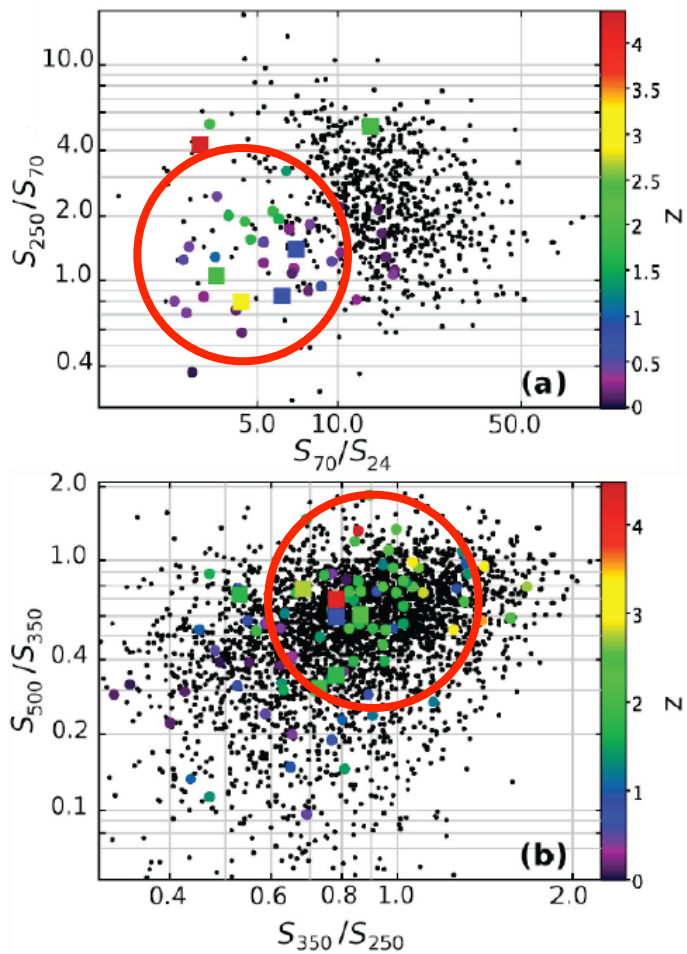
Results Compared to Xu Model



Schulz et al. 2010

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

AGNs and Far-IR Galaxies



E. Hatziminaoglou, 2010
J. Stevens, 2010

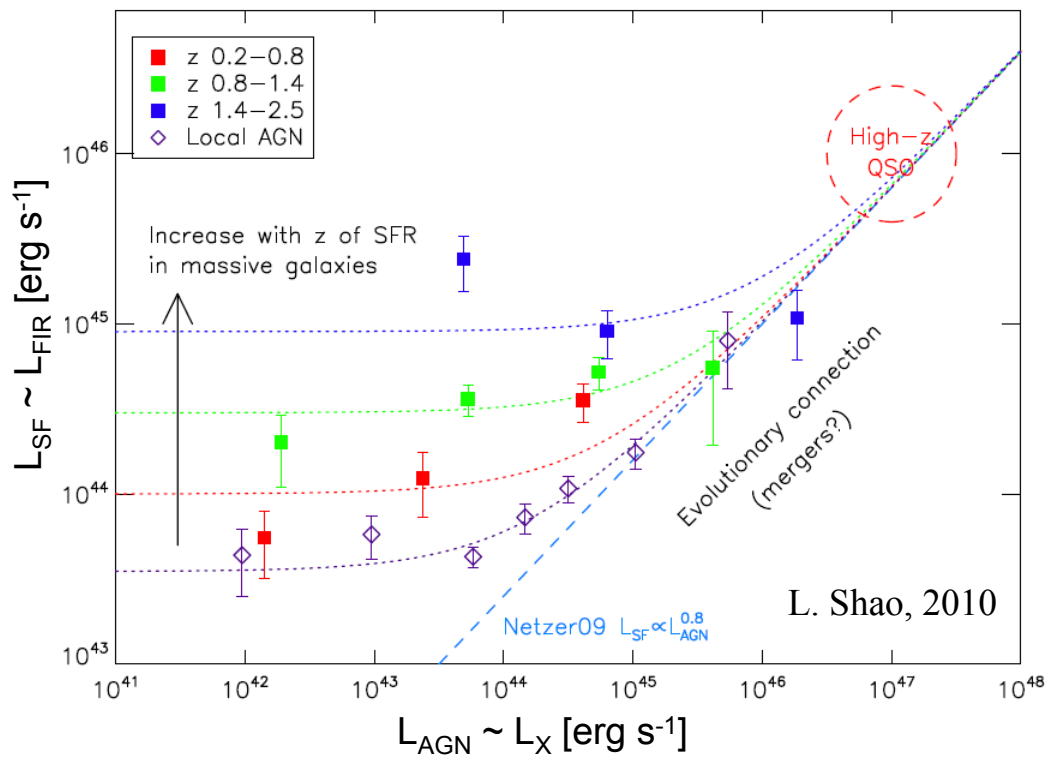
Distinct S_{70}/S_{24} colors, but not $S_{250}/S_{350}/S_{500}$

- FIR emission due to star formation

Higher FIR luminosity of Type 2s

- Inconsistent with unified AGN torus model
- Type 2 AGN associated with enhanced SF?

Two Modes of Host & AGN Evolution?



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

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

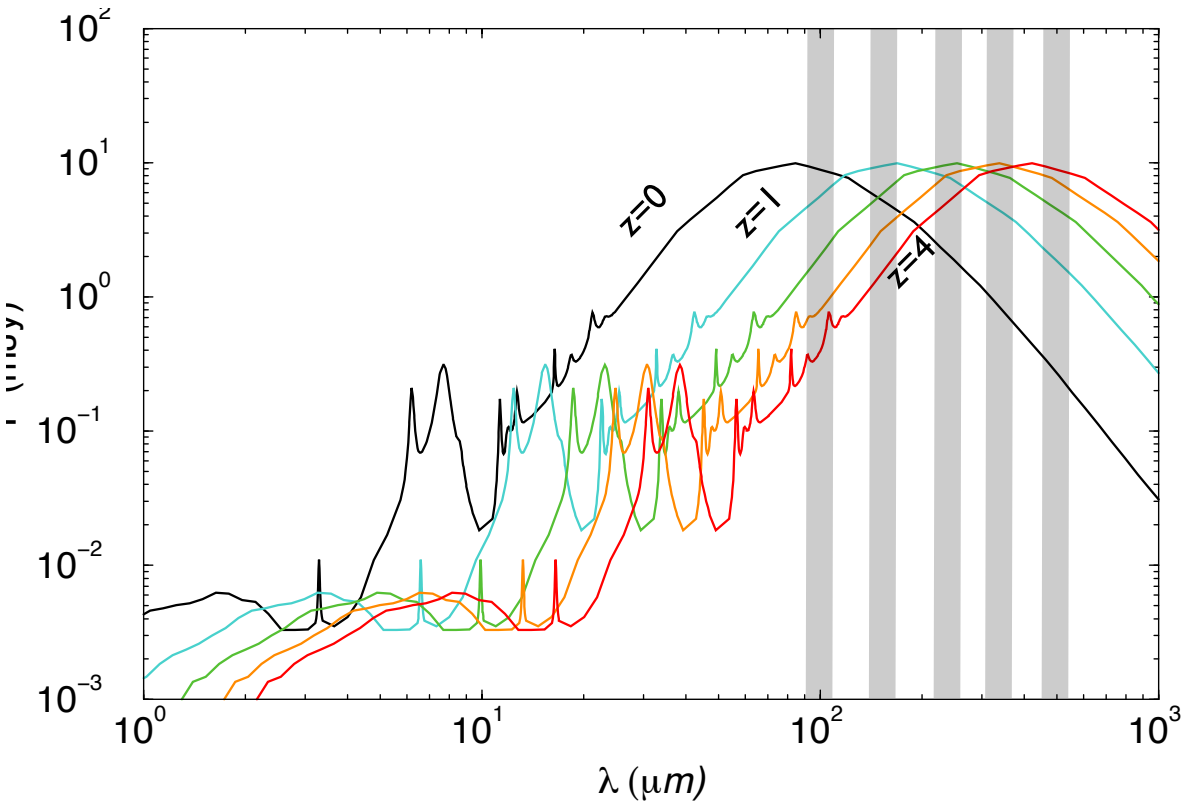
High L_{AGN}: Related to L_{SF}

- Trend is weaker
- Luminosities coupled by mergers?

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

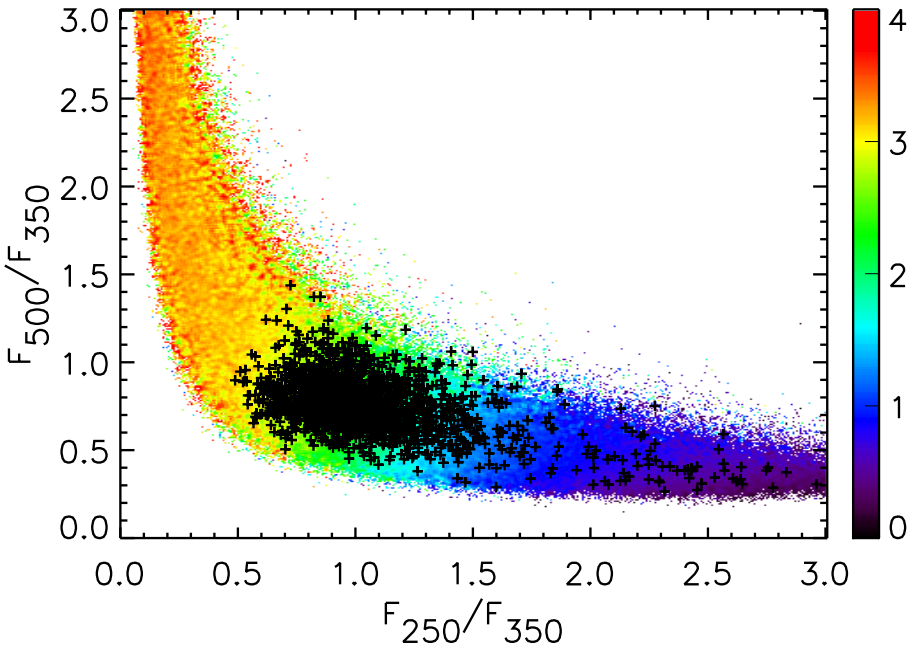
$S_{250} > S_{350} > S_{500}$: z < 2

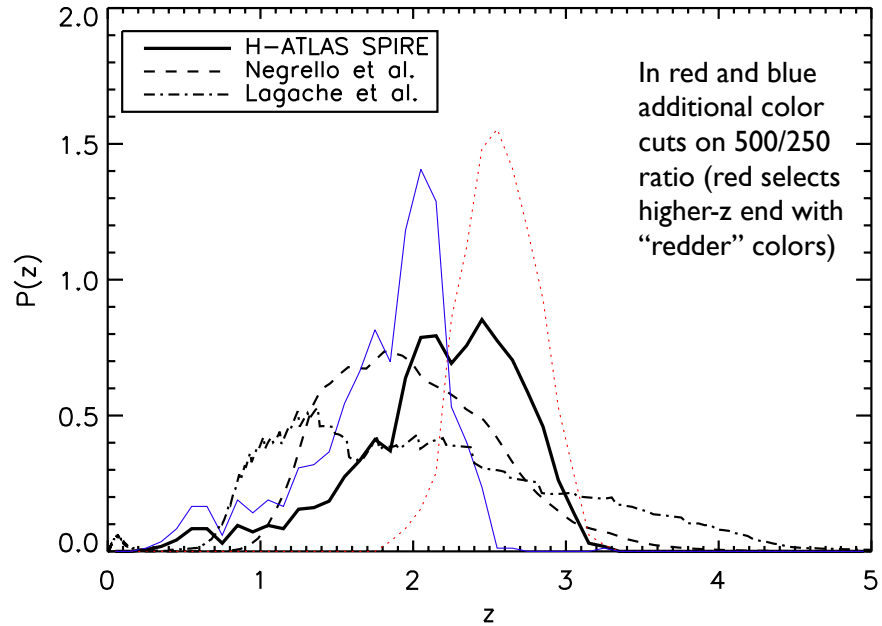
$S_{250} <\sim S_{350} > S_{500}$: z ~ 2 to 3

$S_{250} < S_{350} < S_{500}$: 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?

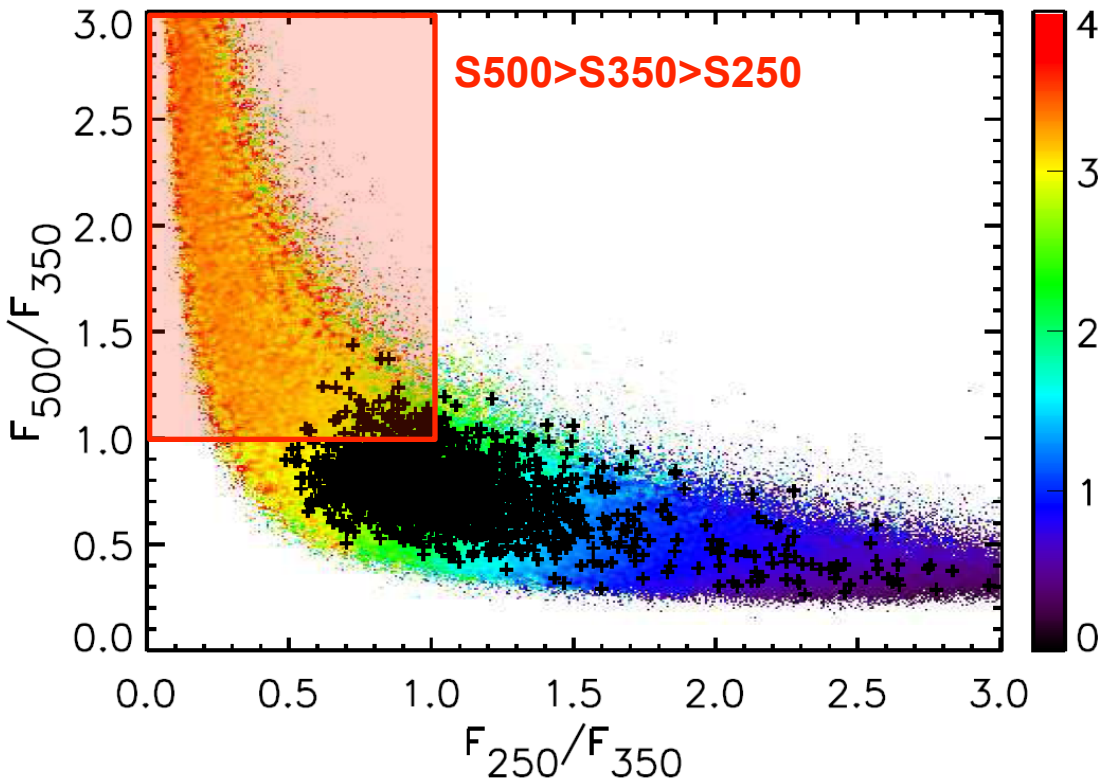
H-ATLAS:

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.

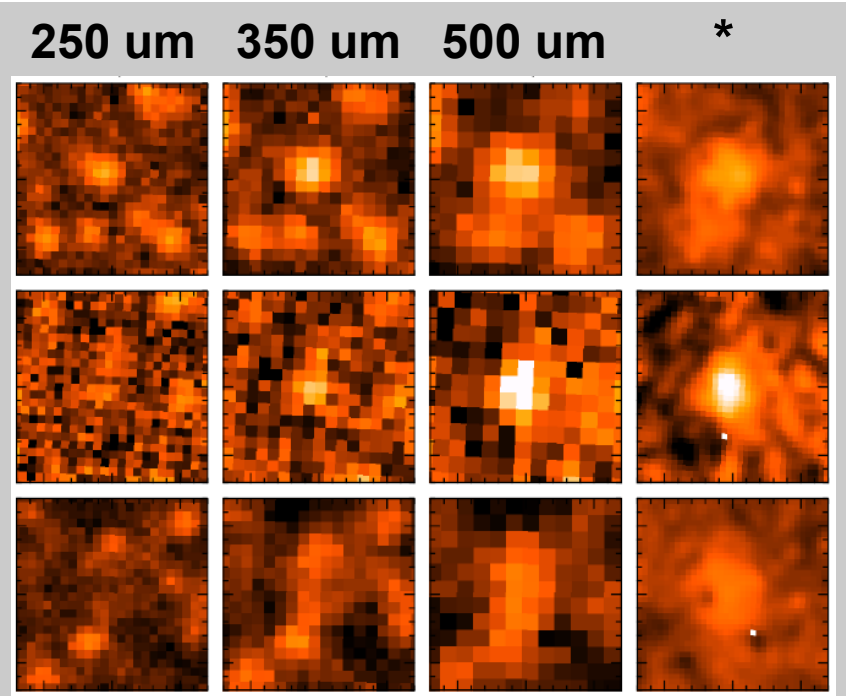
CO-line redshifts?

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?

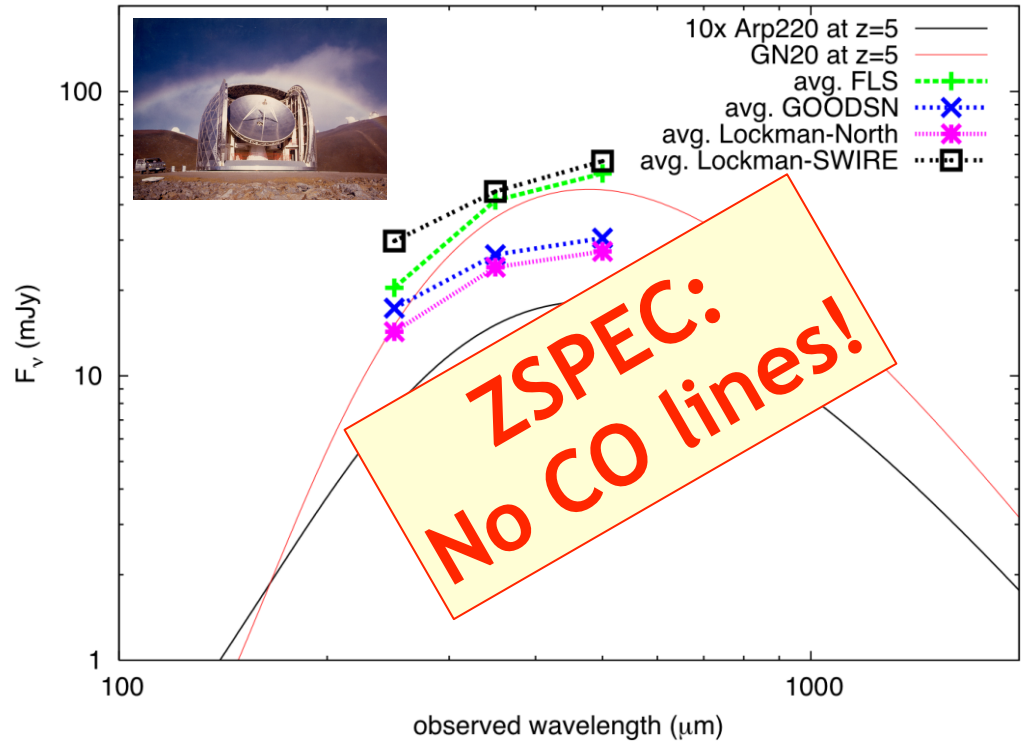
500 um peaked sources

Three examples:



***Confusion reduced S(500) – fS(250)**

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

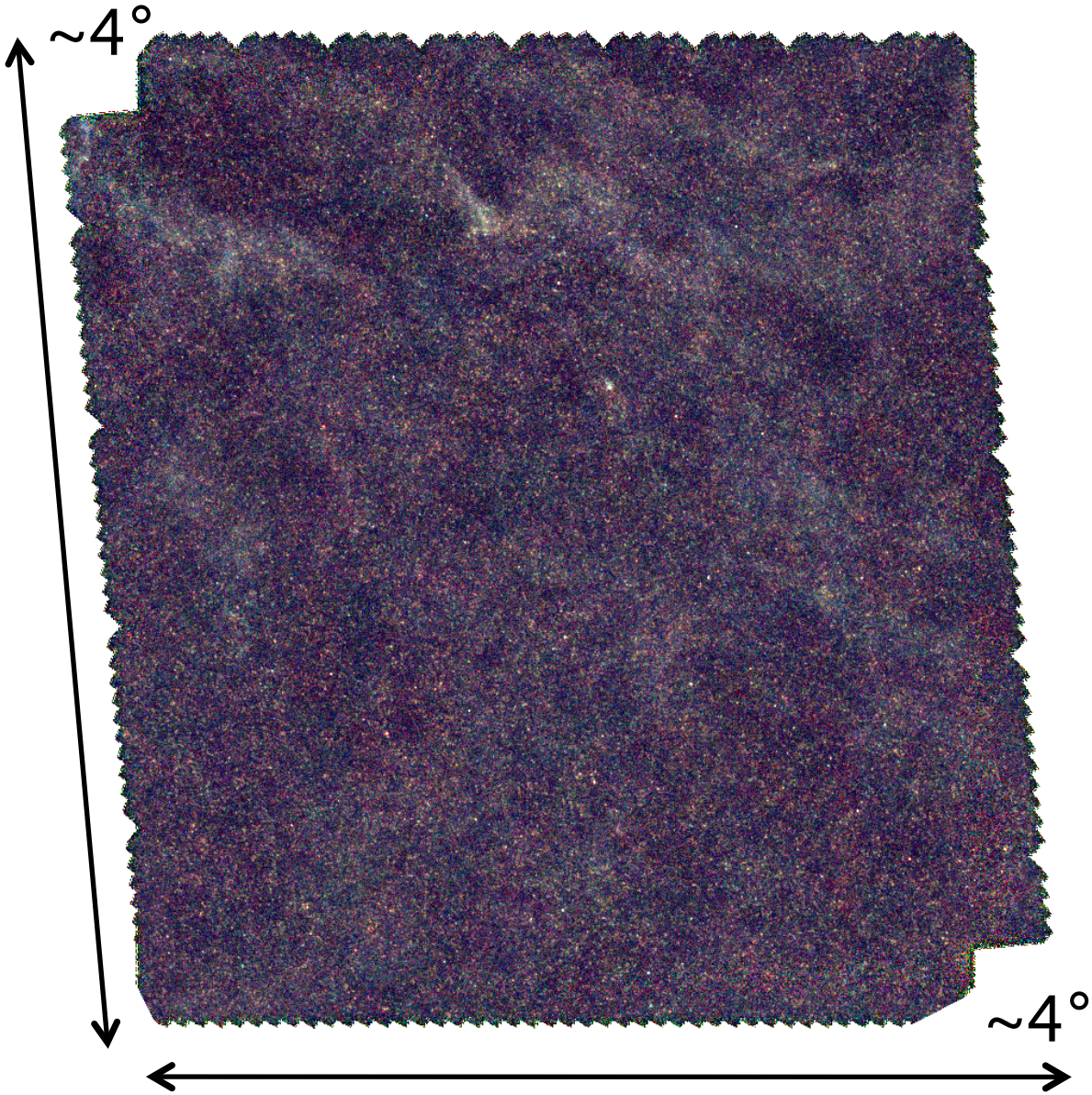


These could be:

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

z = 5, T_{dust} = 35 K HLIRGs…

500 μm BRIGHTEST GALAXIES IN H-ATLAS SDP



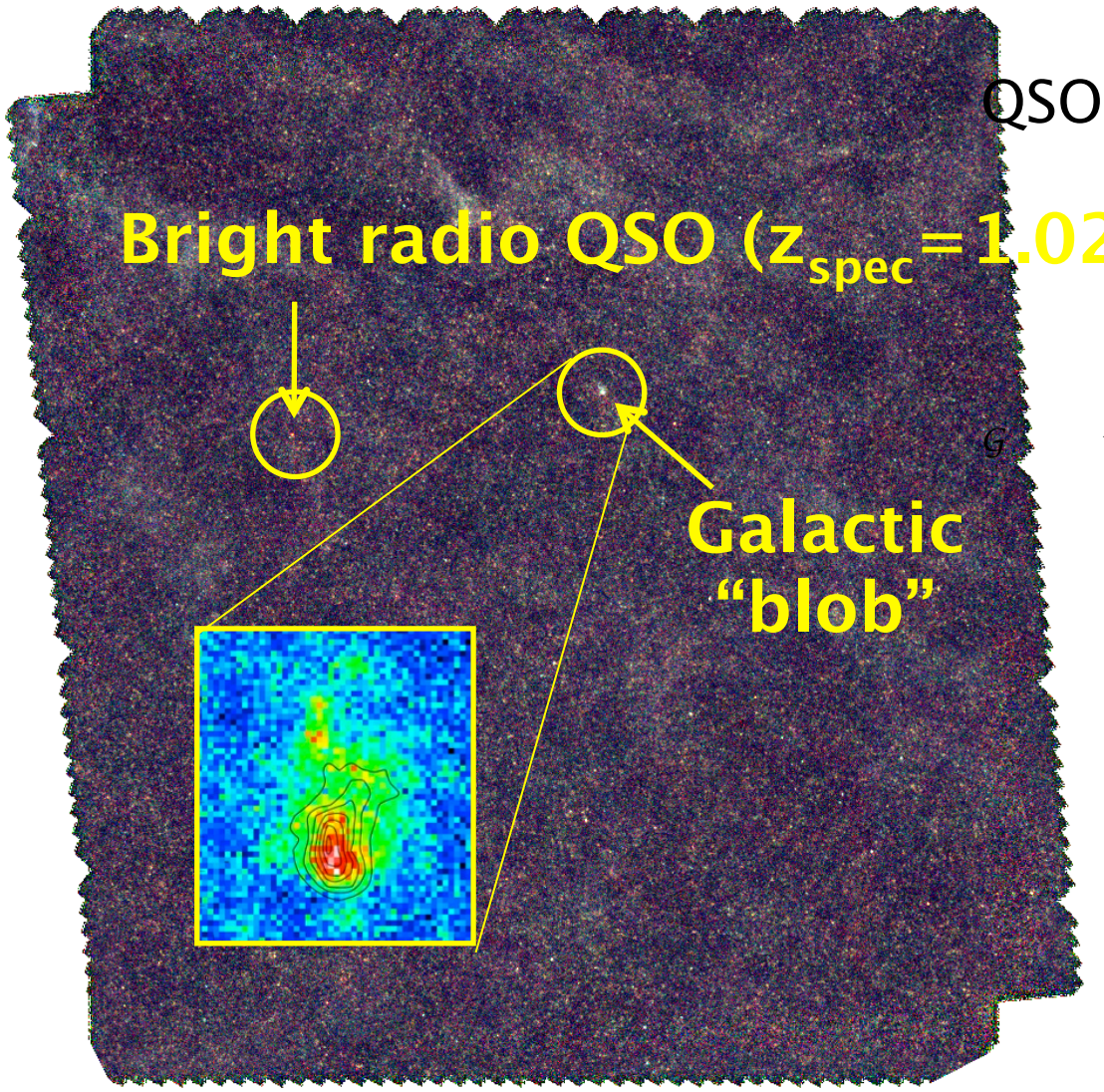
H–ATLAS SDP field

- ~ 14.4 deg^2
- ~ 7000 sources

11 sources with

$S_{500\mu m}$ > 100 mJy

500 μm BRIGHTEST GALAXIES IN H-ATLAS SDP



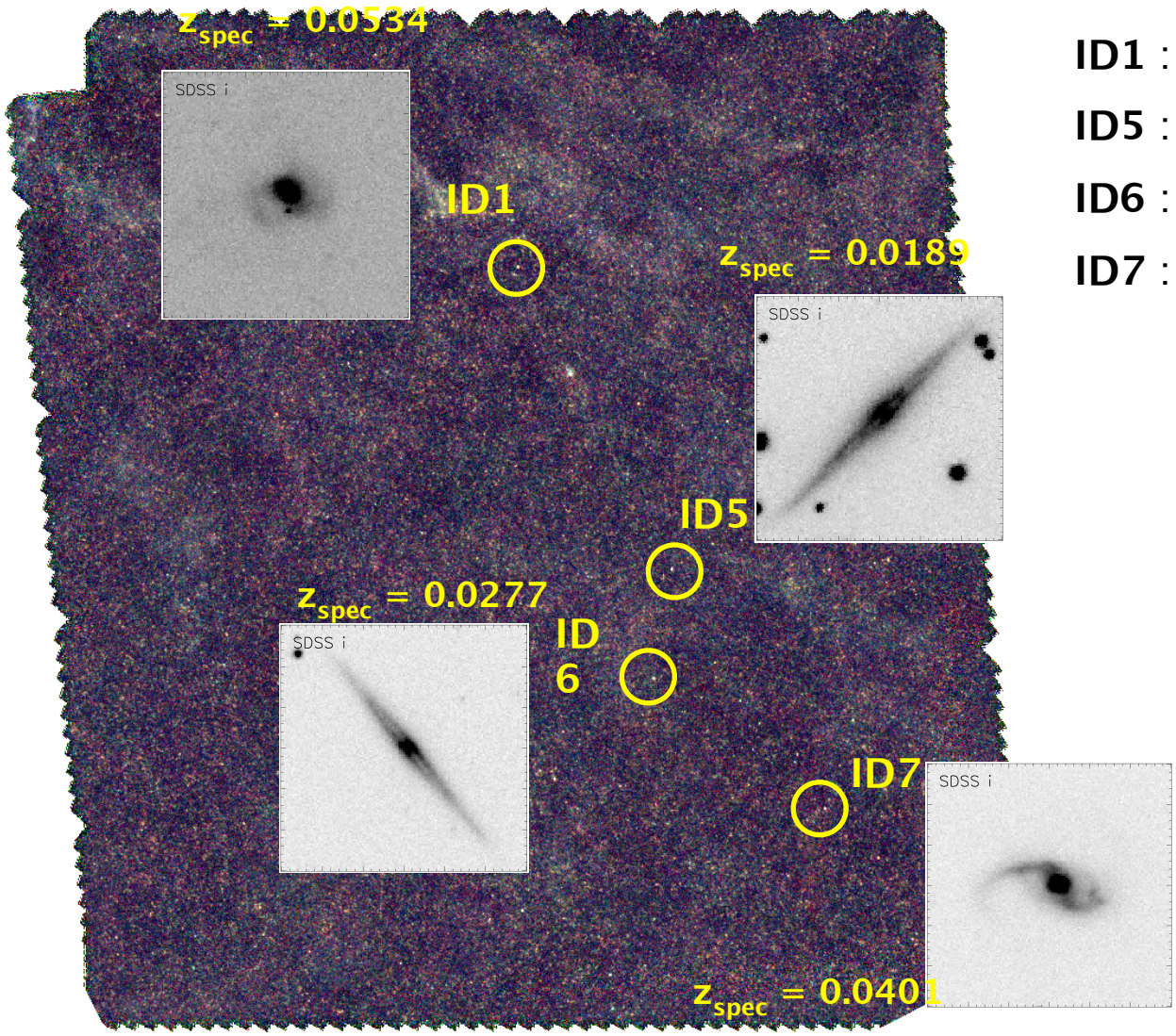
QSO: $S_{250\mu m}$ = 159.6 mJy
$S_{350\mu m}$ = 193.8 mJy
$S_{500\mu m}$ = 265.8 mJy !
$S_{1.4GHz}$ = 571.7 mJy

in WMAP point source catalog!

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

De Zotti et al. (2005)

500 μm BRIGHTEST GALAXIES IN H-ATLAS SDP



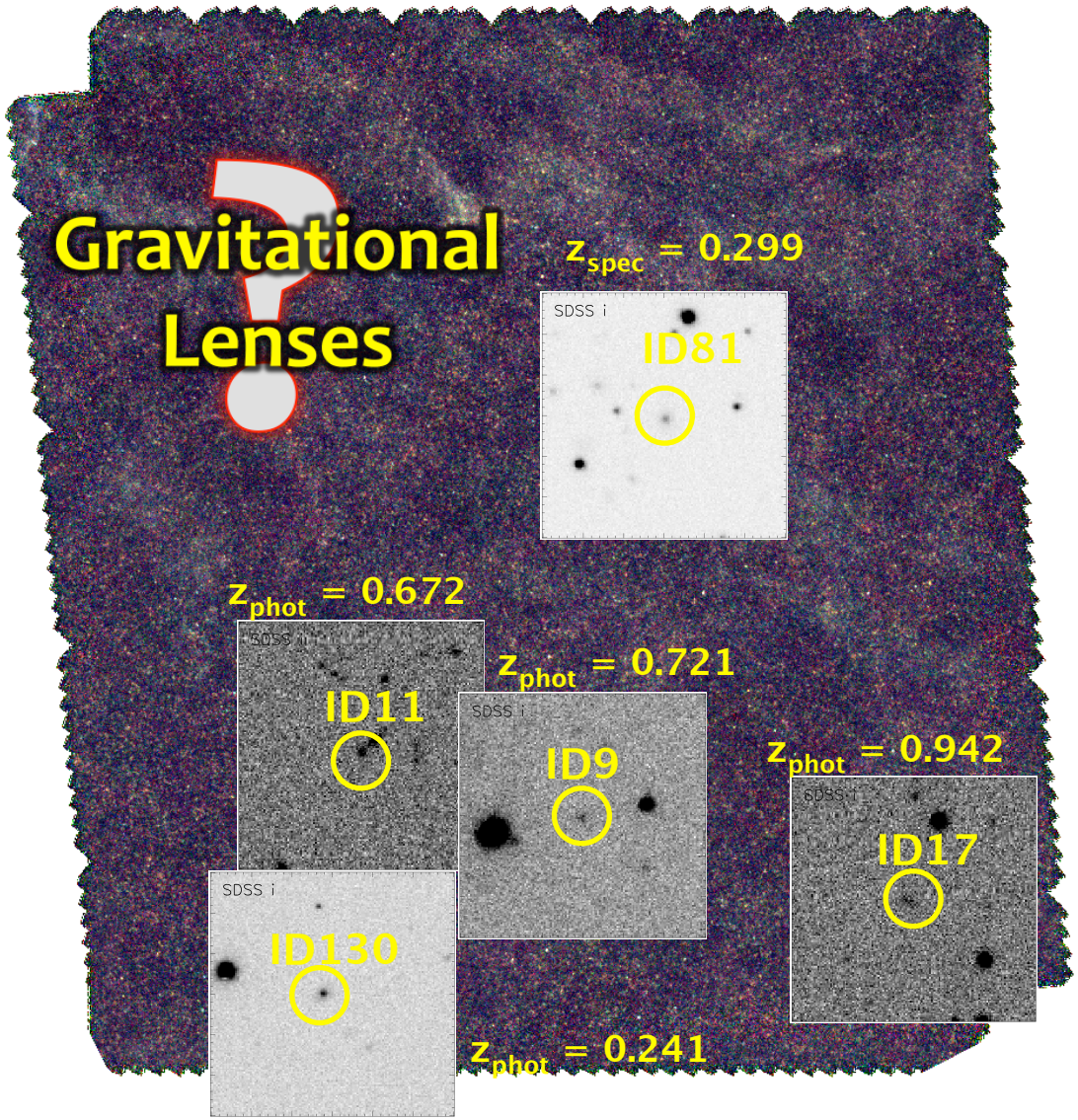
ID1 : $S_{500\mu m}$ = 177 ± 28 mJy

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

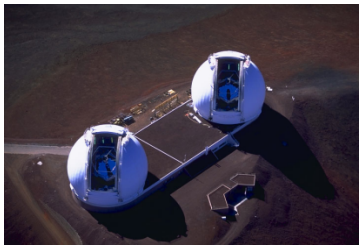
ID130 : $S_{500\mu m}$ = 108 ± 18 mJy

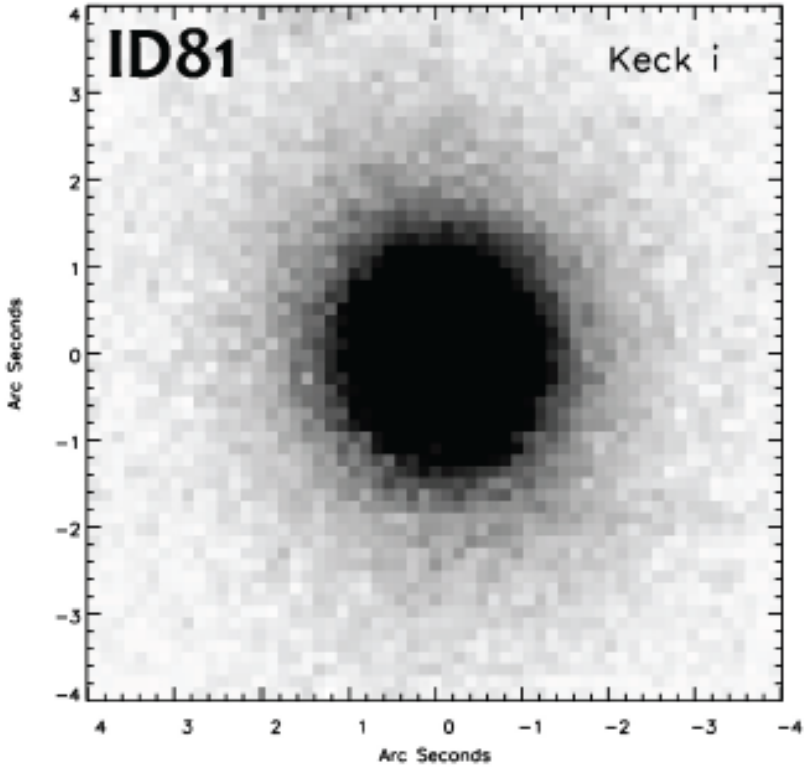
optical counterparts

$z_{phot/spec} < 1.0$

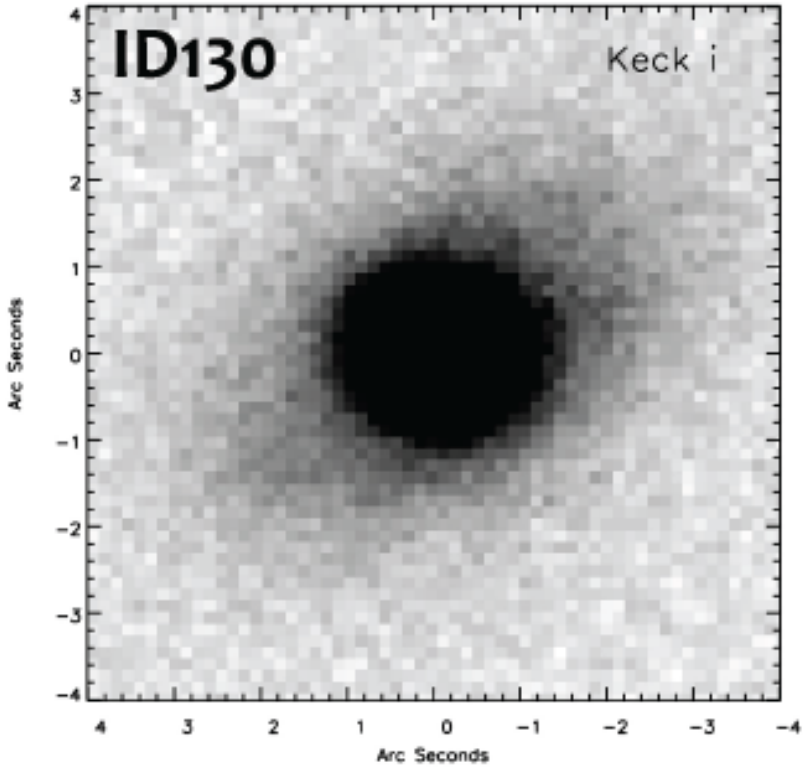
Lensing Candidates ID81 & ID130

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





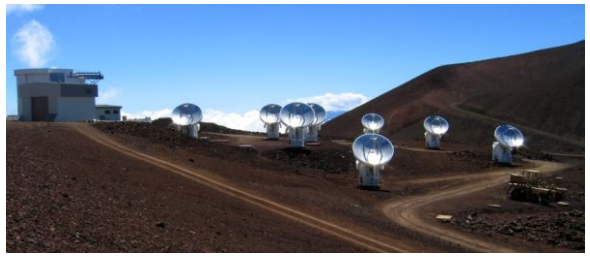
z=0.299

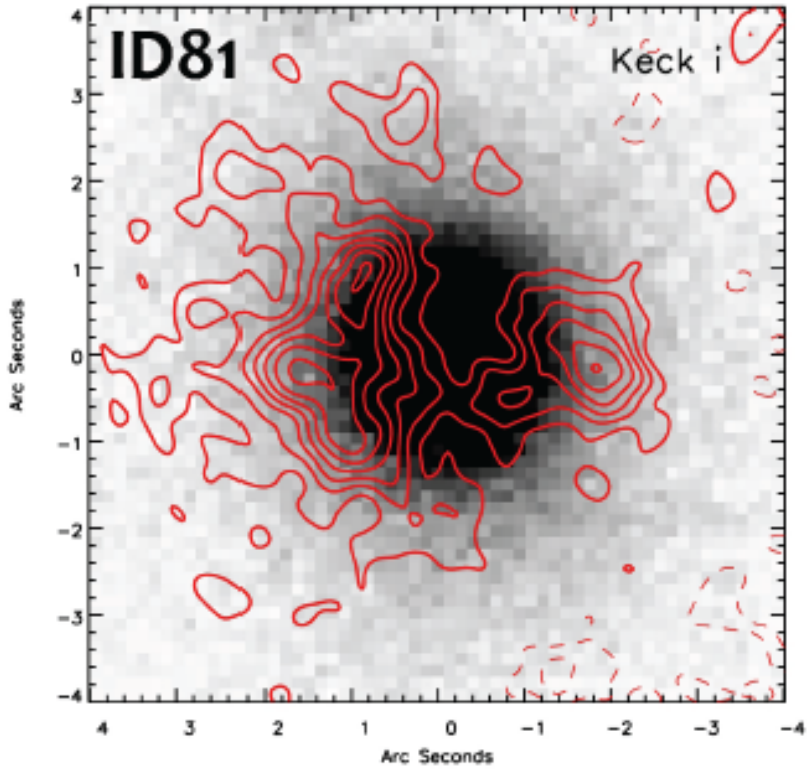


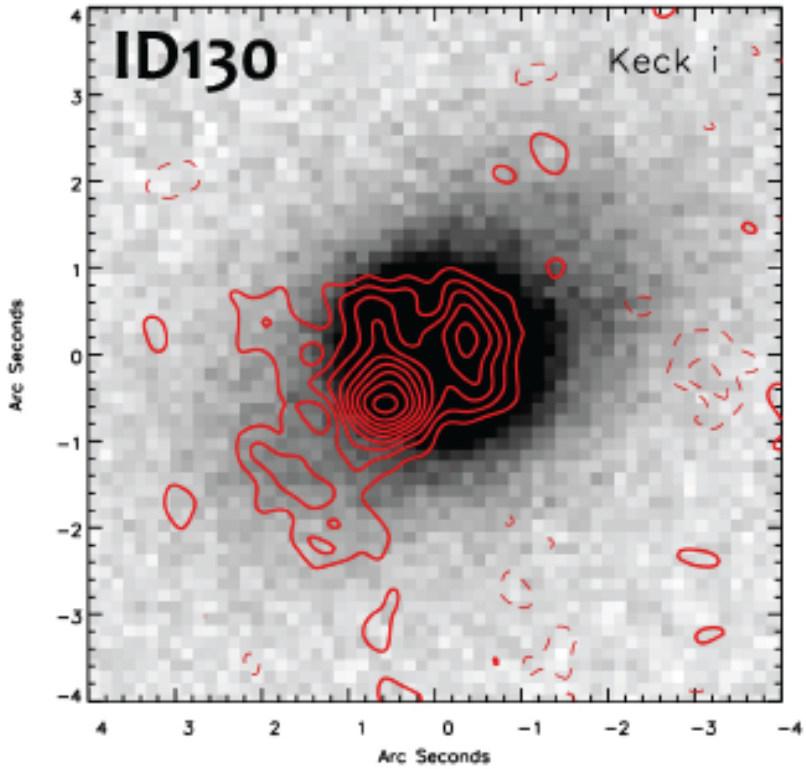
z=0.223

Lensing Candidates ID81 & ID130

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



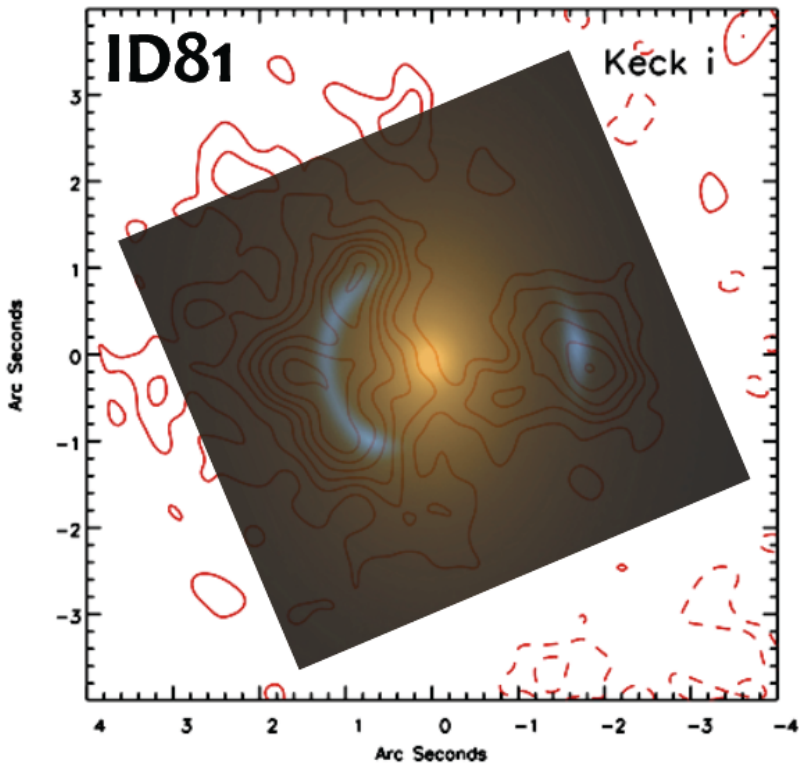


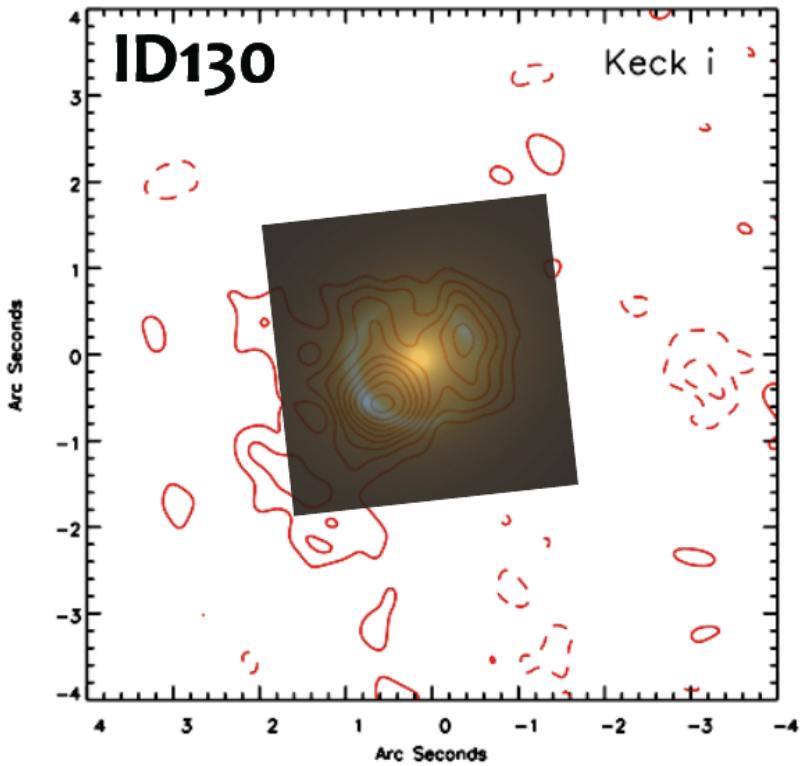


CREDITS: Mark Gurwell (CfA)

Lensing Candidates ID81 & ID130

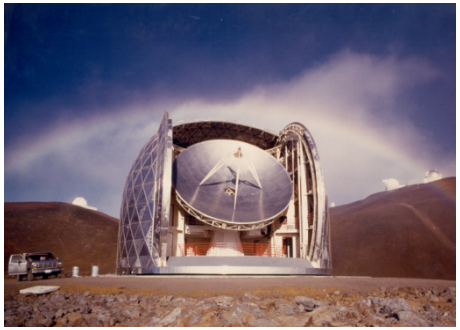
+ Lensing Model to SMA data



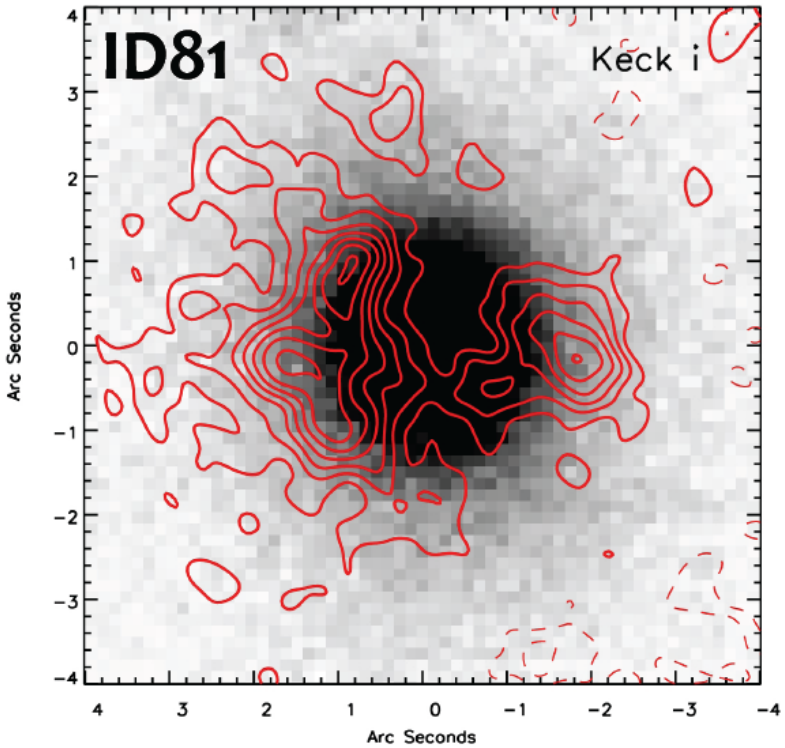


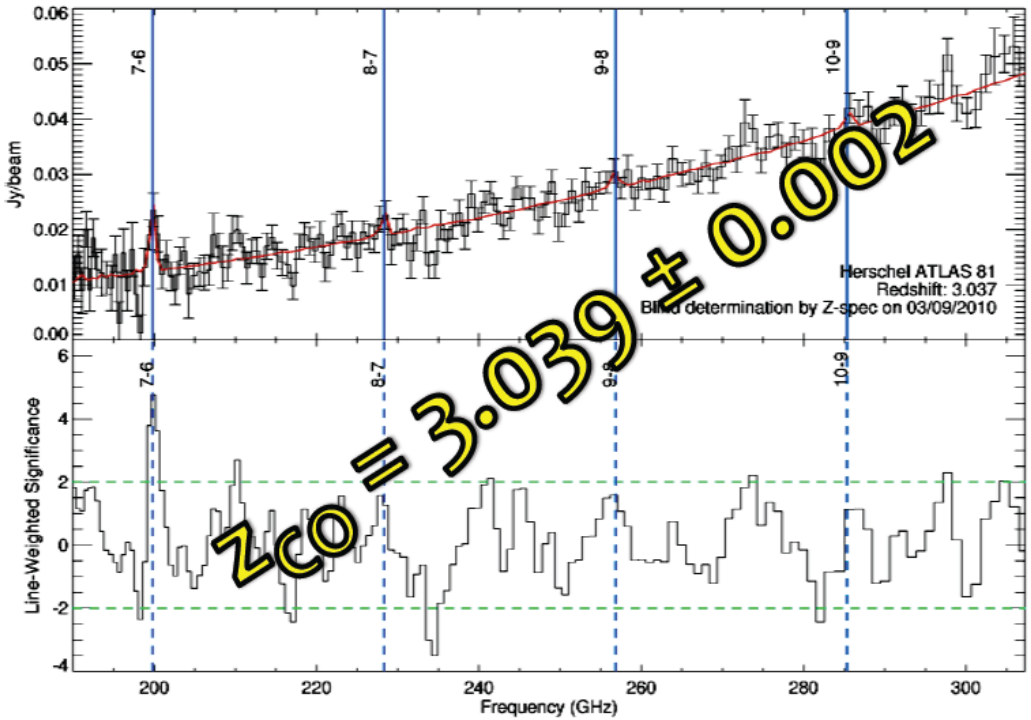
from http://www.slacs.org

First Herschel CO Redshift: ID81



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

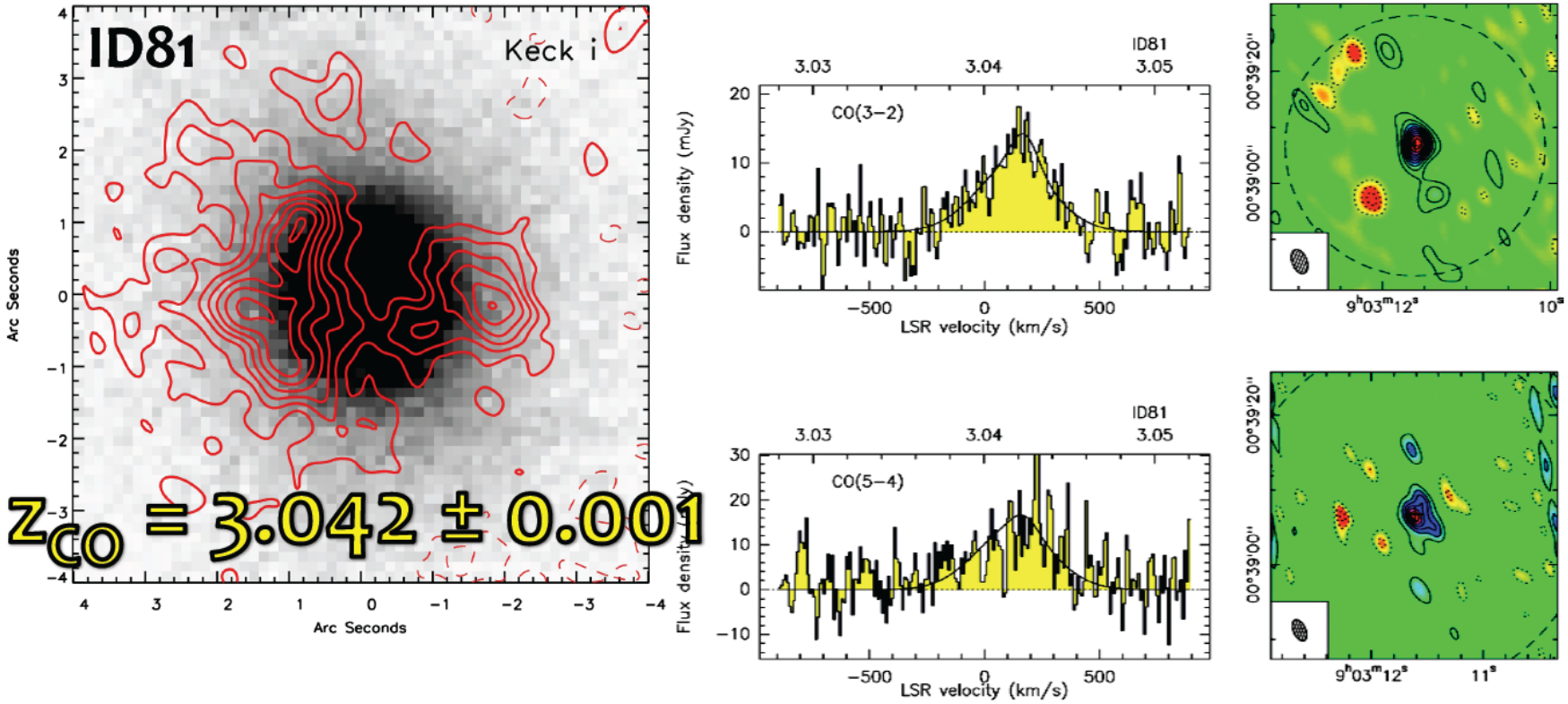




CREDITS: CSO/z-spec team

First Herschel CO Redshift: ID81

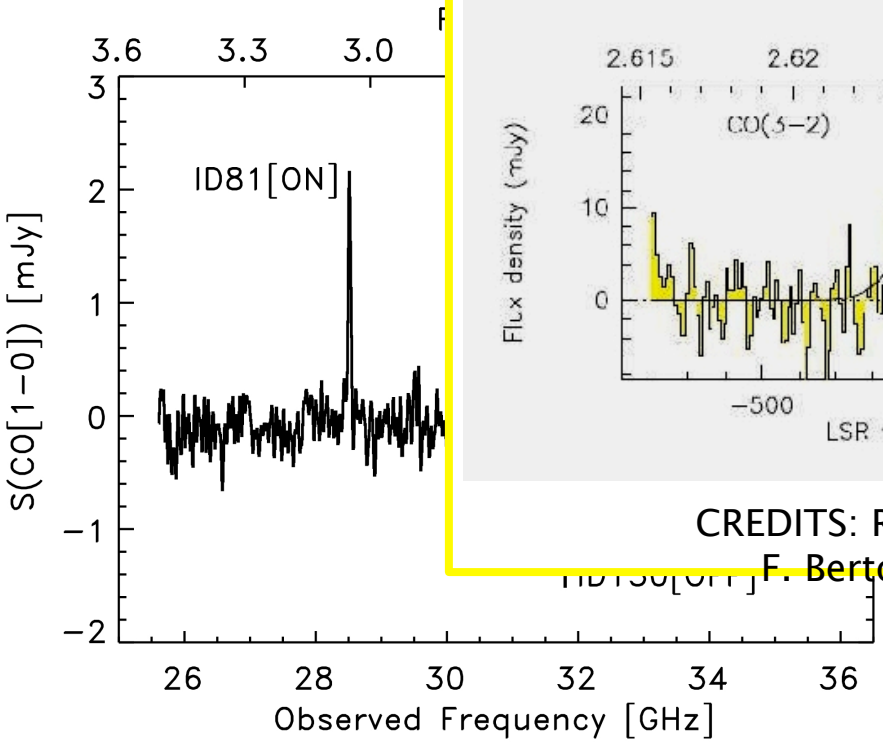
Redshift confirmed by **follow-ups** with the **PdB Interferometer** (March 23 2010) and **GBT/Zpectrometer** (March 25 2010)



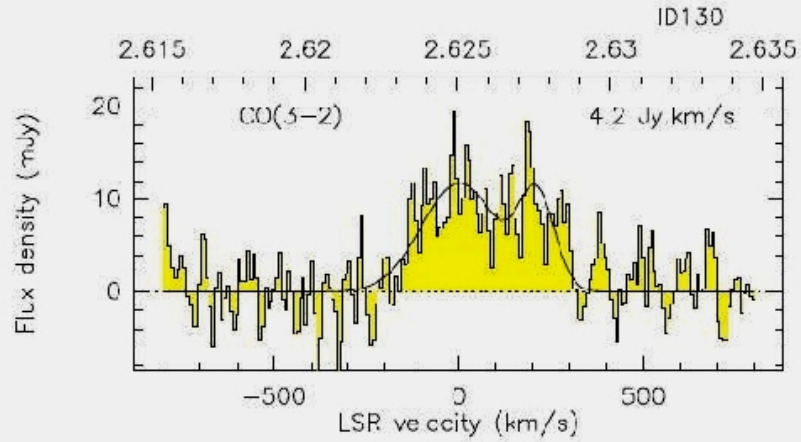
CREDITS: R. Neri, A. Omont, P. Cox, Beelen, Dannerbauer, F. Bertoldi

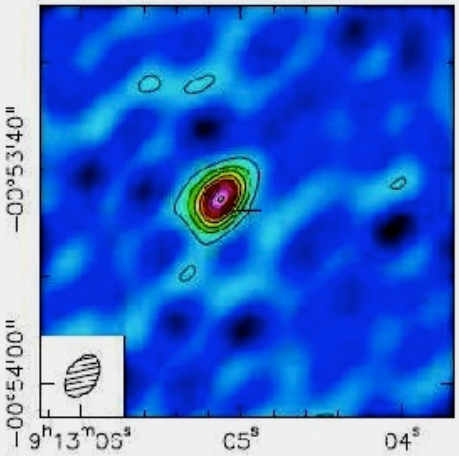
GRAVITATIONAL LENS CANDIDATES ID130

CO(1-0) redshift from GBT/Zpectrometer



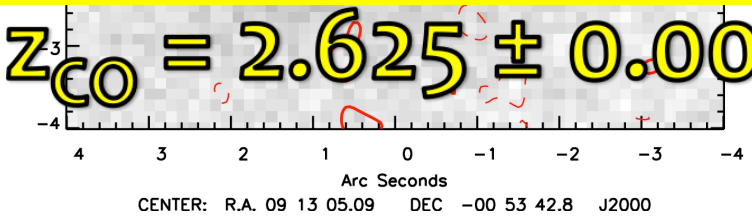
confirmed by **PdBI**





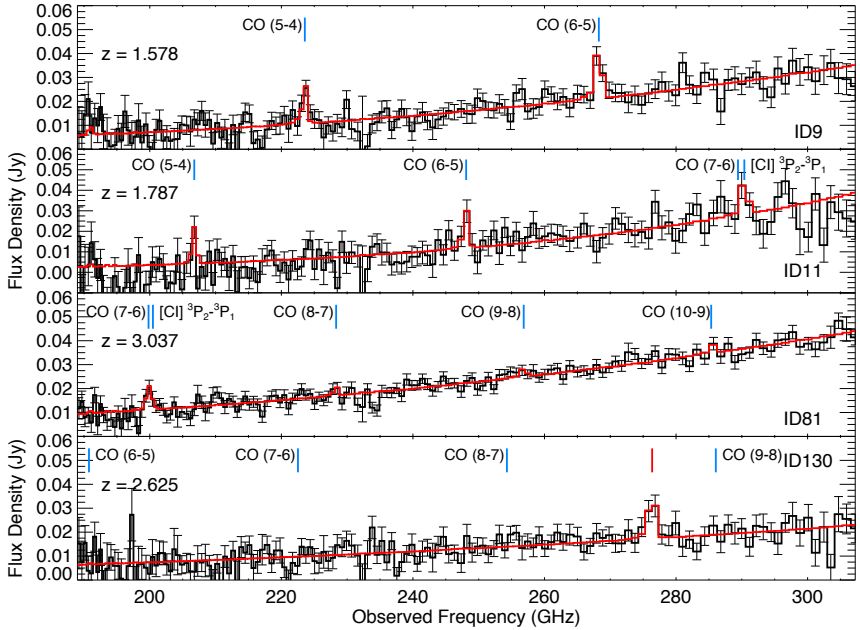
CREDITS: R. Neri, A. Omont, P. Cox, Beelen, Dannerbauer, F. Bertoldi

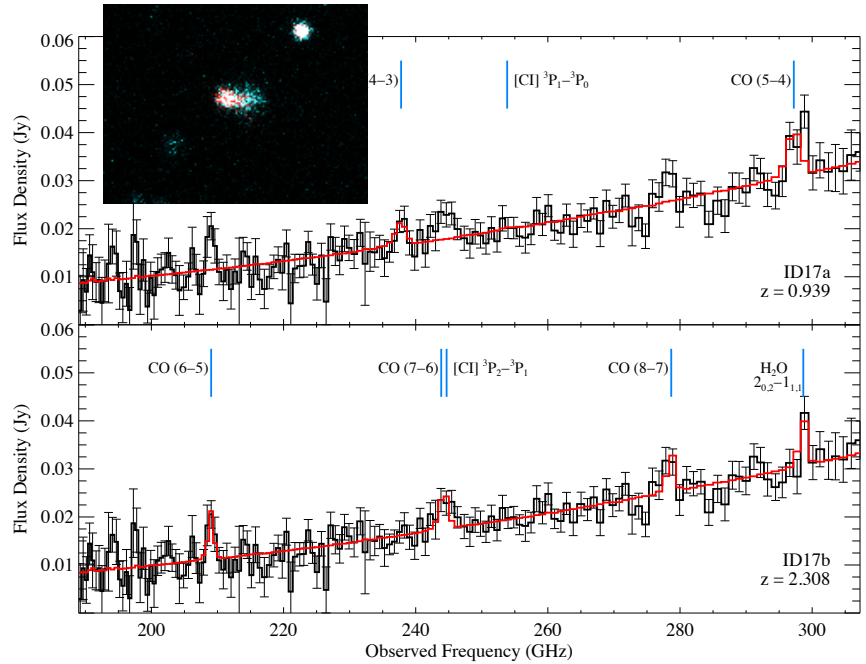
$z_{CO} = 2.625 \pm 0.001$

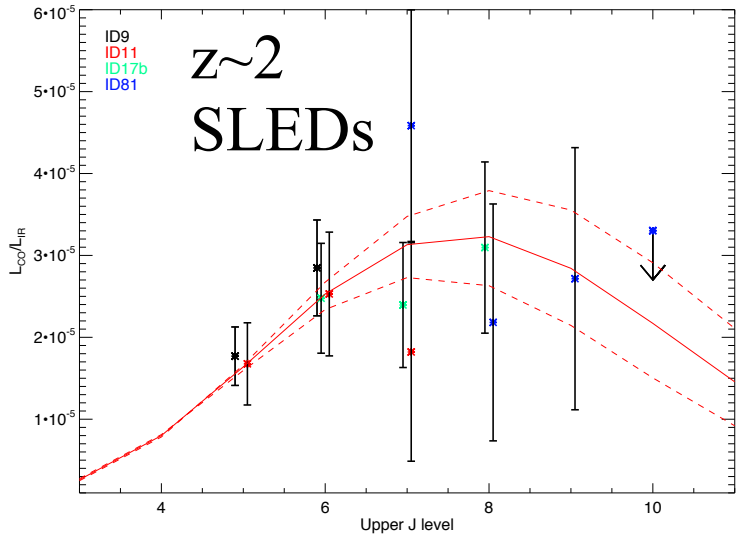


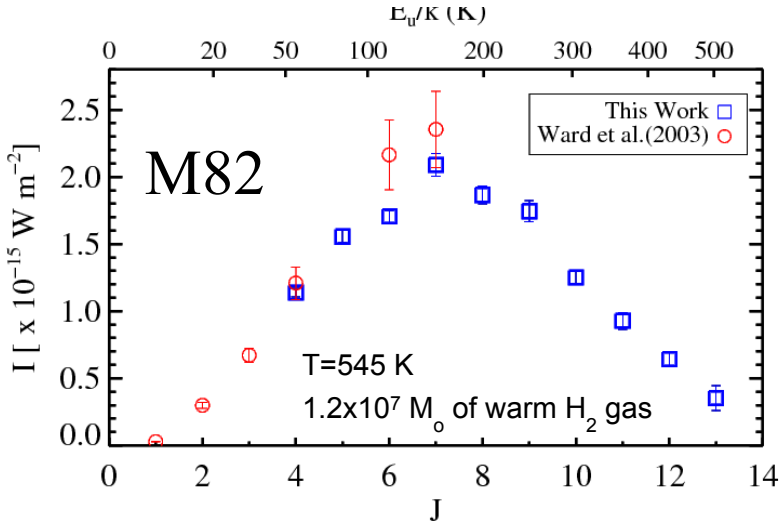
CREDITS: D. Frayer, A. Harris, A. Baker, R. Maddalena et al.

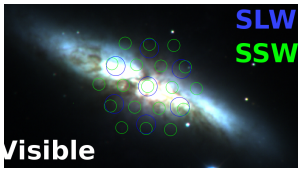
Atlas First Gravitational Lenses





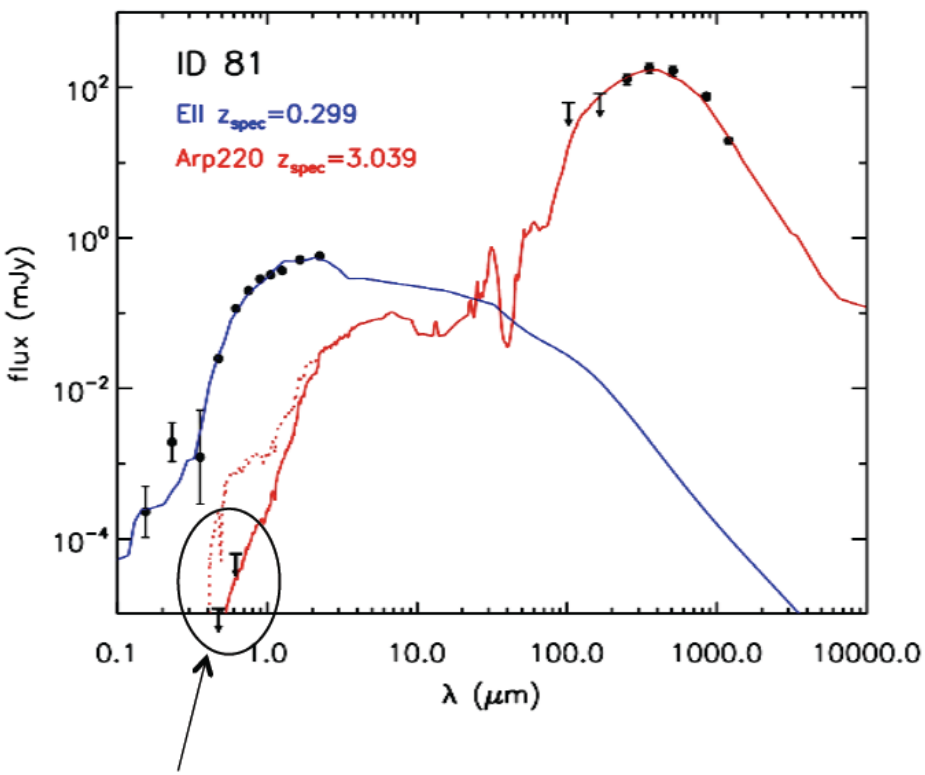




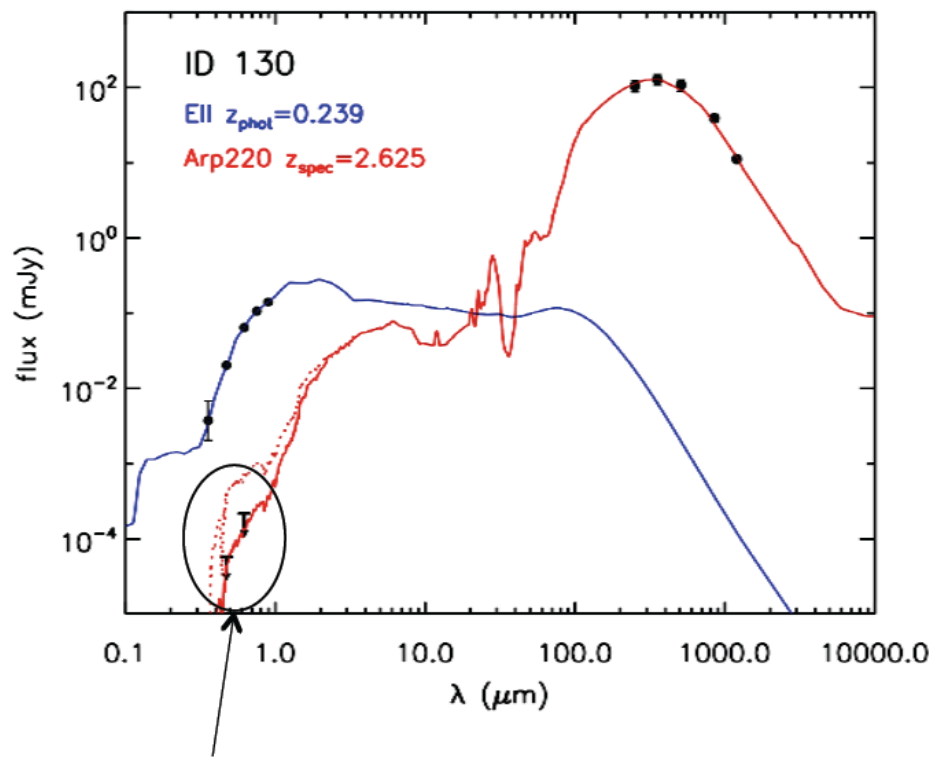


Atlas First Gravitational Lenses

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



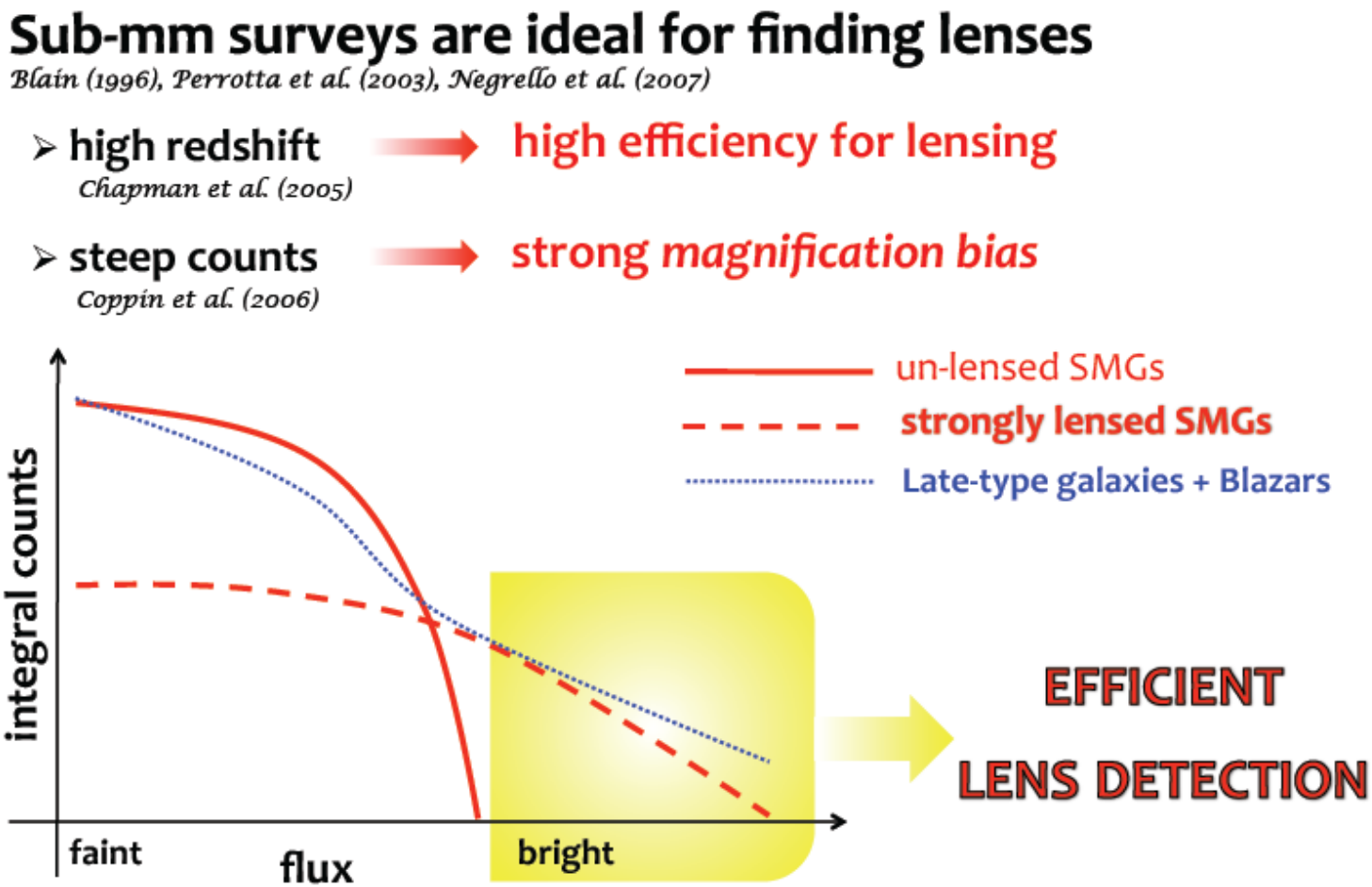
Keck 3σ upper limits



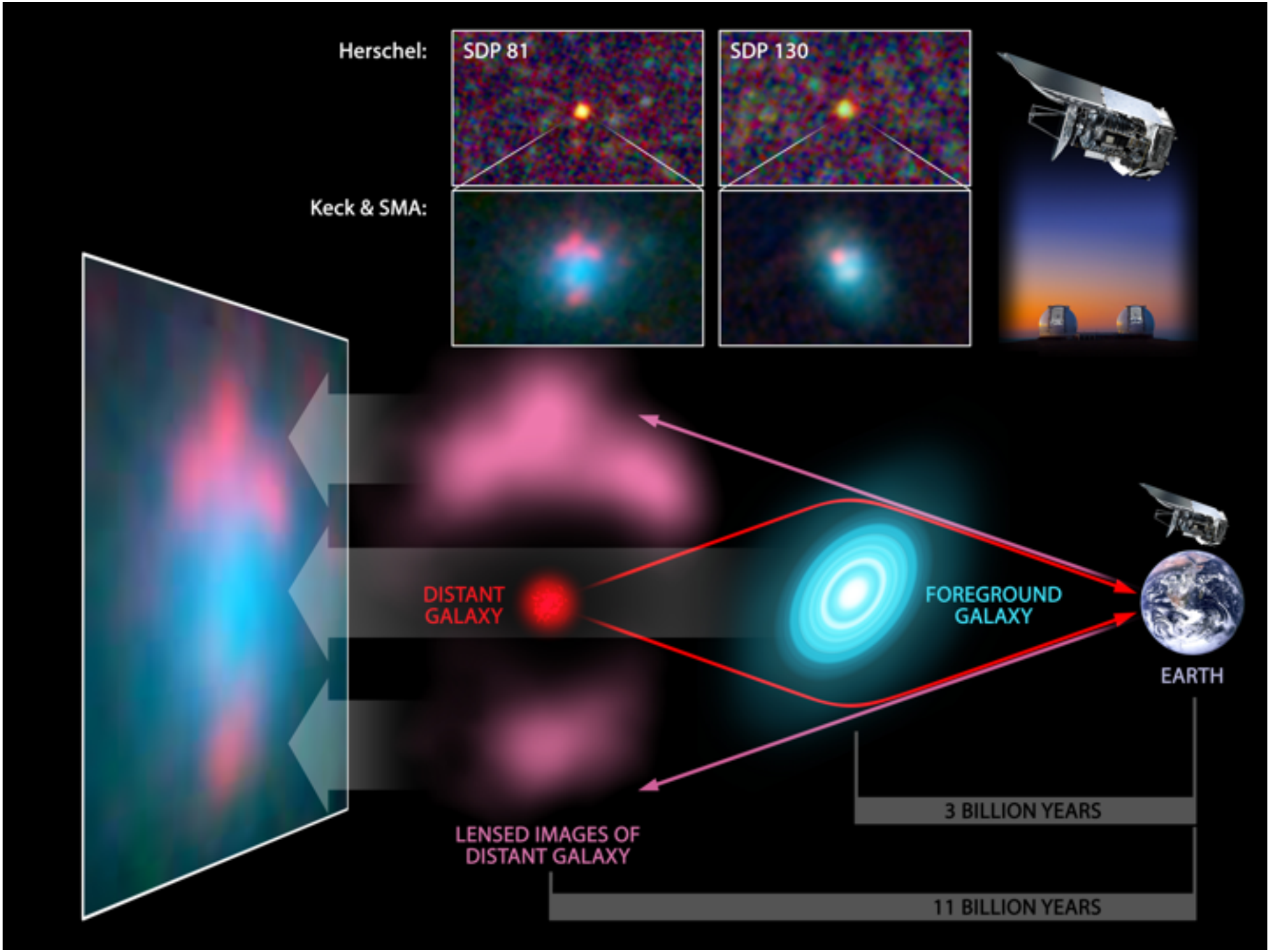
Keck 3σ upper limits

>20 clear examples of compact lensed SMGs by low-z ellipticals!

100% efficiency of identifying Lensed Galaxies

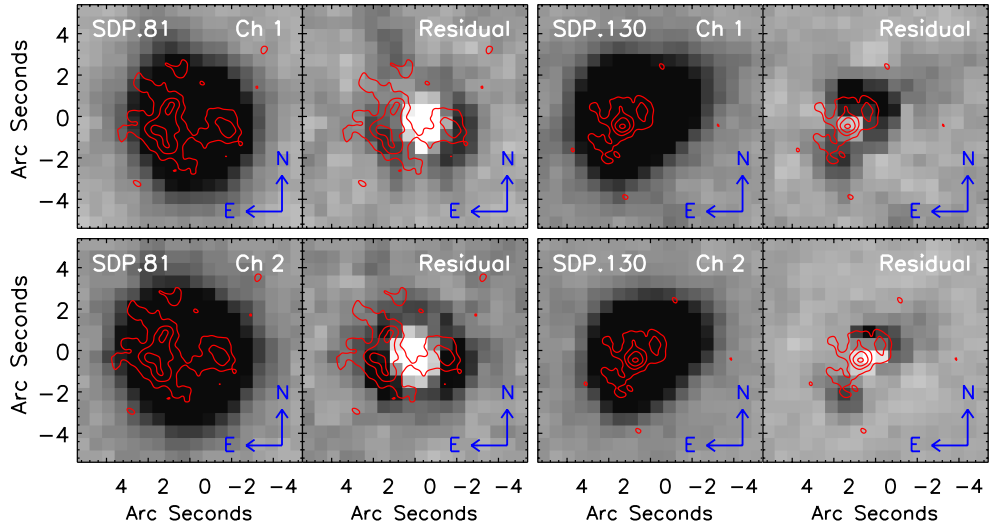


Negrello et al. Science, Oct 22nd issue; 4+ parallel papers in ApJ on the same sources

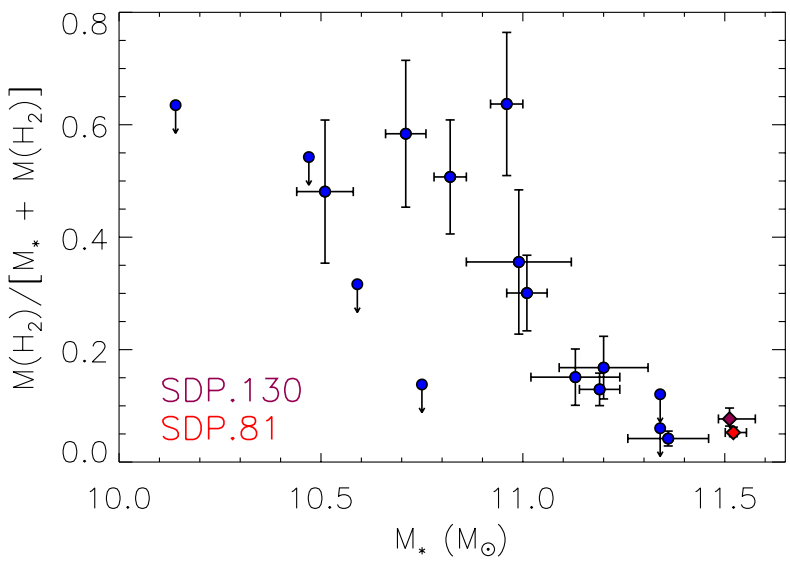

Herschel:
SDP 81
SDP 130
Keck & SMA:
DISTANT GALAXY
FOREGROUND GALAXY
EARTH
3 BILLION YEARS
LENSED IMAGES OF DISTANT GALAXY
11 BILLION YEARS

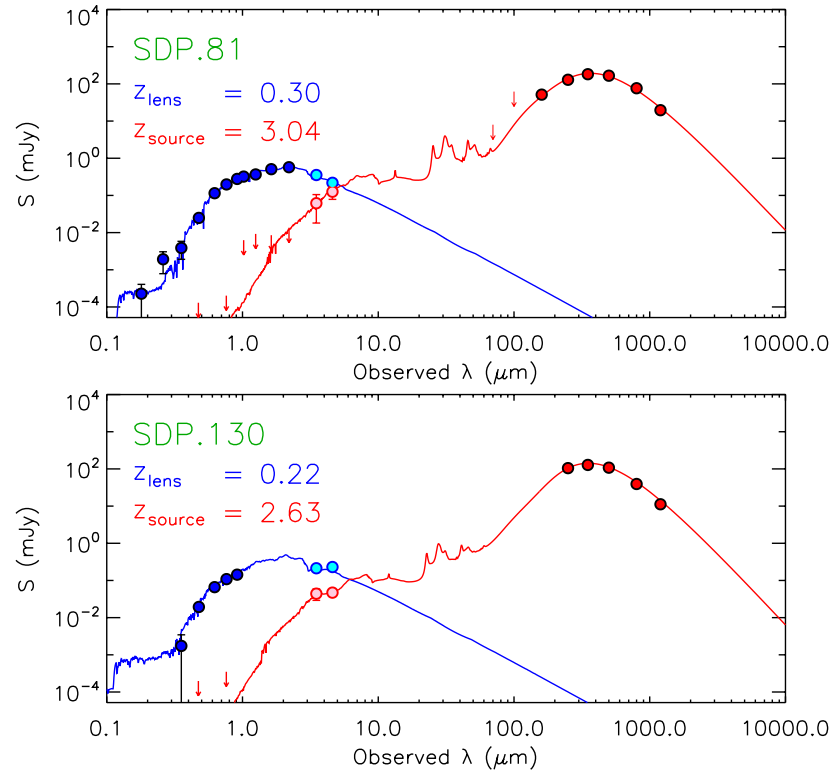
ATLAS First Gravitational Lenses

Background galaxies seen in Spitzer?



(1100 seconds integrations/pixel)



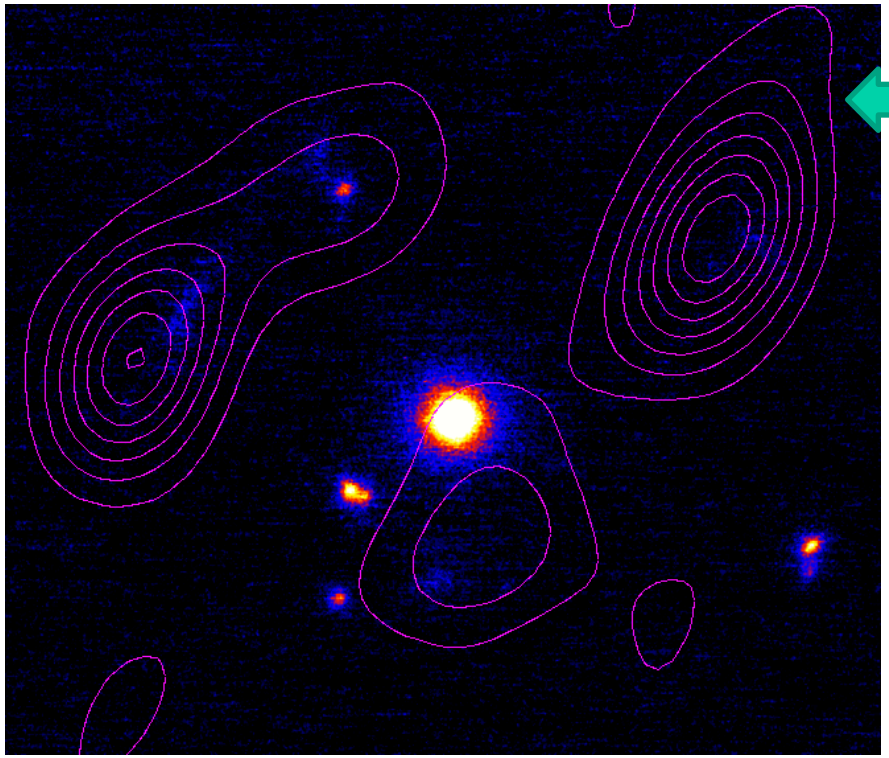


$\log L_{dust} = 12.7 \pm 0.05$
$\log M_{dust} = 8.9 \pm 0.03$ (Herschel/MAMBO/SMA SED)
$\log M_{stars} = 11.7 \pm 0.3$ (Spitzer SED)
$\log M_{gas} = 10.1 \pm 0.5$ (CO line spectra)
$\log SFR = 2.5 \pm 0.1$
$Av = 4.4 \pm 0.6$
Gas fraction = (5-8)%

Hopwood et al ApJL submitted

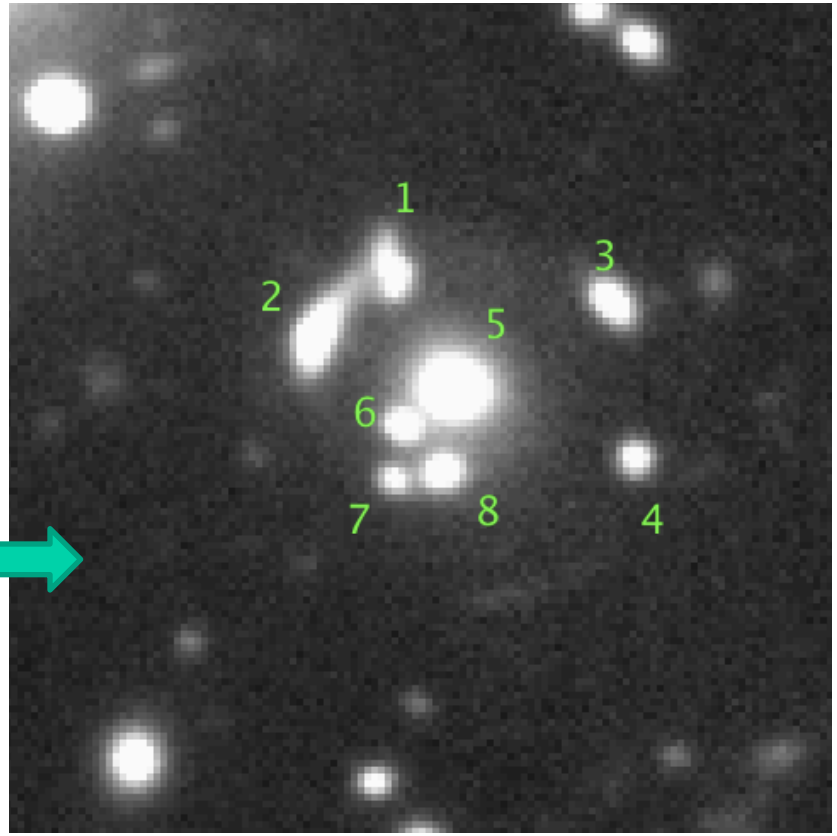
Lensed SMGs in HerMES: An example

9" Lensed Galaxy in HerMES
(brightest extragalactic SMG found by Herschel so far;
250 micron = 420 mJy, 15% brighter than eye-lash)



SMA 870 micron + Keck NIRC2 LGS AO

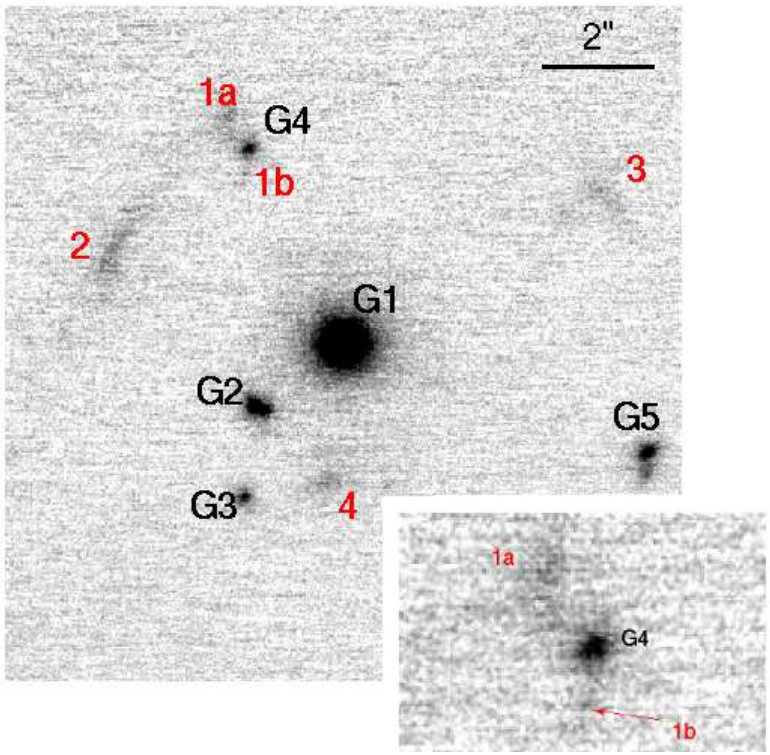
Subaru image

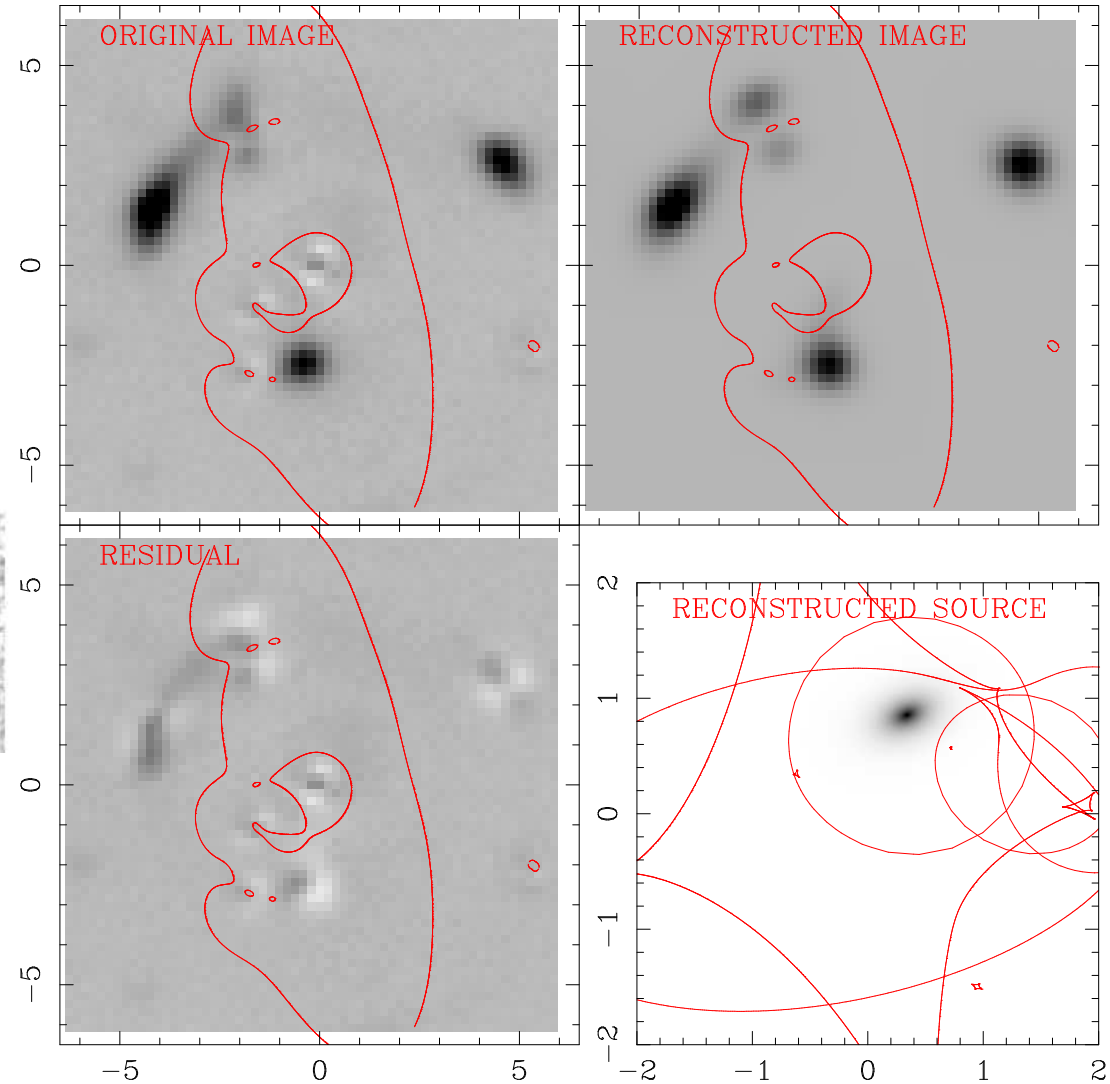


(4 papers soon in ApJL: Conley et al; Riechers et al; Scott et al; Gavazzi et al.)

Lensed SMGs in HerMES: An example

(brightest extragalactic SMG found by Herschel so far; 250 micron = 420 mJy, 15% brighter than eye-lash)





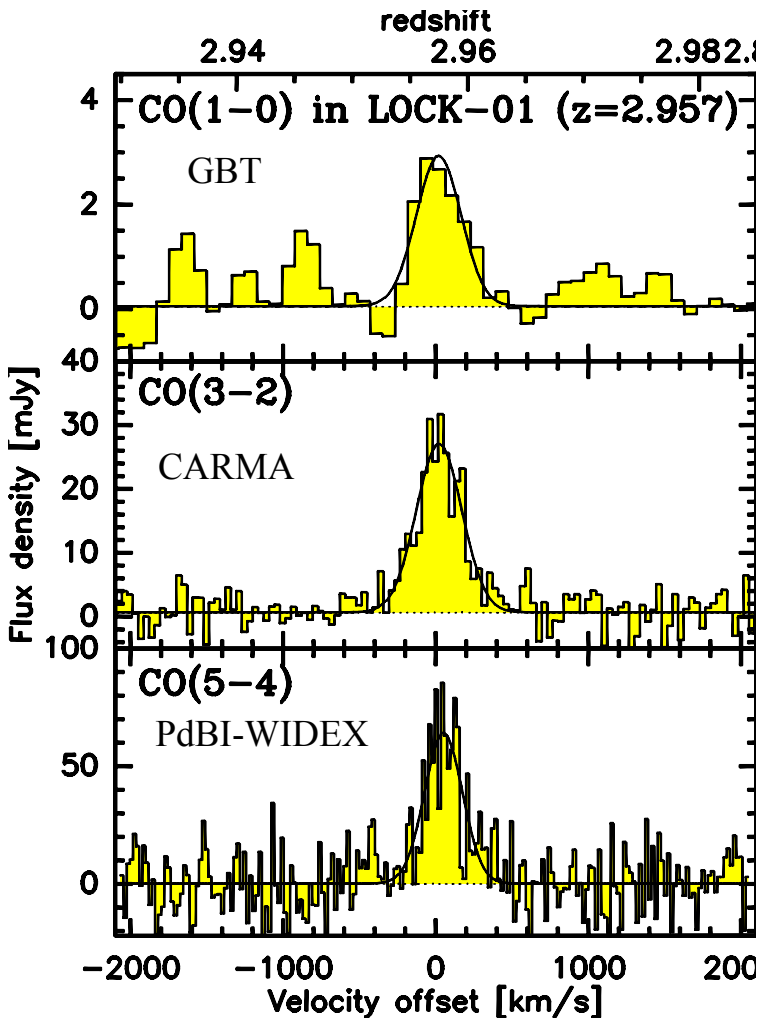
5 lenses, G1 at z=0.59; redshifts of rest unclear

G1 and G4 masses are well determined

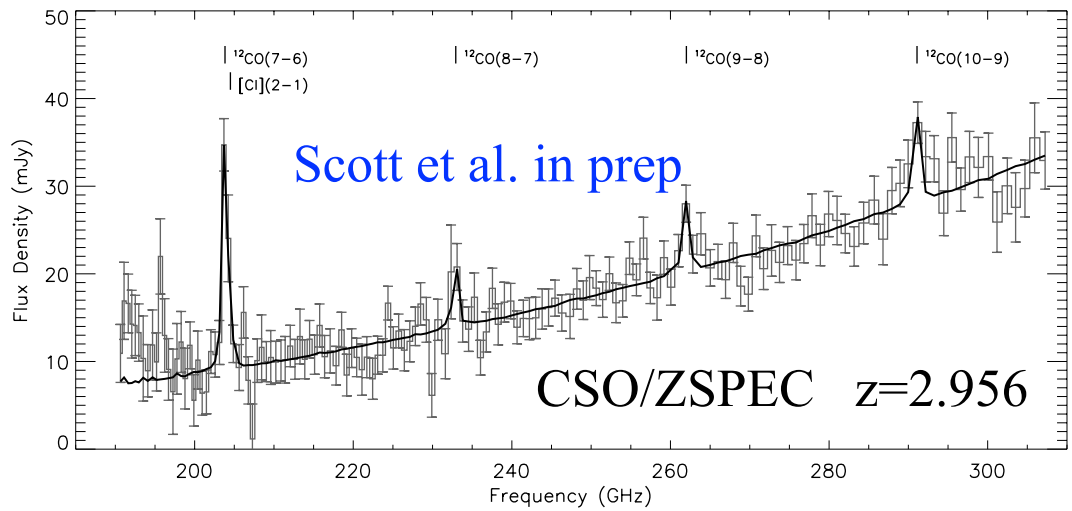
Gavazzi et al. in prep

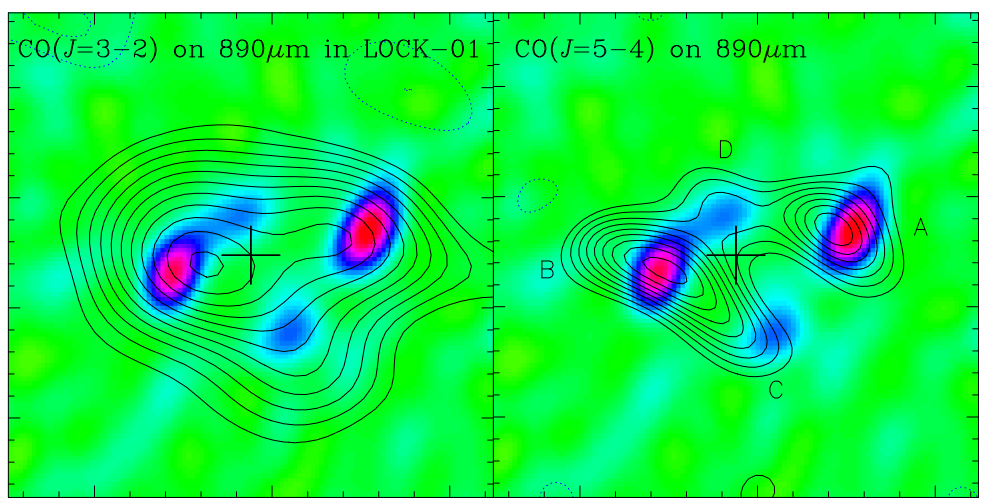
Lensed SMGs in HerMES: An example

(brightest extragalactic SMG found by Herschel so far; 250 micron = 420 mJy, 15% brighter than eye-lash)



Riechers et al. in prep



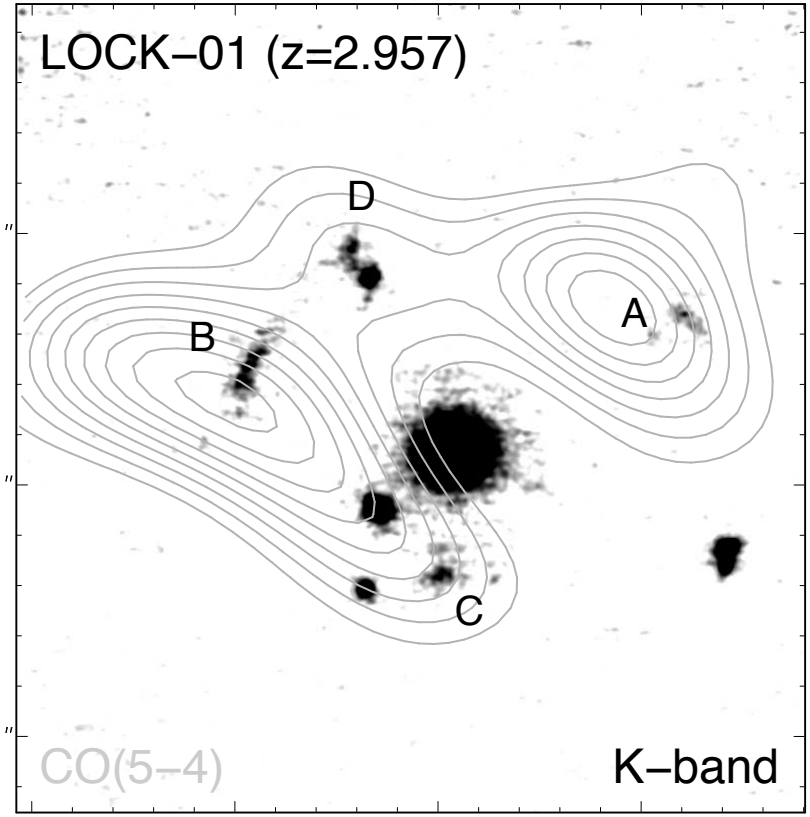


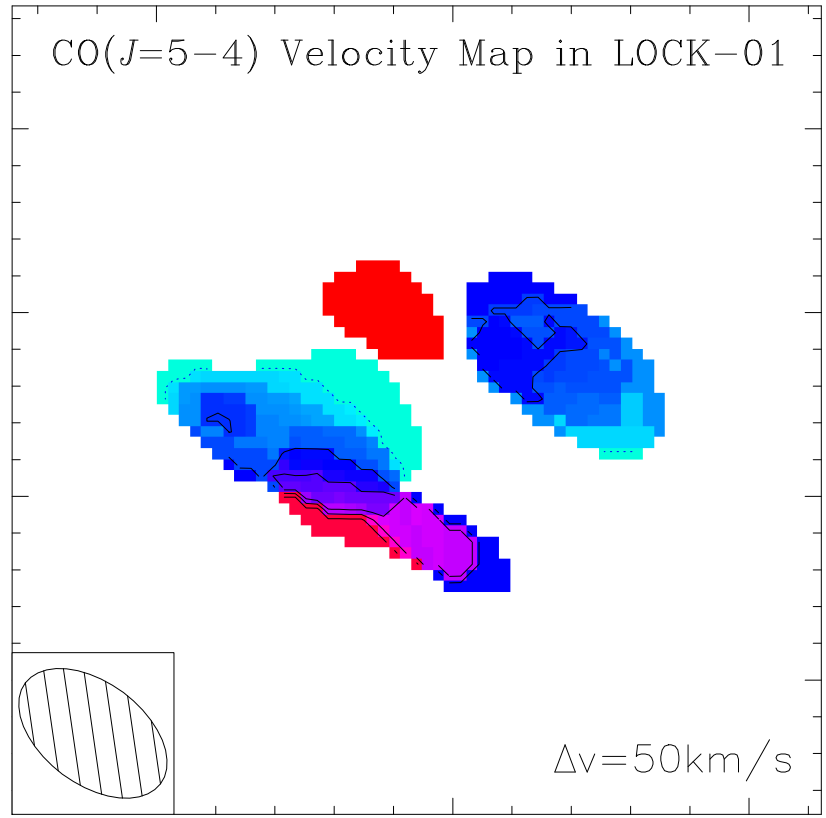
CO already spatially resolved in the 5-4 PdBI map

$M_{gas} = 4 \times 10^{10}\ M_{sun}$ (corrected for magnification)

Lensed SMGs in HerMES: An example

(brightest extragalactic SMG found by Herschel so far; 250 micron = 420 mJy, 15% brighter than eye-lash)

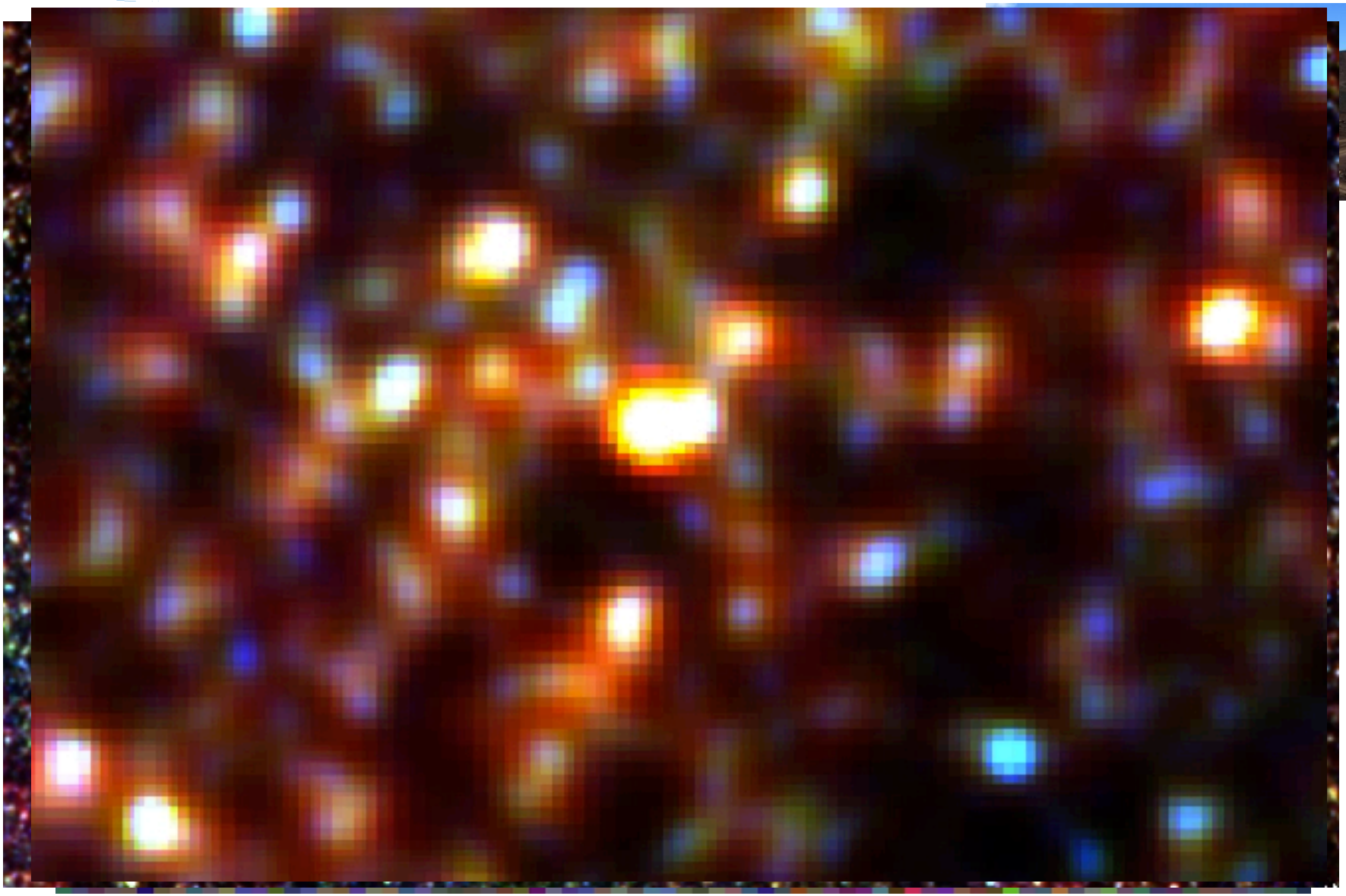




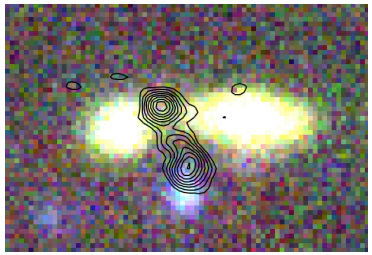
A and B same velocity while D and C same; we are resolving different regions of the CO gas at z=2.957

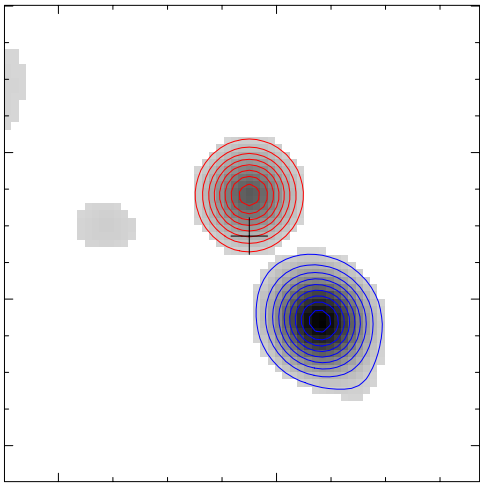
also dynamically resolved, thus a multi-component source

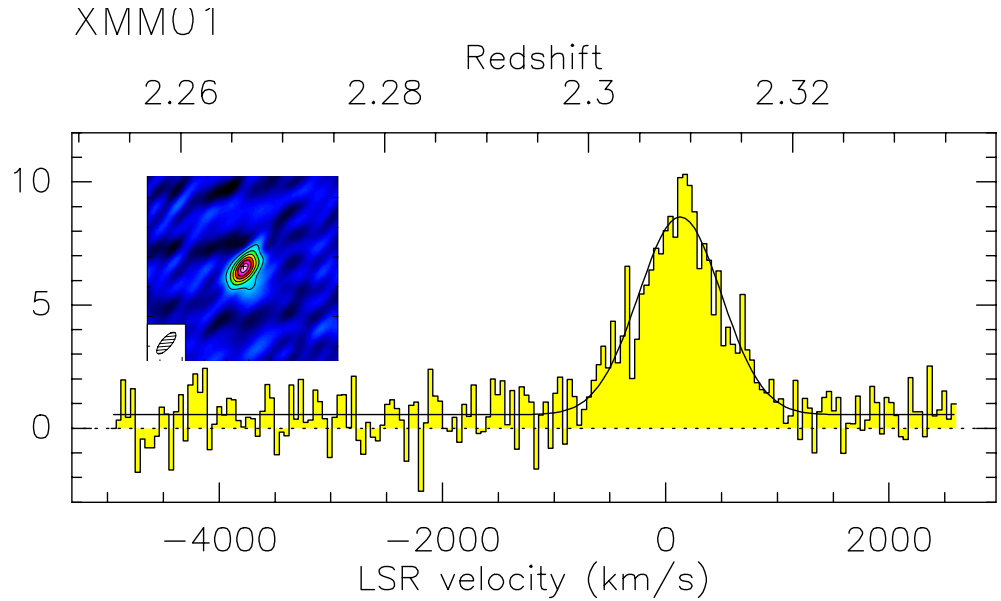
Herschel lensed sources in the XMM field

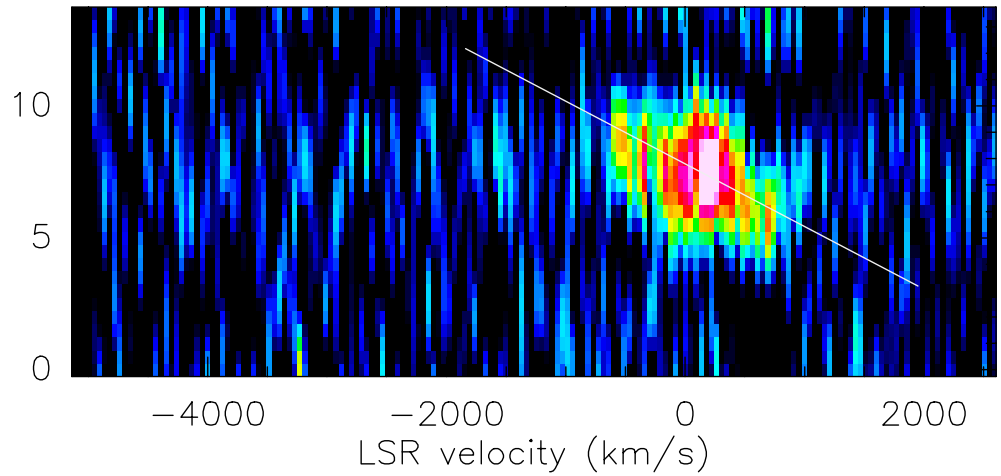


Herschel lensed sources in the XMM field







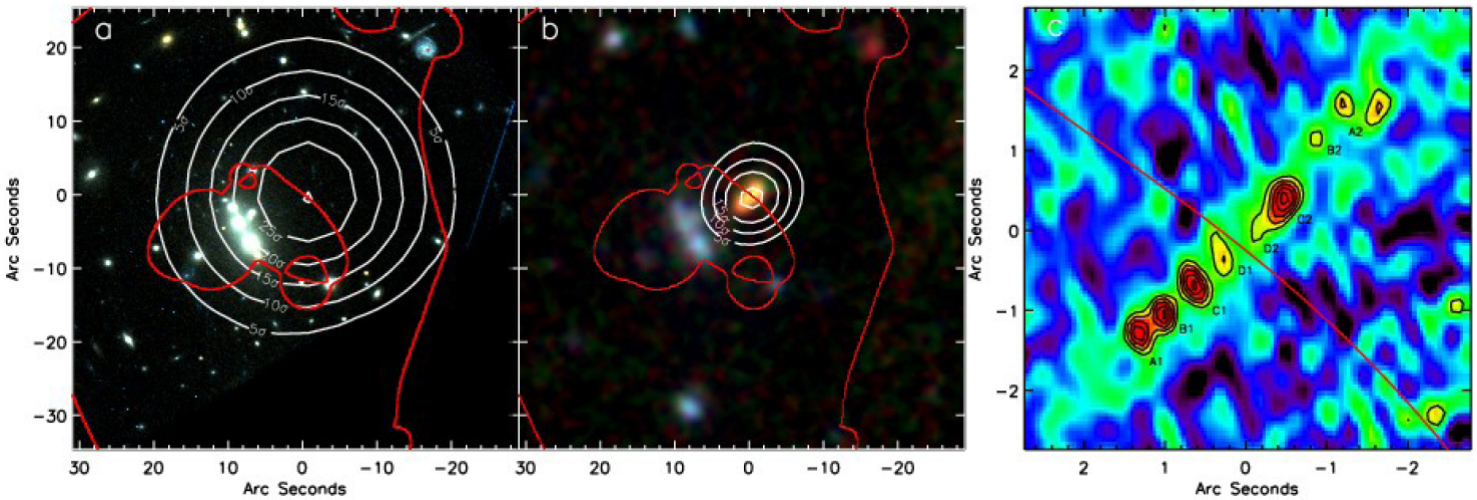


Two components have two different CO velocities, and thus are from two different places in the SMG.

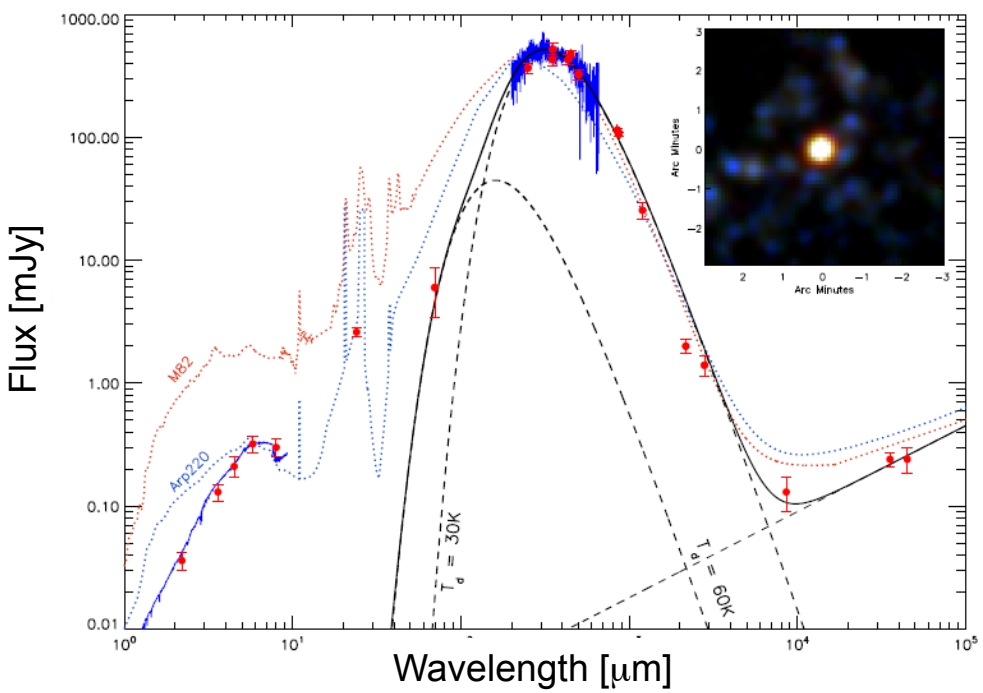
Preliminary lens models show higher-resolution structure within each of the components made up of two images.

Probes the integrated mass of two galaxies. Center of the DM potential is away from light profile.

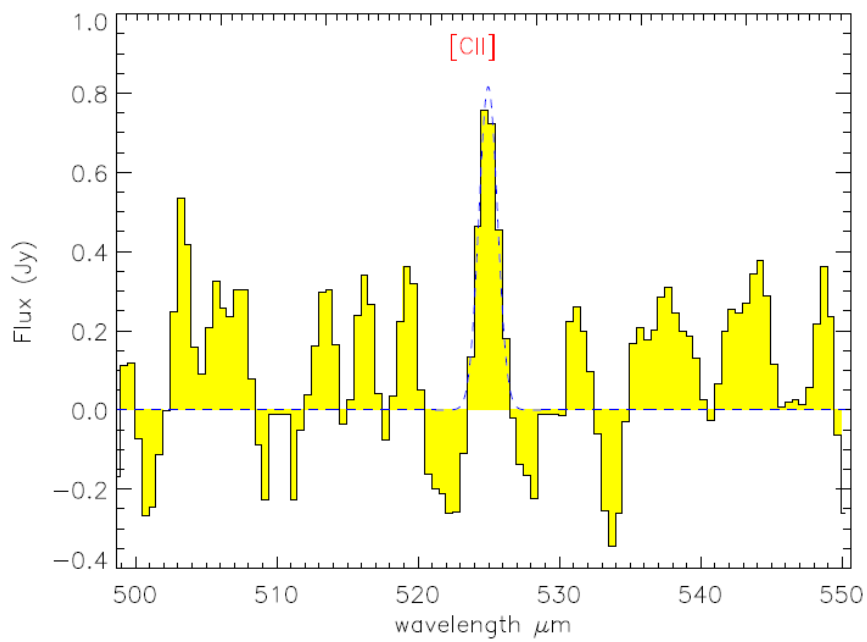
C+ in the 'Eyelash'



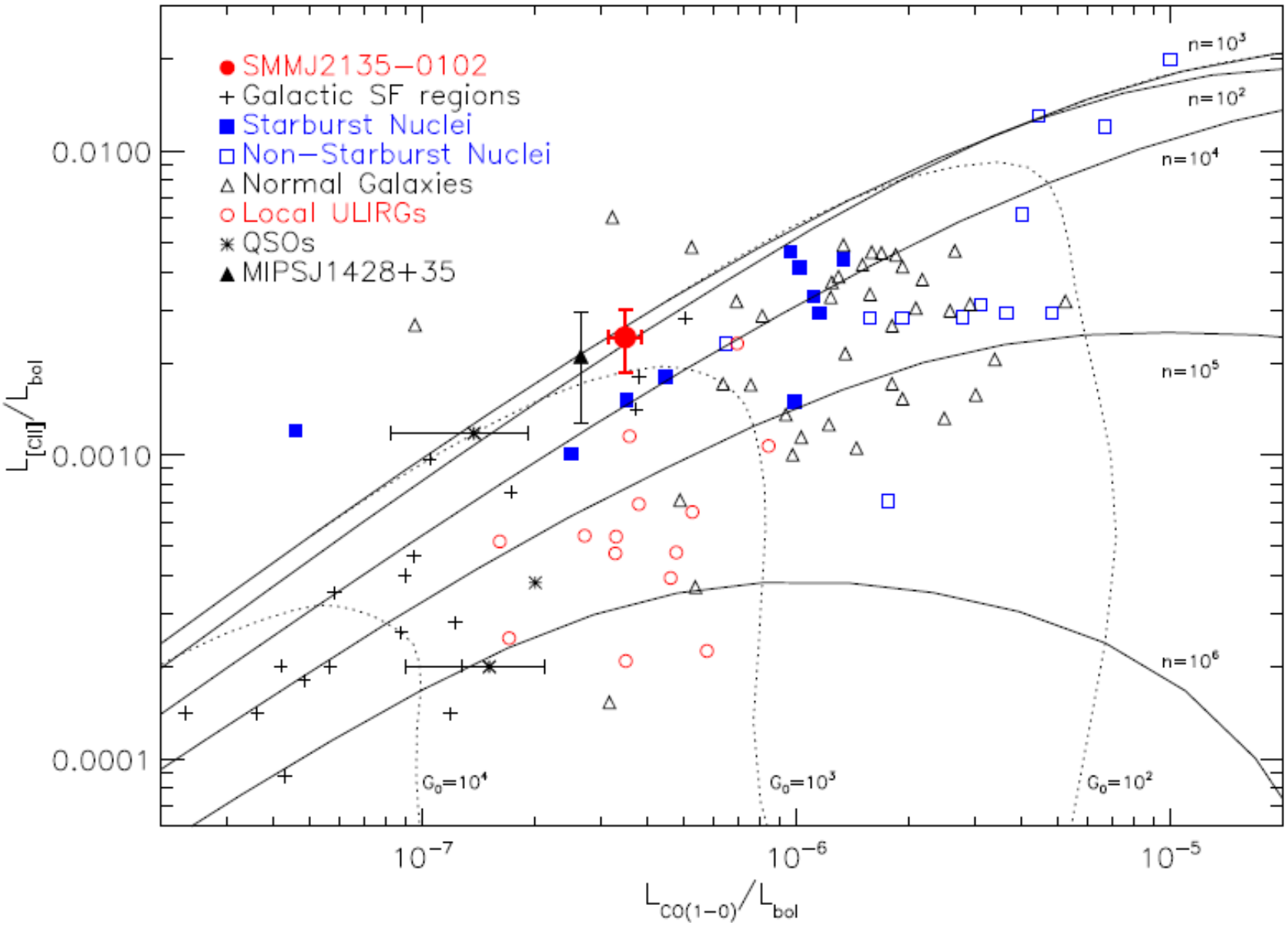
Highly magnified (32 +/- 4) source discovered by LABOCA/APEX, z = 2.33

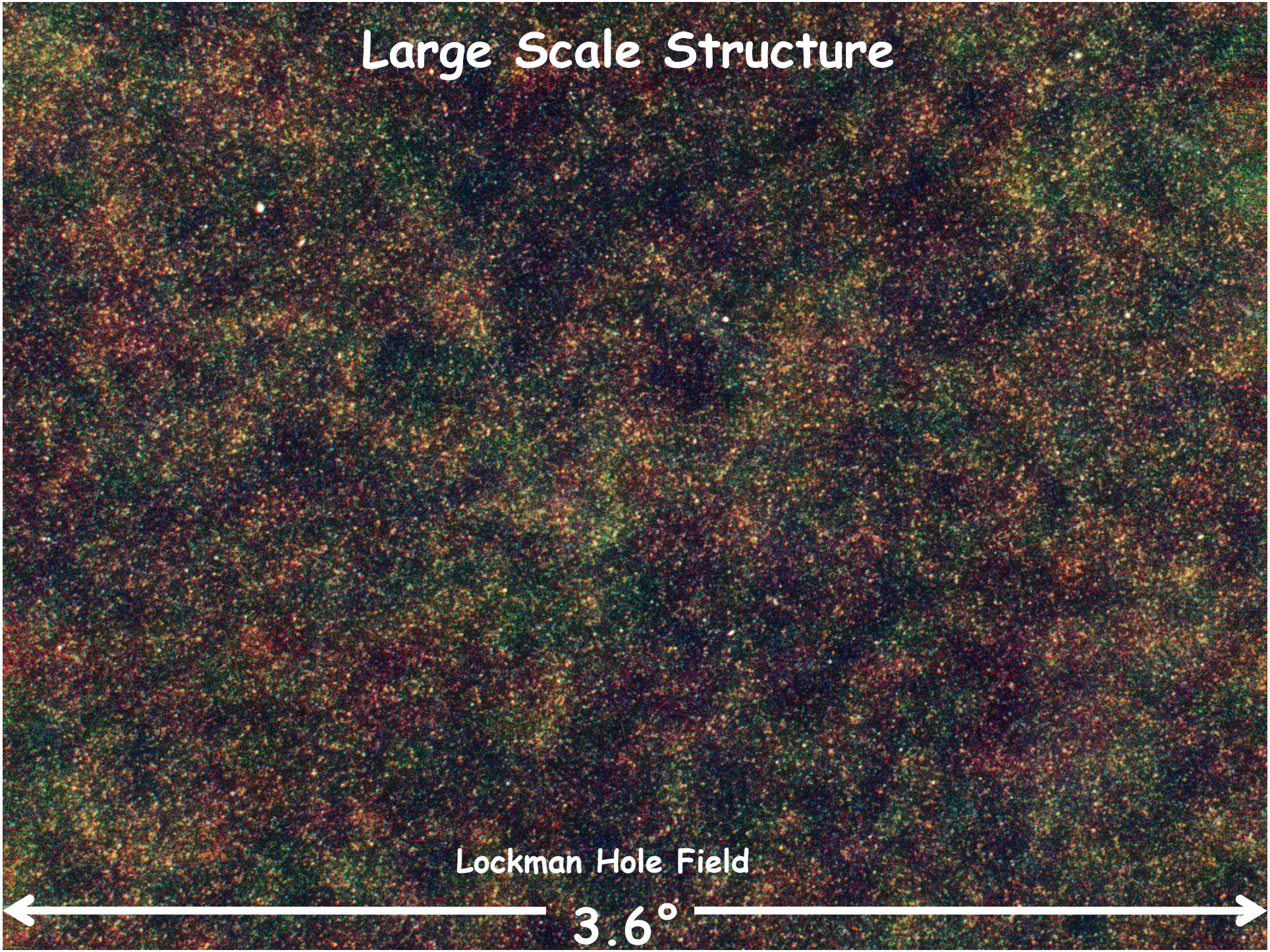


Herschel/SPIRE [CII] detection



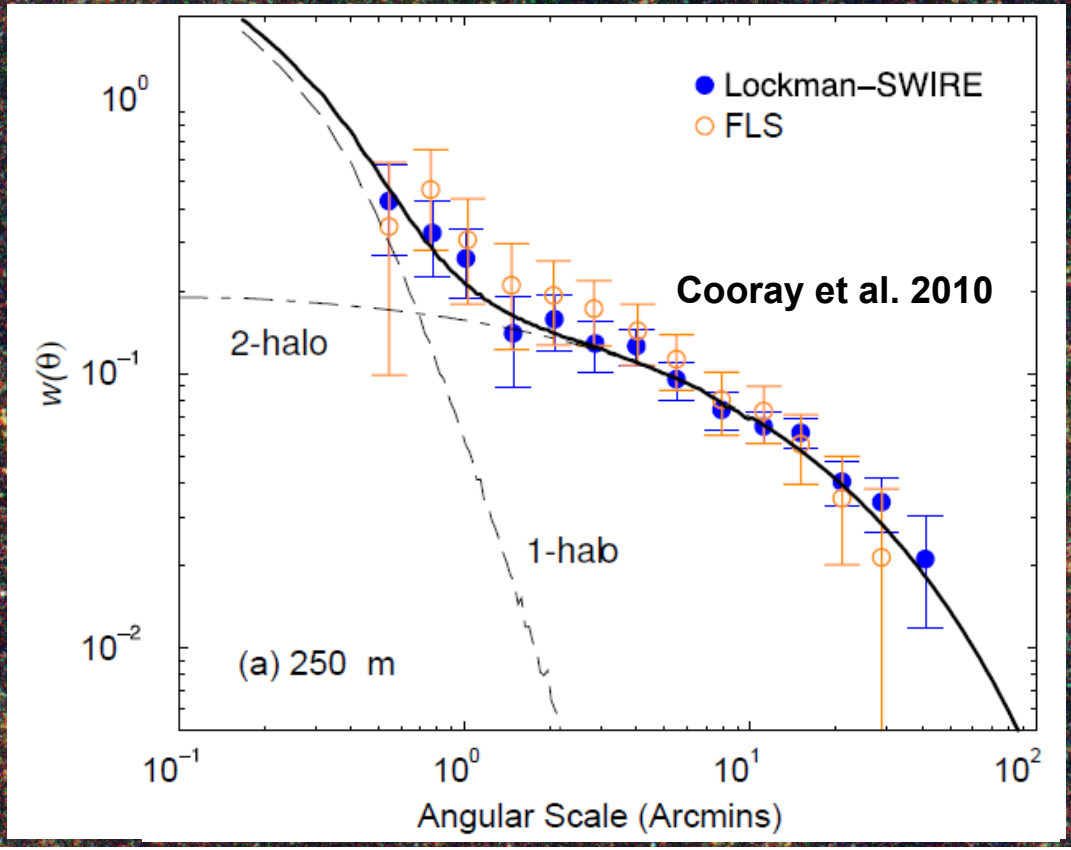
C+ in the 'Eyelash'

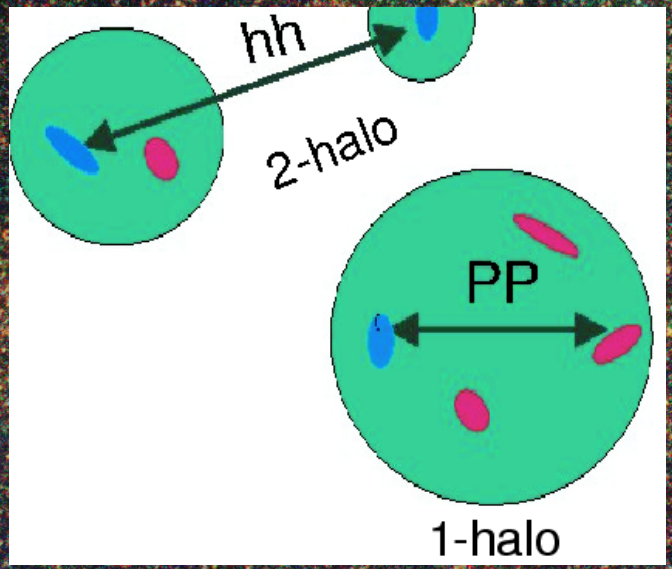



Large Scale Structure
Lockman Hole Field
3.6°

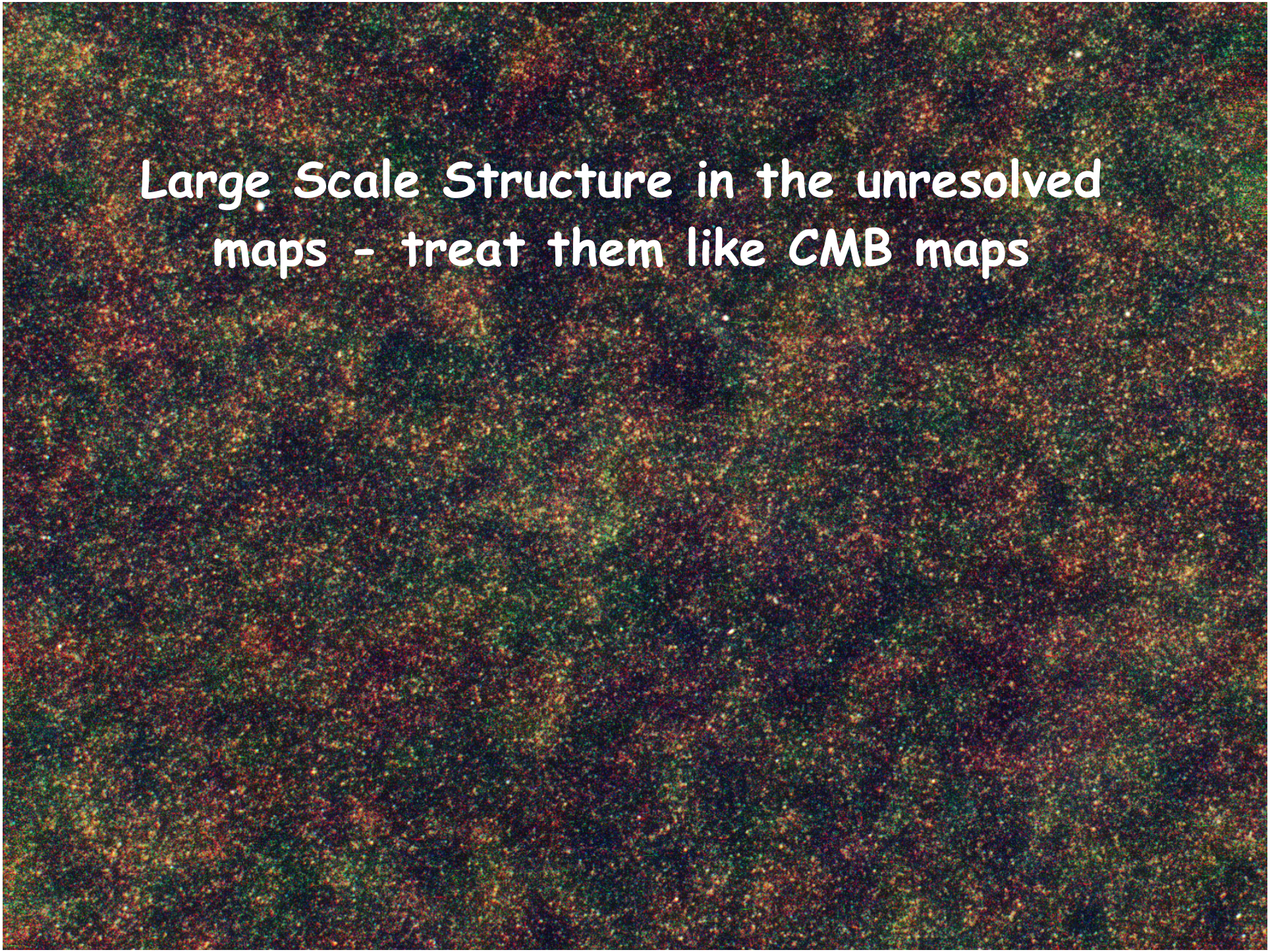
Large Scale Structure

Angular Correlation of Detected Galaxies

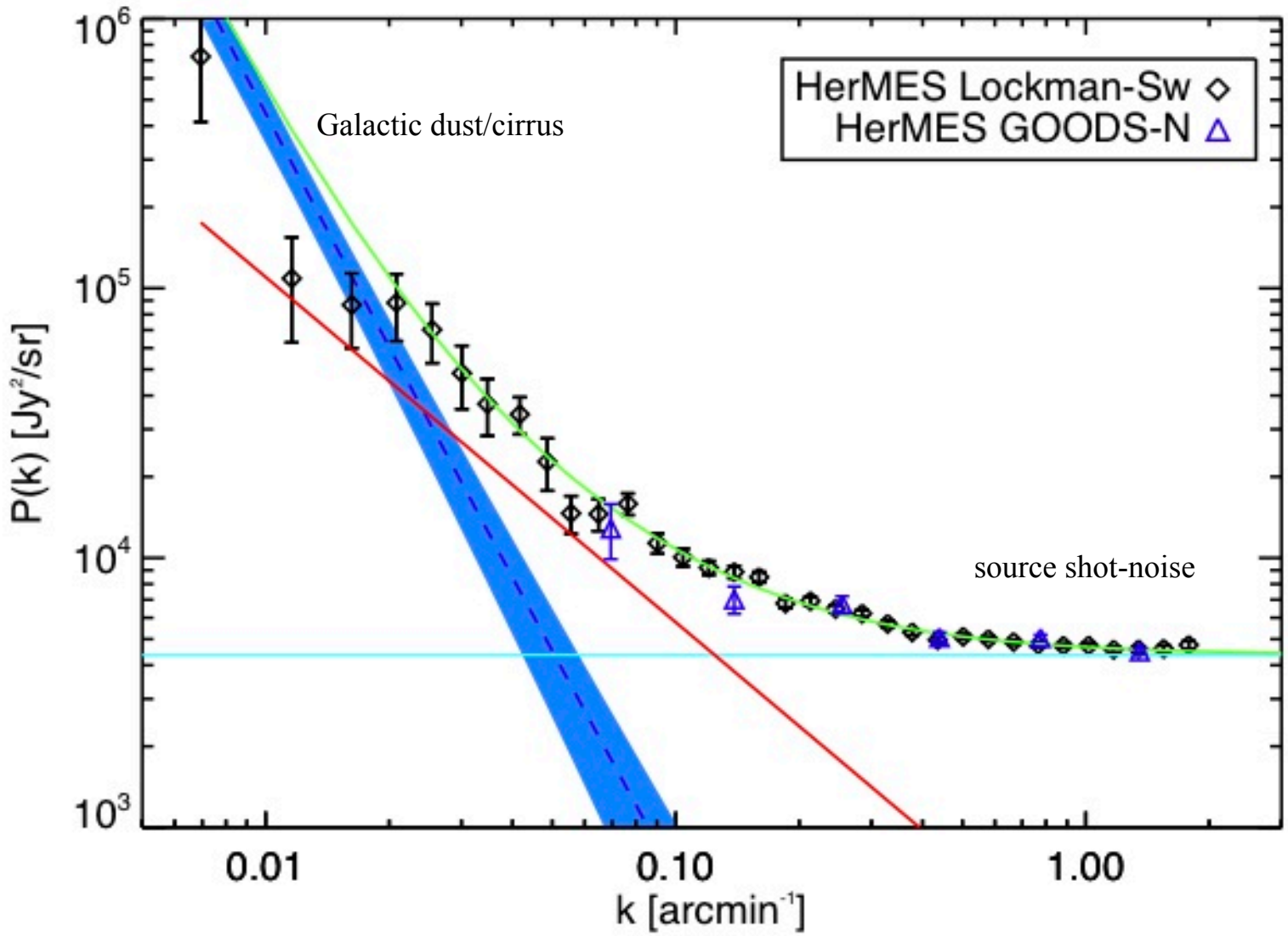




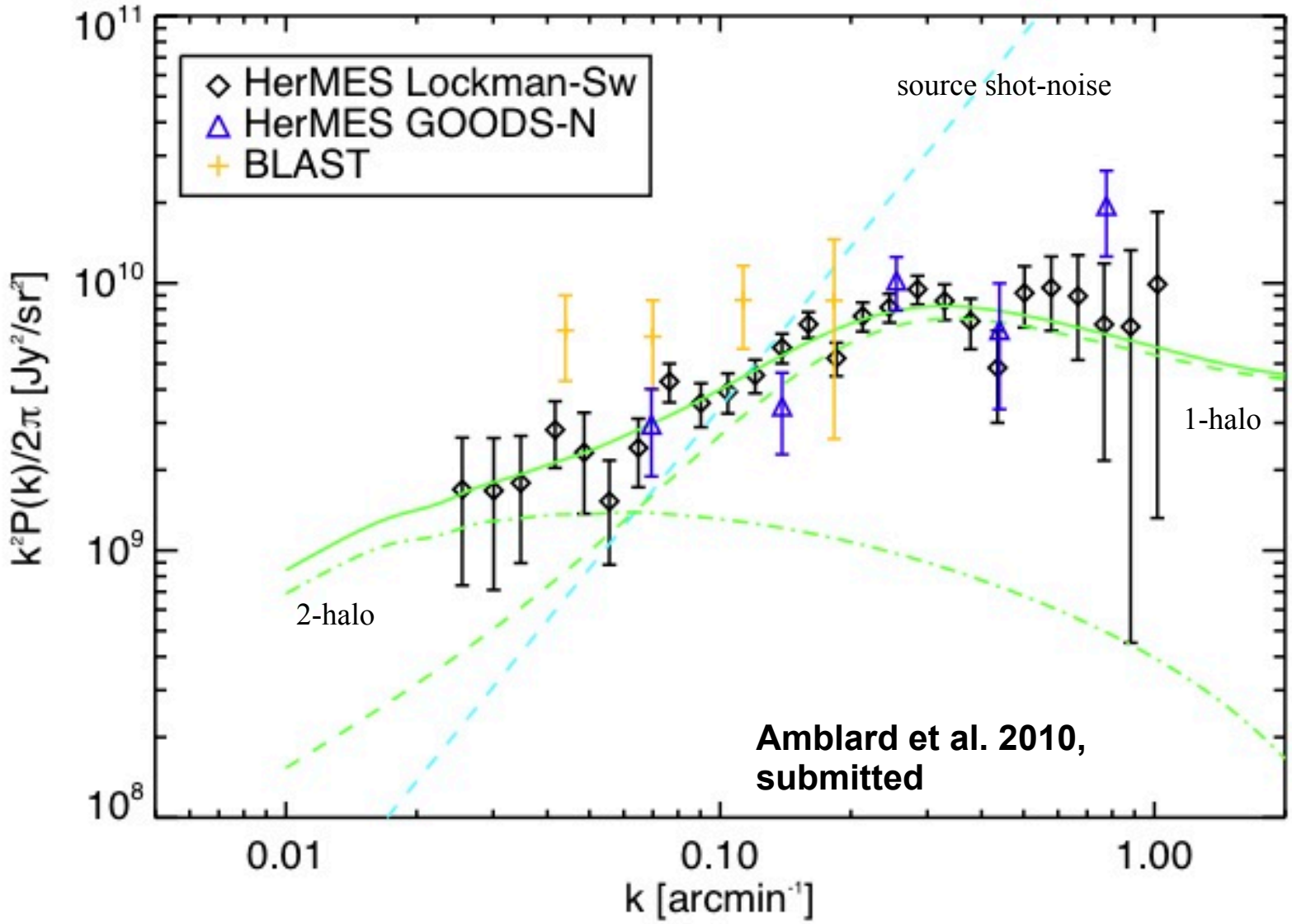
- Spatial clustering of bright SMGs compared to halo model
- Halo needed to host a S_{250} > 30 mJy FIR galaxy: $M = 10^{12.6}\ M_{solar}$
- ~15% appear as satellites in more massive halos $M \sim 10^{13.1}\ M_{solar}$
- Population statistics consistent with so-called "dust obscured galaxies"


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

Spatial Power Spectrum of Background

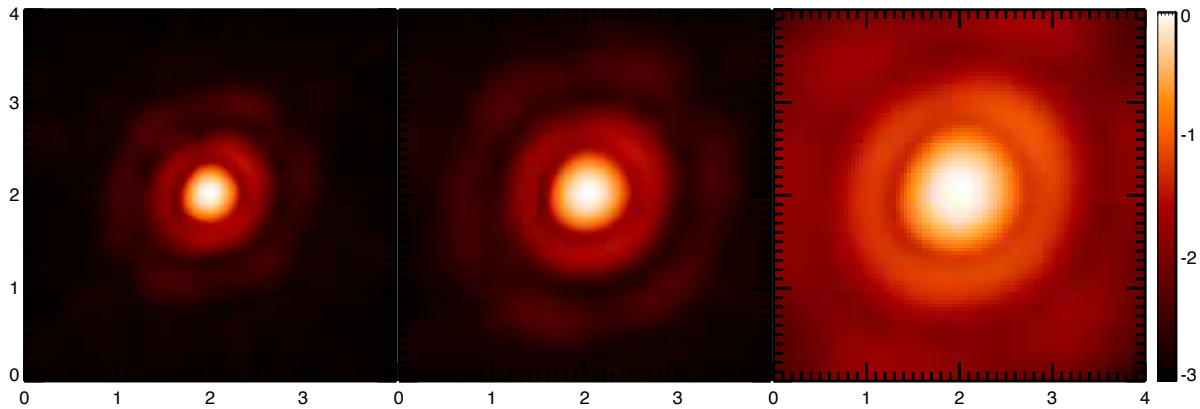


Spatial Power Spectrum of Background

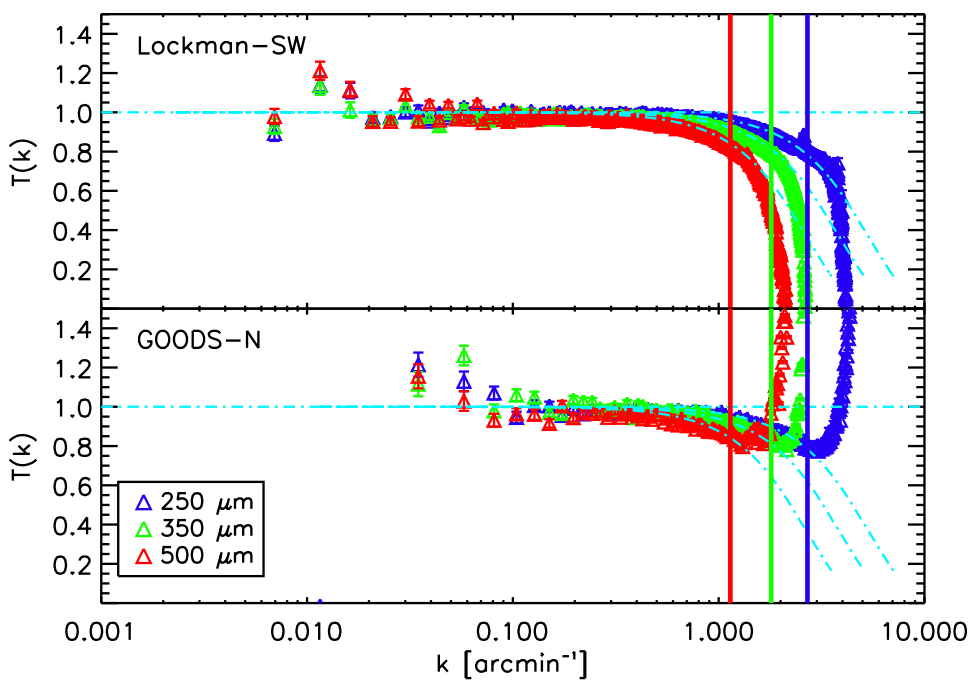


Amblard et al. 2010, submitted

Spatial Power Spectrum of Background

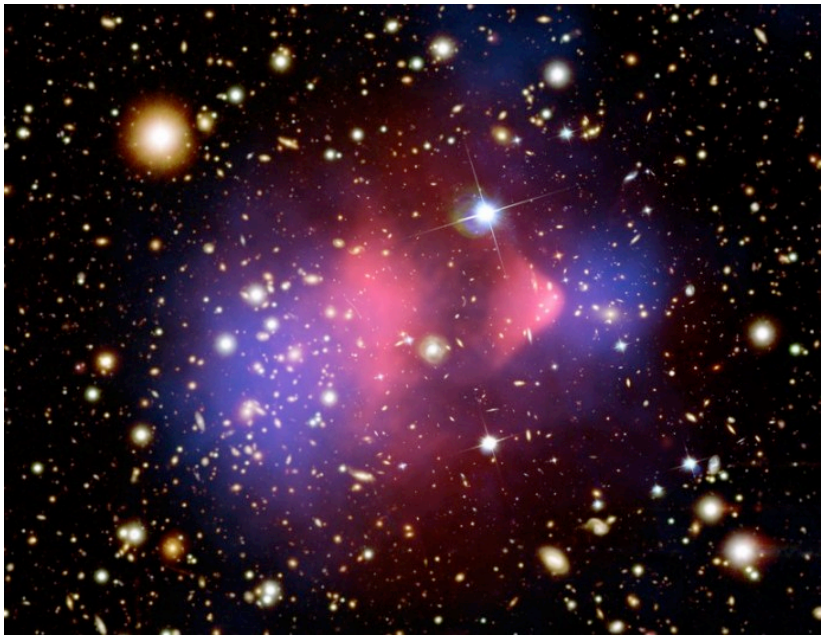


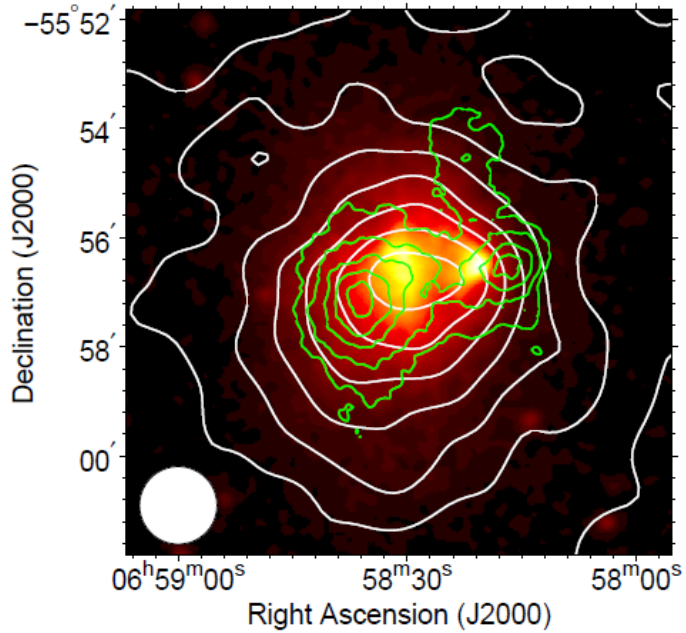
Neptune beam maps (700 scans across Neptune)

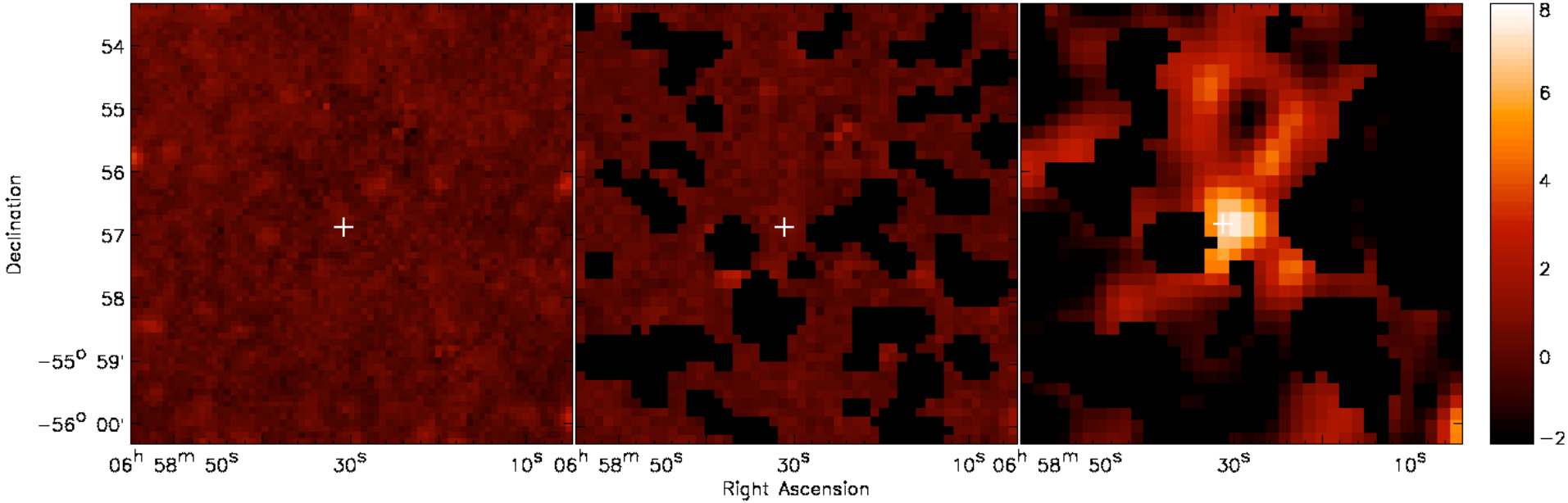


Map-making transfer function (sky through an instrument simulator to maps pipeline)

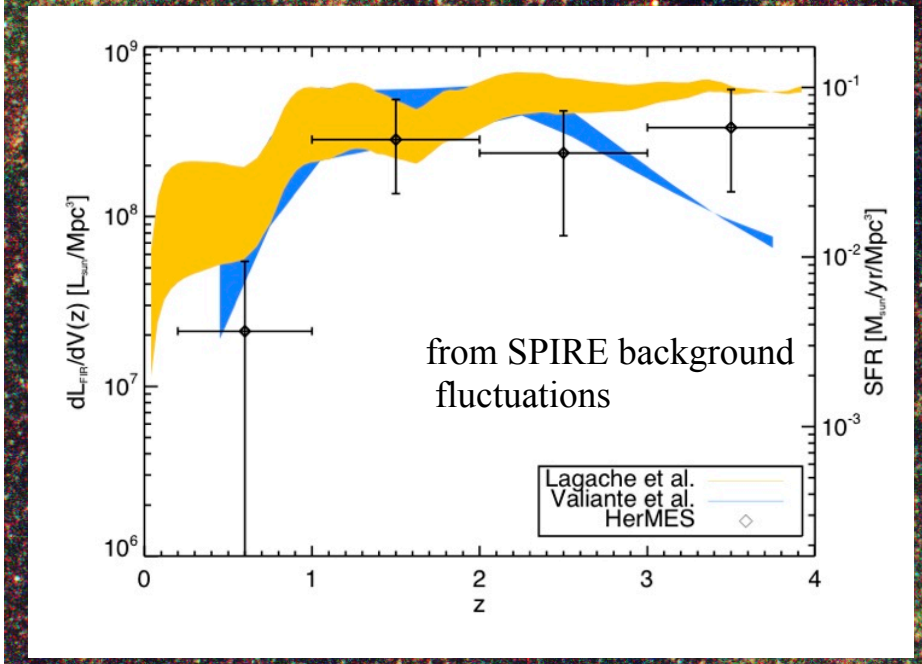
Imaging the Bullet Cluster







Where is the bulk of the far-IR Background Produced?



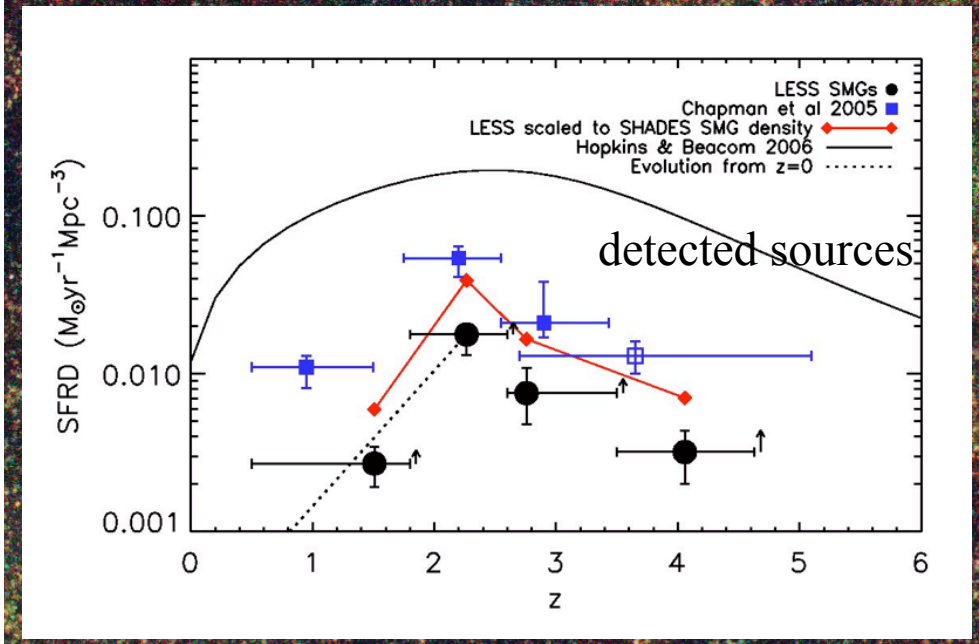
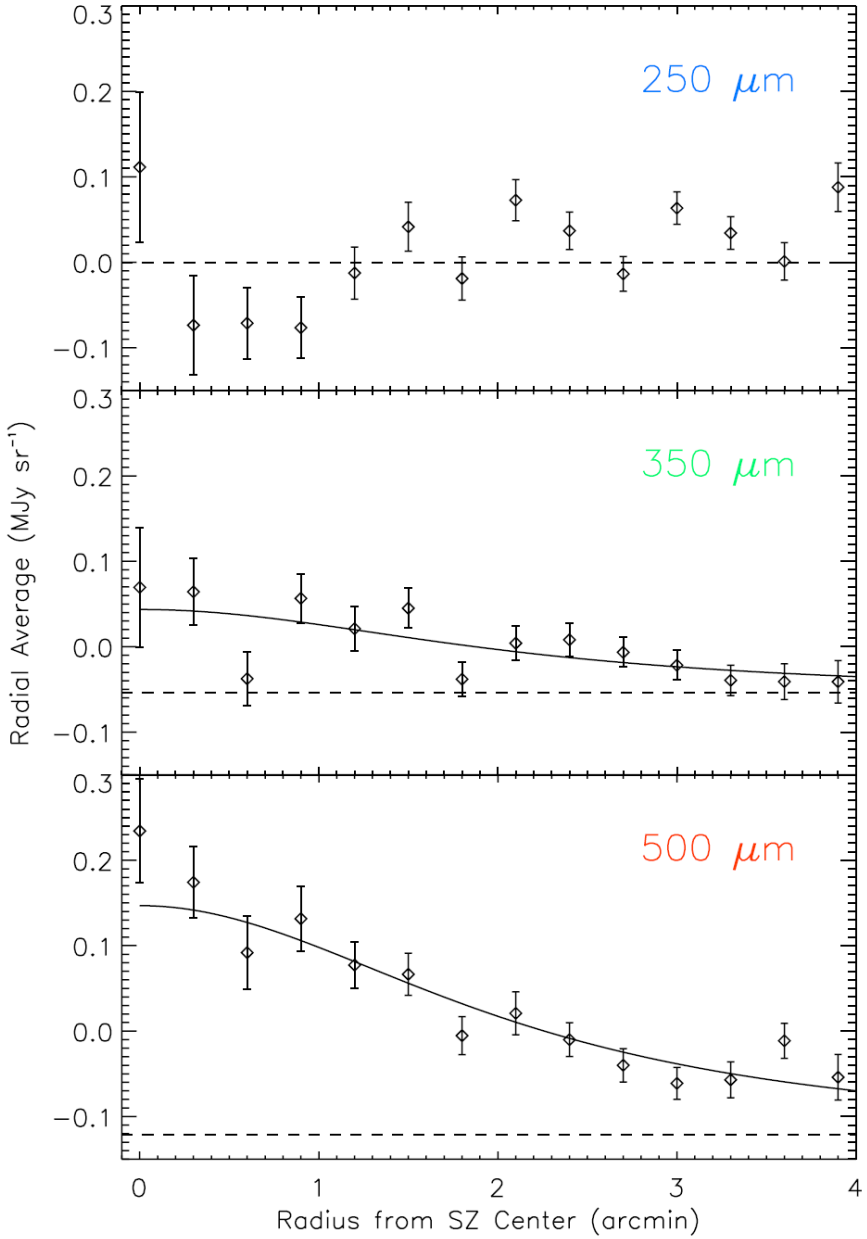


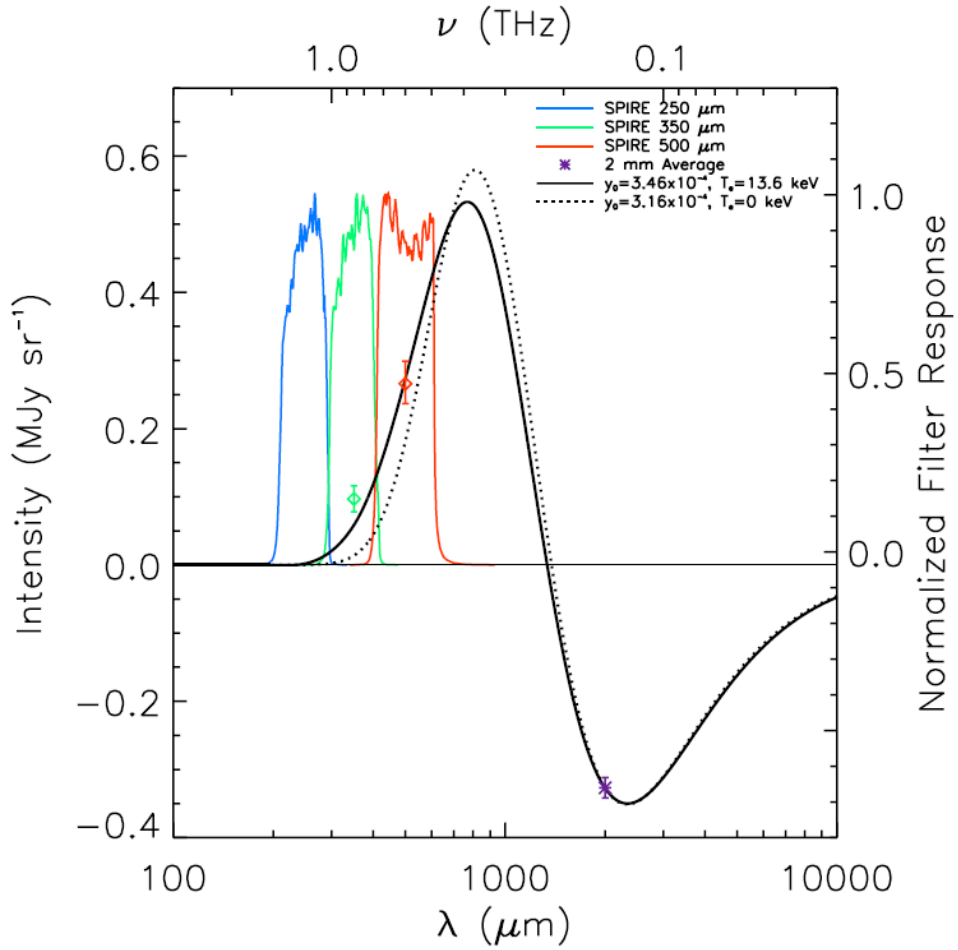
Table 2: Halo model best fit values

	$log[M_{\rm min}/M_\odot]$	α	$\langle b \rangle_z$	shot-noise (Jy^2/sr)	χ^2/d.o.f.
250 μm	$11.1^{+1.0}_{-1.1}$	1.6 ± 0.2	$2.0^{+0.9}_{-0.1}$	6139^{+23}_{-113}	0.77
350 μm	$11.6^{+0.8}_{-1.6}$	1.8 ± 0.2	$2.4^{+1.0}_{-0.1}$	4607^{+19}_{-101}	1.02
500 μm	$12.0^{+0.4}_{-2.0}$	1.8 ± 0.2	$2.8^{+0.5}_{-0.3}$	1885^{+45}_{-59}	1.46

Halo mass scale for efficient star-formation in the universe is about 10^{11} M_{sun} (Bouche et al. 2010 for a prediction based on stellar masses and "downsizing")

Detecting the SZ Effect with Herschel!





Zemcov et al. 2010

Herschel Followup: A new paradigm

SCUBA followup: deep VLA to get radio positions, Keck spectroscopy at radio positions; took a 4 year effort to get the SCUBA z-distribution for 70 or so sources (Chapman et al. 2004,2005)

Herschel HerMES followup: 24 micron Spitzer MIPS as a way to ID counterparts (then 24 micron to IRAC channels); usually we can identify 60% of our sources down to SWIRE depth with Spitzer. 20% no clear counterparts even in deep Spitzer imaging.

Bright lensed source follow-up (lensed, high-z etc): coordinates to SMA and other sub-mm facilities, coordinates to CO spectrometers and CO imaging facilities (CARMA, PdBI, GBT). IR IFU spectroscopy on CO redshifts. *No blind optical redshift measurements attempted.*

We seem to be finding about ~0.5 to 1 very bright lensed source per sq. degree (500 micron > 100 mJy and 870 micron > 20 mJy).

The expectation is Herschel will find about ~300 lensed SMGs in HerMES and H-ATLAS.

large programs at SMA, CARMA, PdBI, GBT (Zpectrometer), z-spec

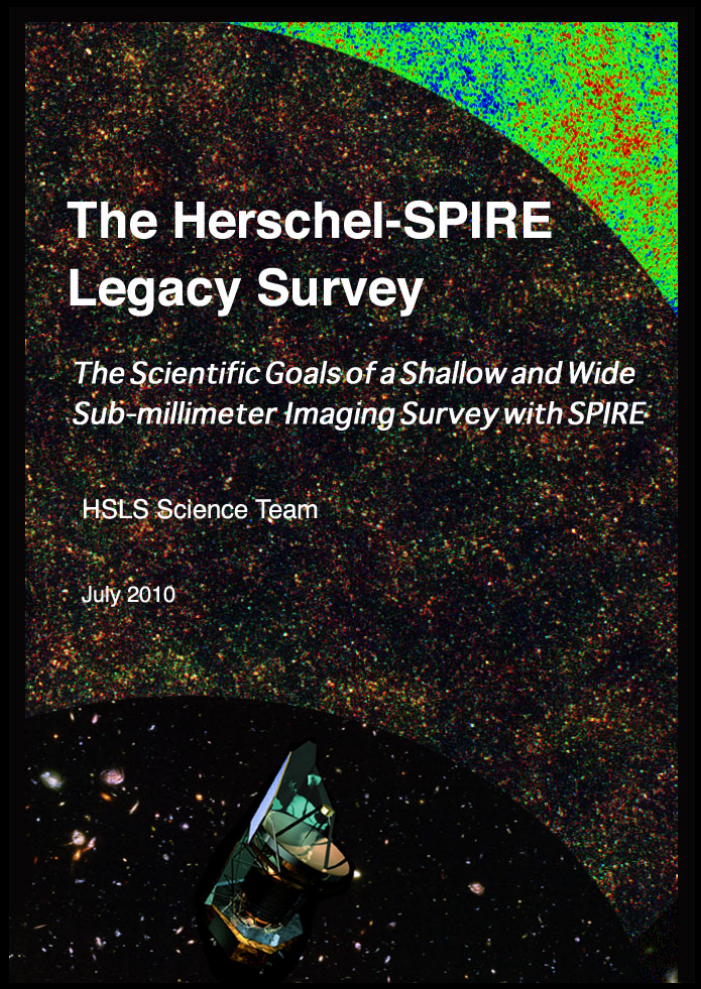
The era of sub-mm astronomy:

Telescope	Instrument	Frequency Range	Bandwidth
GBT	Zpectrometer	25.6 – 36.1 GHz	34%
CSO	Z-Spec	190 – 305 GHz	46%
CSO	ZEUS[a]	632 – 710 GHz	4%
IRAM 30m	EMIR[a]	83 – 117 GHz	8%
PdBI	WideX[a]	80 – 116 GHz	3.6%
CARMA[a,b]		85 – 116 GHz	8%
EVLA[c]		12 – 50 GHz	53–18%
LMT[c]	RSR	74 – 111 GHz	40%
ALMA[a,c]		84 – 116 GHz	8%

(Frayer et al. 2010)

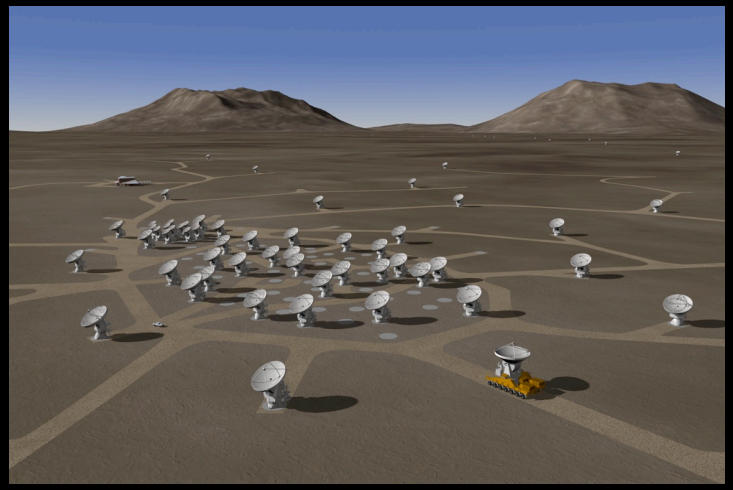
Herschel-SPIRE Legacy Survey (HSLS)

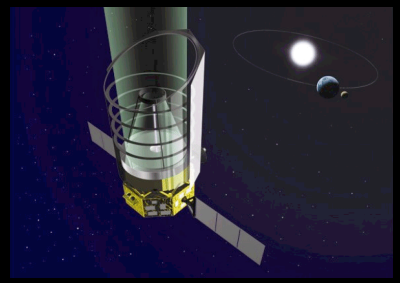
Map 4000 sq. degrees on the sky with SPIRE instrument in fast scan mode starting 2011.
780 hours to complete, single scans in SPIRE fast-mode (60”/sec)

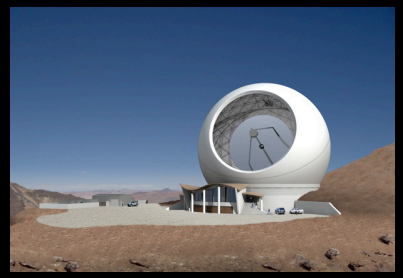


The HSLS will find 2.5 to 3 million dusty galaxies, ~1.5 million at z~2, 10,000 at z>4, ~1000 at z >5. Follow-up targets for ALMA, SPICA etc.
~2000 strongly lensed bright sources easily identified a goldmine for cosmology!

see the HSLS White Paper on the arxiv 1007.3519 now; 250 team members covering all of CMB to Galactic communities.





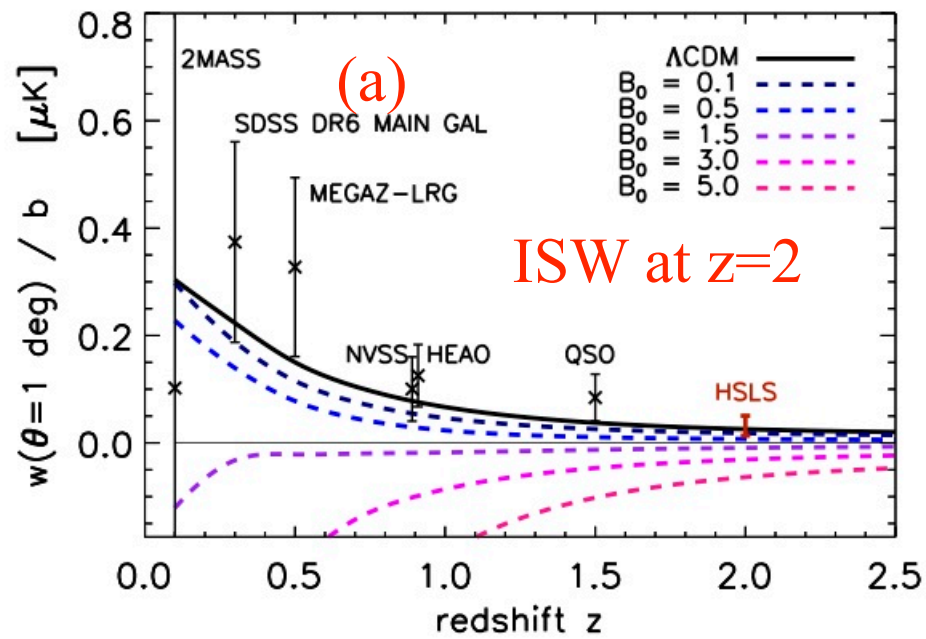


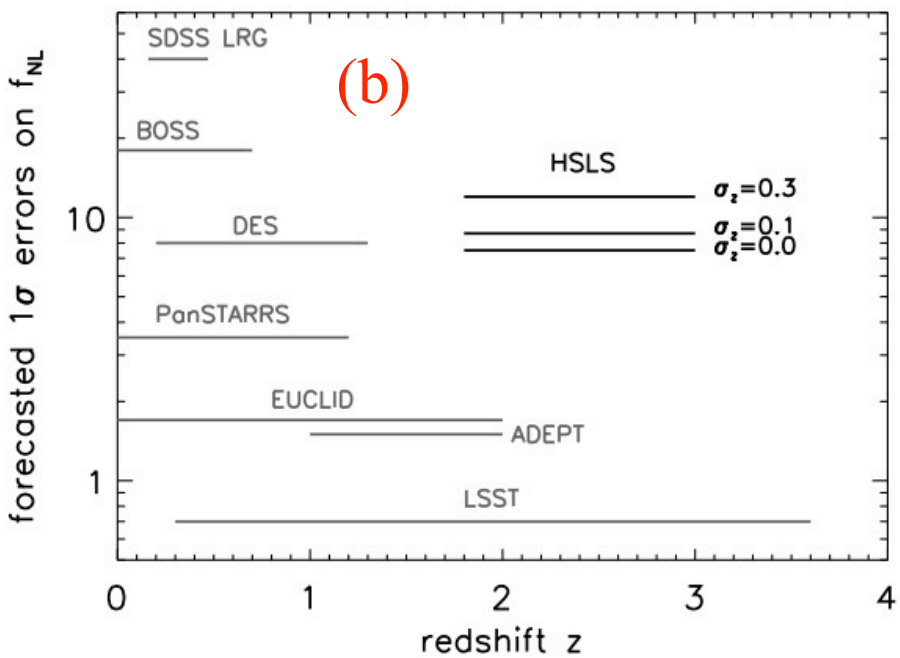
Cosmological Applications with HSLS

(a) ISW at z=2: A strong probe of modified gravity theories for acceleration

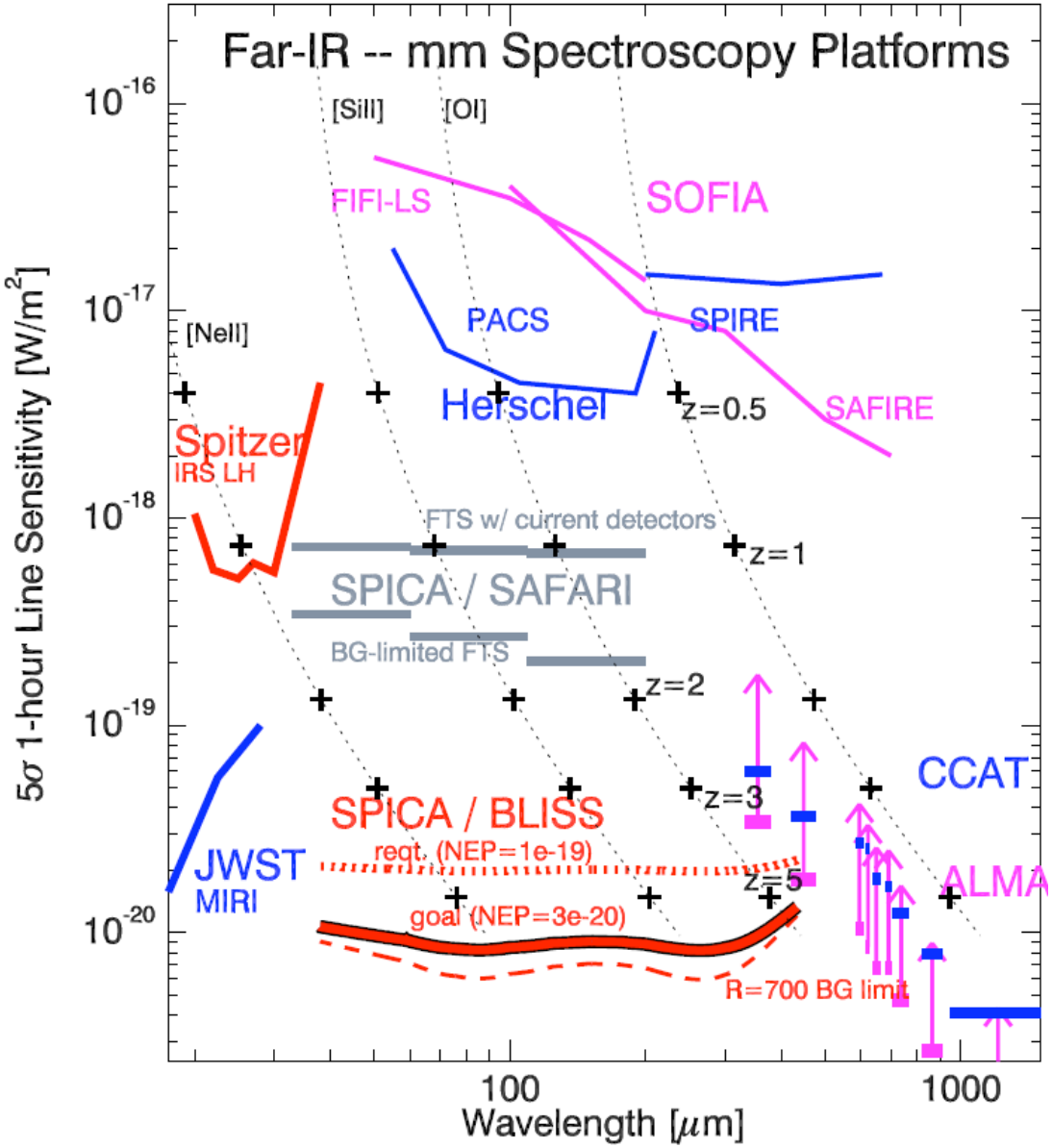
(b) large-scale clustering constrain primordial non-Gaussianity with a higher z probe than Euclid/LSST

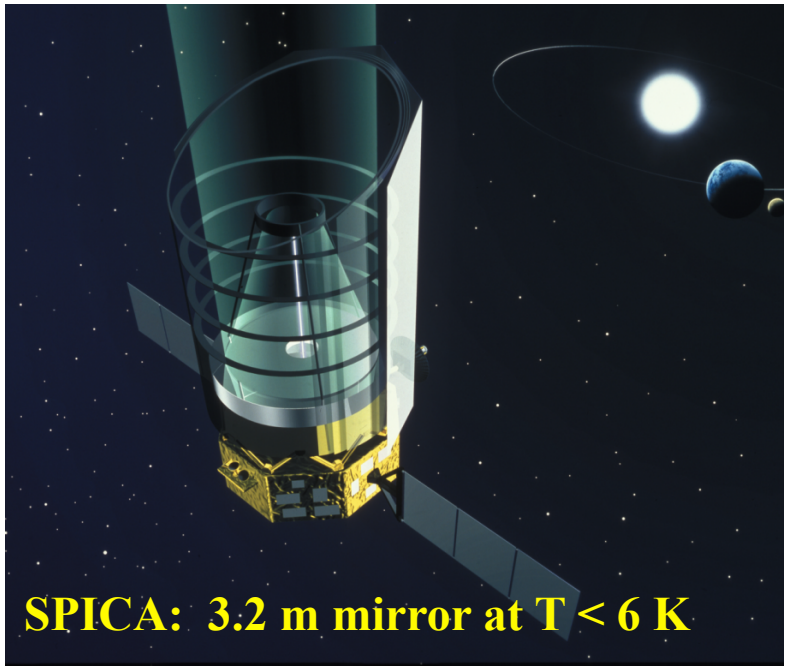
Please see HSLS white paper on the web for more details, arxiv.org:1007.3519



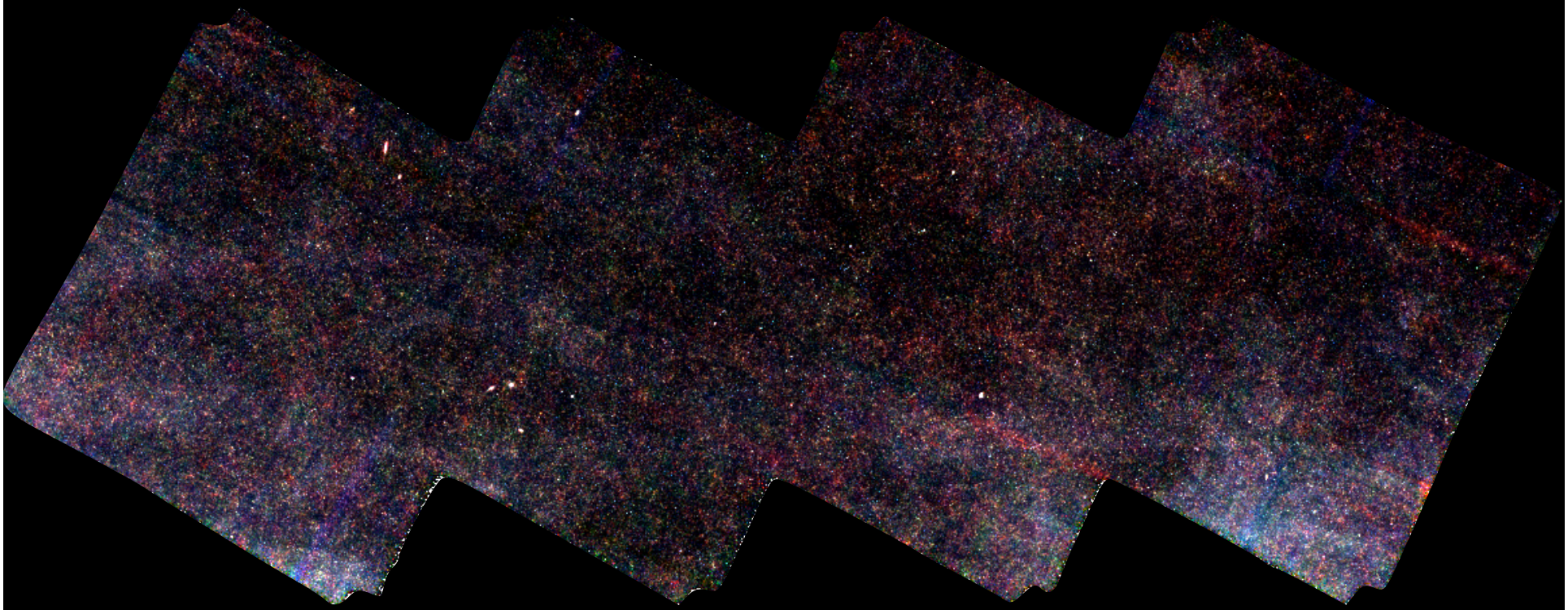


BLISS Spectrometer for SPICA

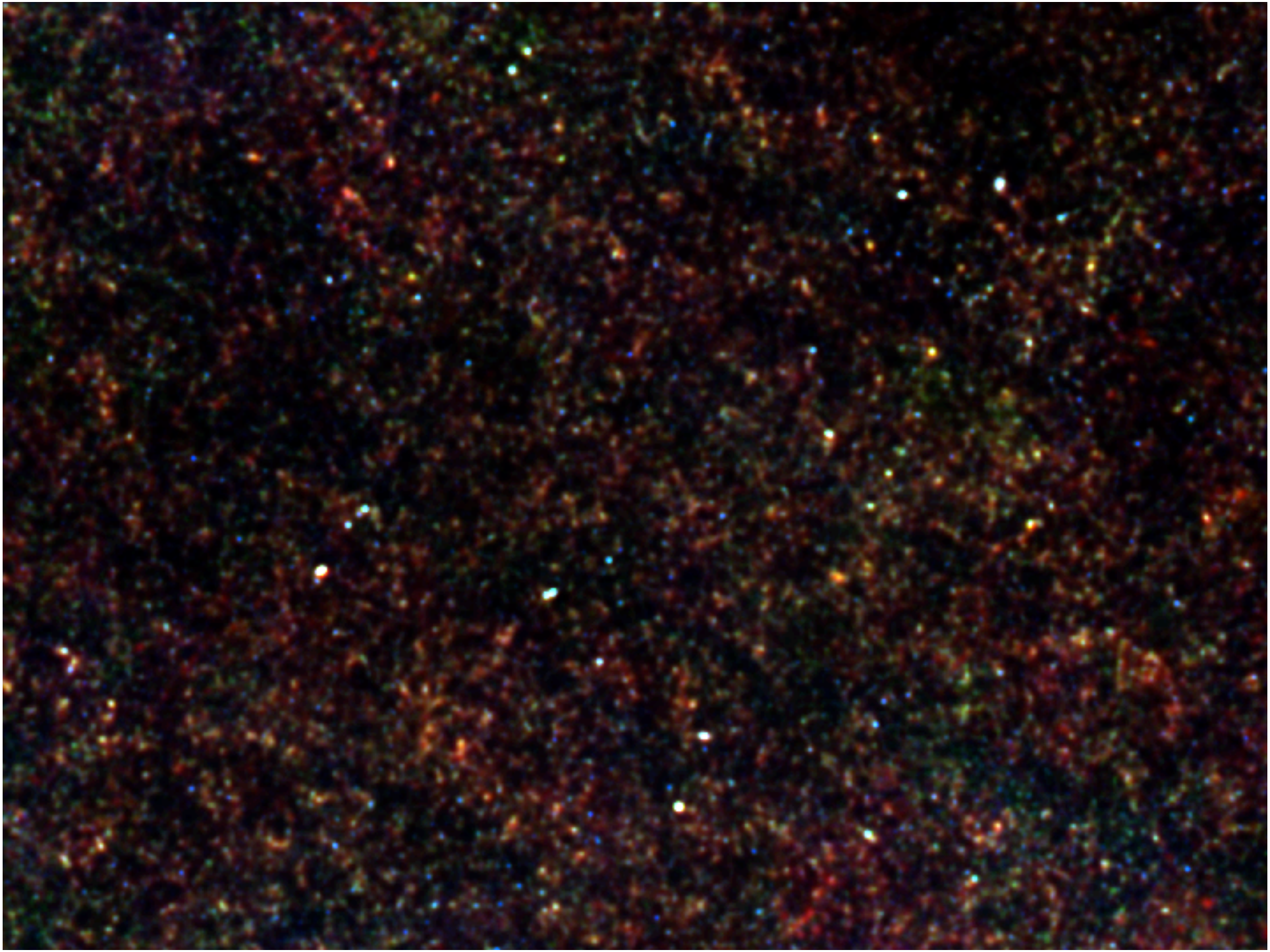




Covering more areas with Herschel



GAMA-15 field, 45+ sq. degrees



Conclusions

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

And after waiting 10 years, we are finally buried in data

More discoveries to come.

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