Results from Herschel-SPIRE

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Cardiff University

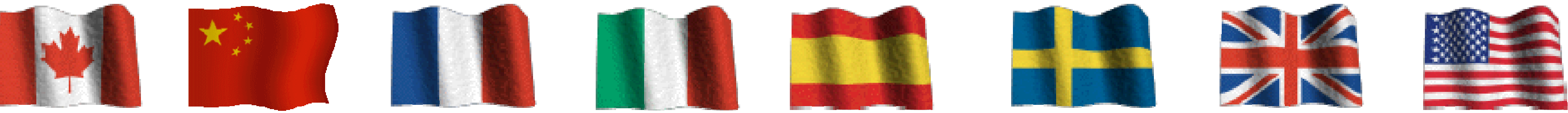
Structure

- Brief intro to Herschel & SPIRE
- Galactic Surveys
- Local Galaxies
- Nearby Galaxies
- Cosmological surveys
- Comments on implications for CCAT as I go along…

Herschel

The SPIRE Consortium

Canada China France Italy Spain Swede UK USA

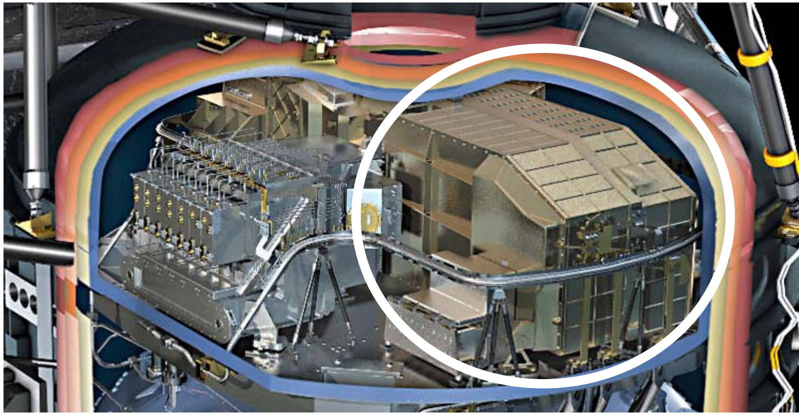


- Cardiff University, UK
- CEA Service d'Astrophysique, Saclay, France
- Institut d'Astrophysique Spatiale, Orsay, France
- Imperial College, London, UK
- Instituto de Astrofisica de Canarias, Tenerife, Spain
- Istituto di Fisica dello Spazio Interplanetario, Rome, Italy
- Jet Propulsion Laboratory/Caltech, Pasadena, USA
- Laboratoire d'Astronomie Spatiale, Marseille, France
- Mullard Space Science Laboratory, Surrey, UK
- NAOC, Beijing, China
- Observatoire de Paris, Meudon, France
- Rutherford Appleton Laboratory, Oxfordshire, UK
- Stockholm Observatory, Sweden
- UK Astronomy Technology Centre, Edinburgh, UK
- University of Colorado, USA
- University of Lethbridge, Canada
- Università di Padova, Italy
- University of Sussex, UK

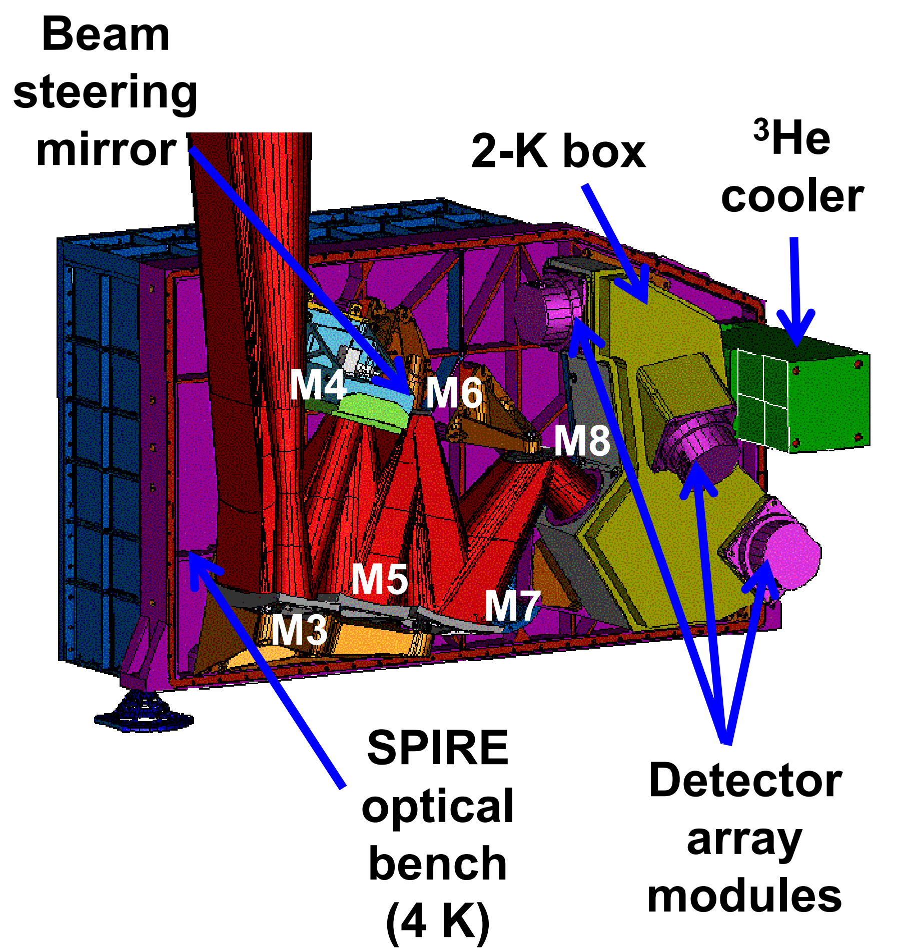
Spectral and Photometric Imaging Receiver

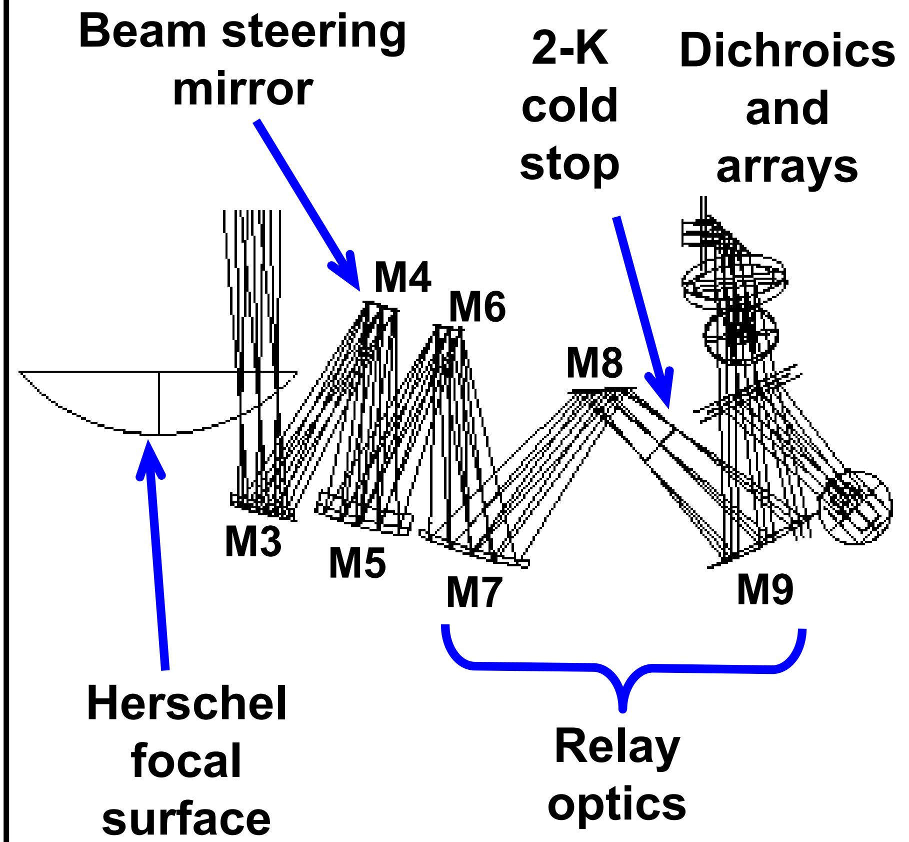
- **3-band imaging photometer**
  - 250, 350, 500 μm (simultaneous)
  - $\lambda/\Delta\lambda \sim 3$
  - 4 x 8 arcminute field of view
  - Diffraction limited beams (18, 25, 36")

- **Imaging Fourier Transform Spectrometer**
  - 194 - 671 μm (simultaneously)
  - 2.6 arcminute field of view
  - Spectral resolution up to $\Delta\sigma = 0.04$ cm^{-1} ($\lambda/\Delta\lambda \sim 1000$ at 250 μm)



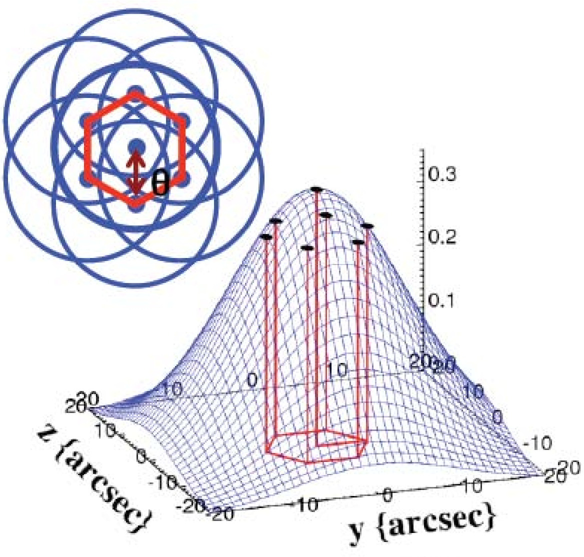
Photometer Layout and Optics



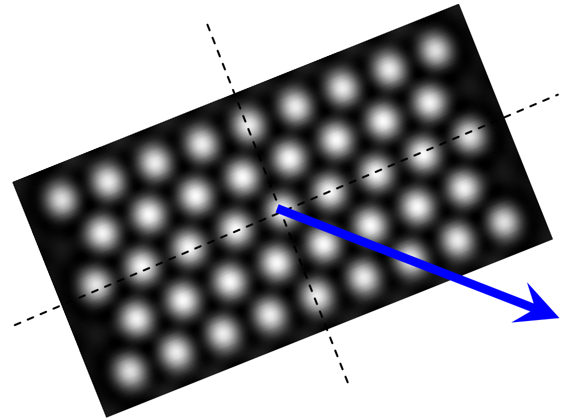


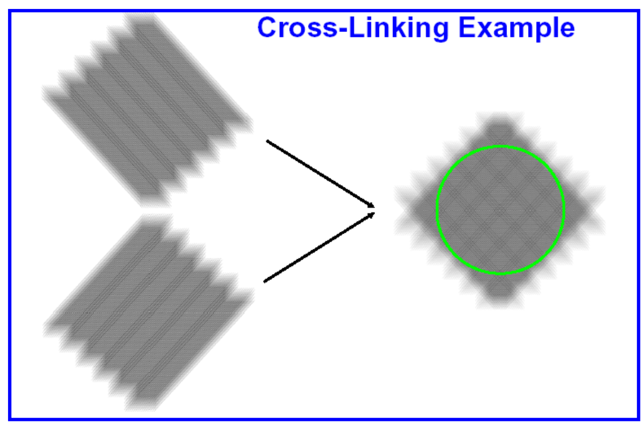
Photometer Observing Modes

Point source: 7-point jiggle



Scan-map

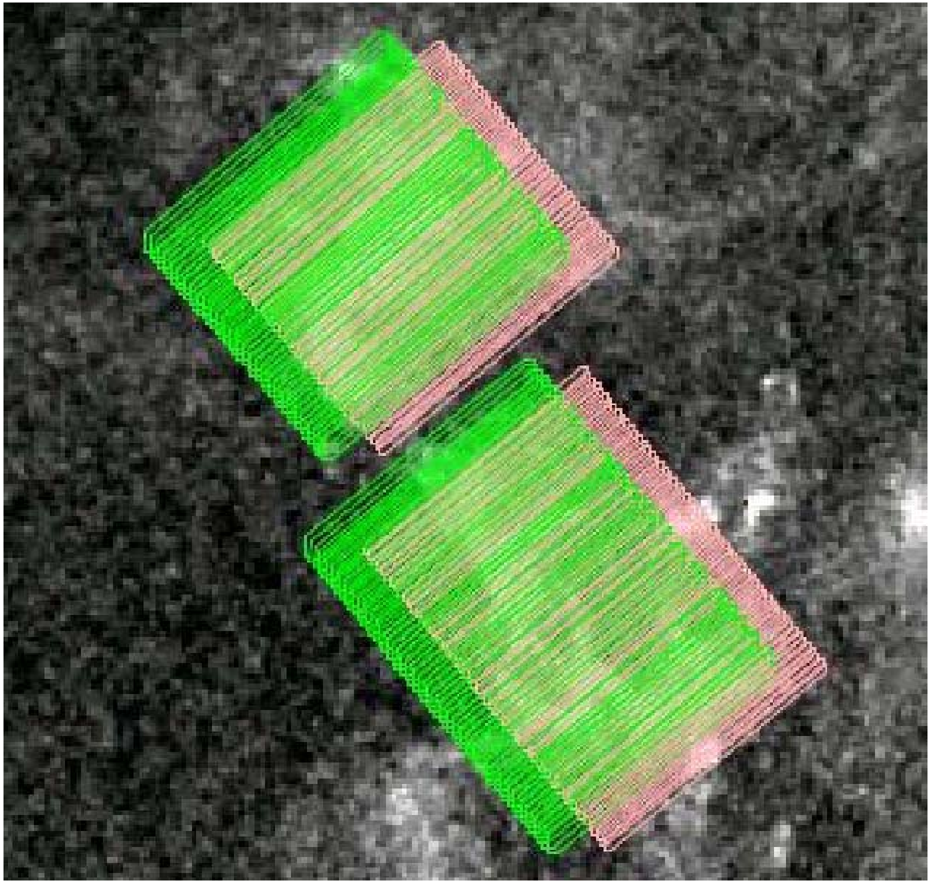


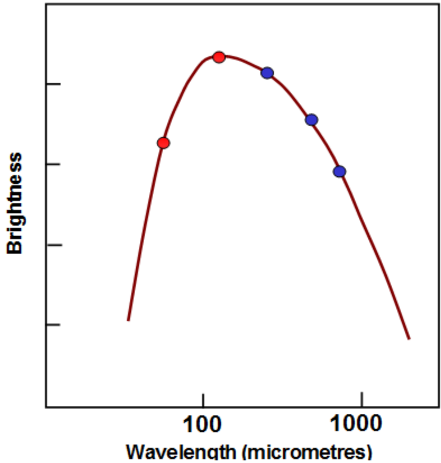


One map repeat = two cross-linked scans

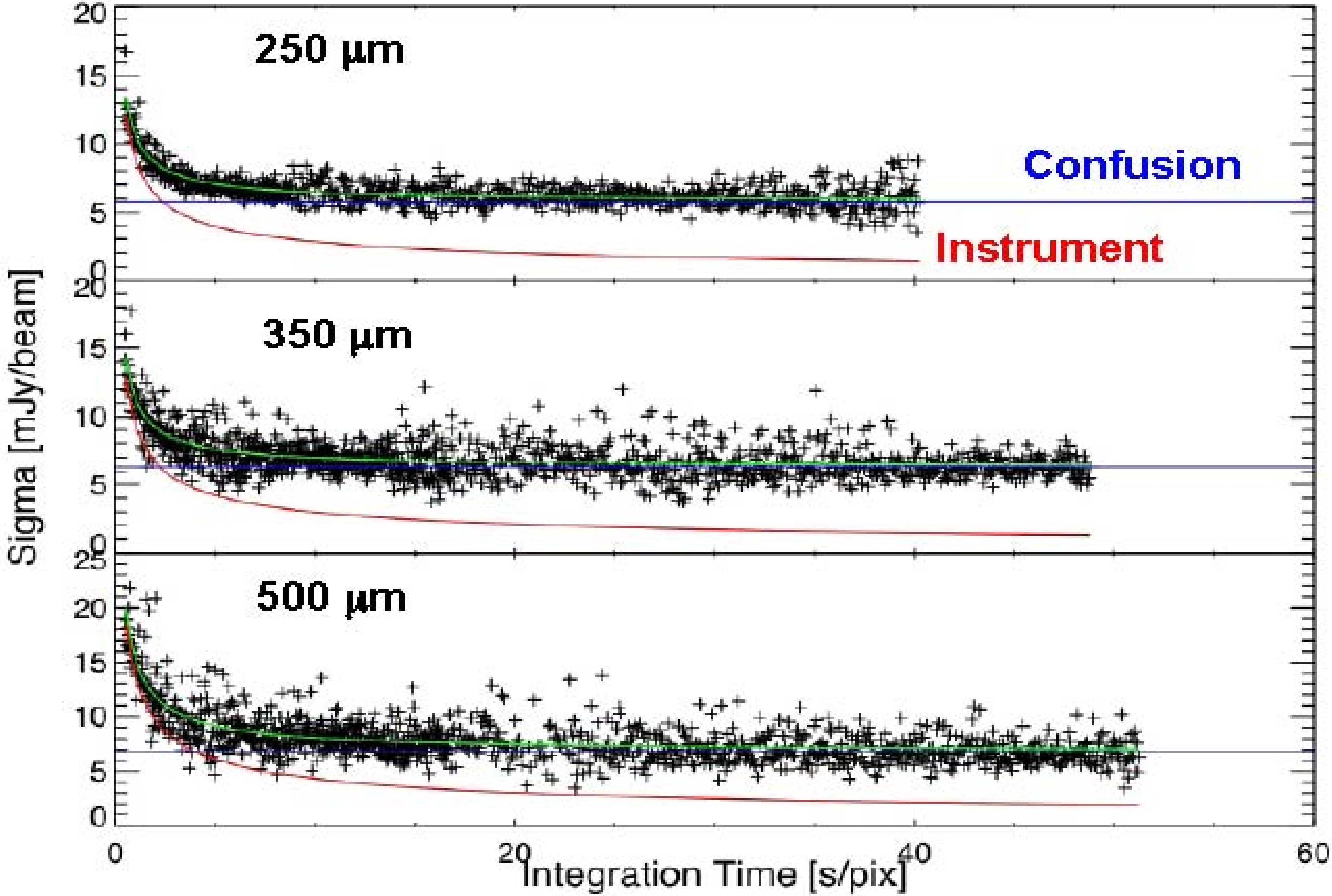
SPIRE-PACS Parallel Mode

- Scan map with SPIRE and PACS
  - Simultaneous 5-band mapping (3 SPIRE and 2 PACS bands)

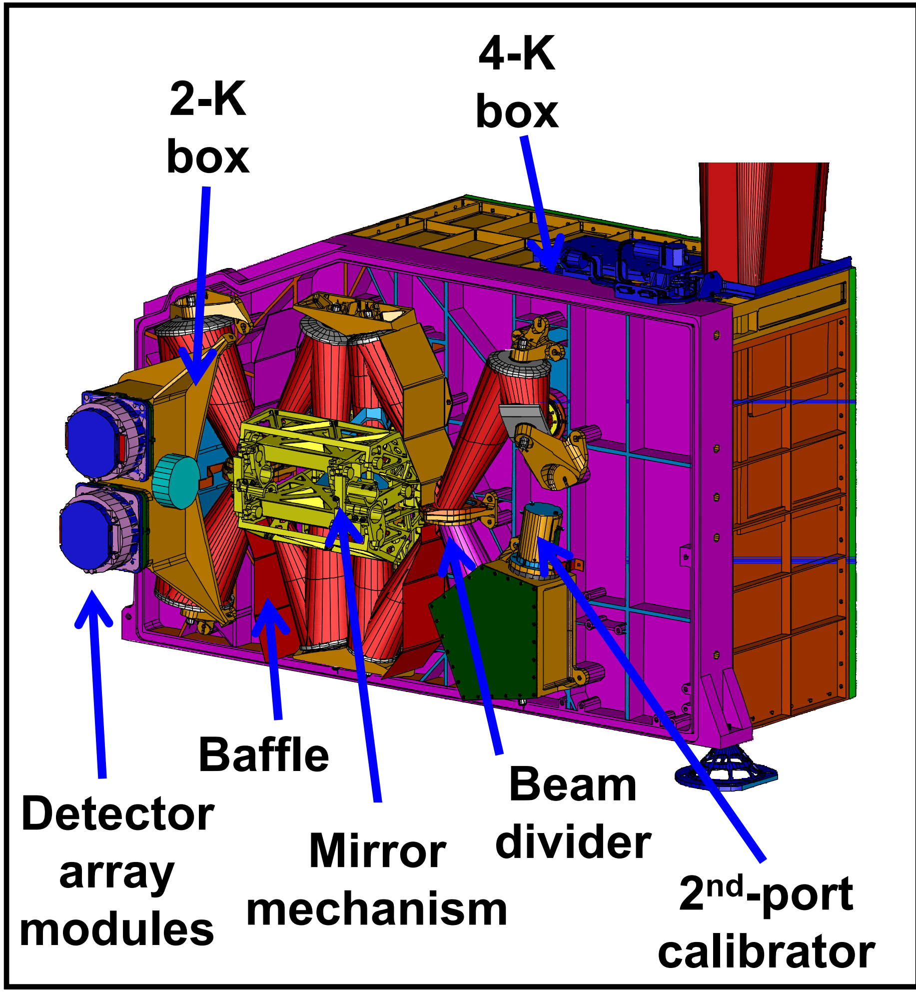


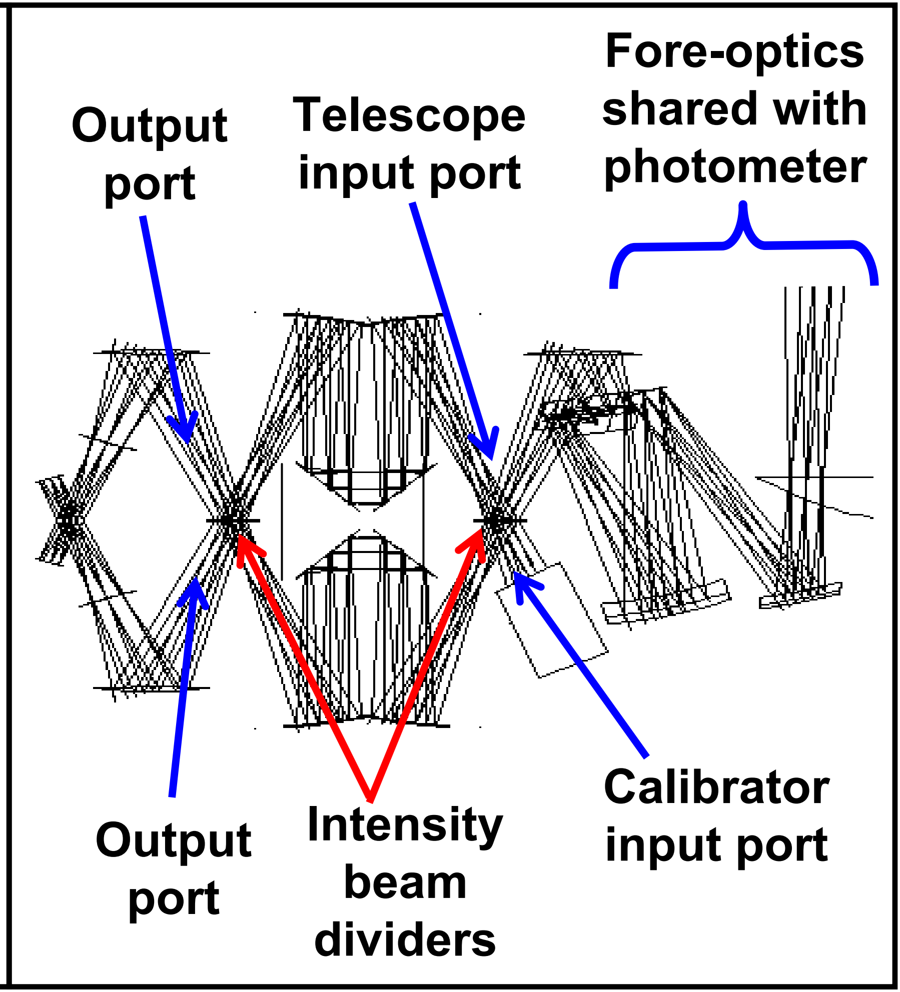


Instrument and Confusion Noise

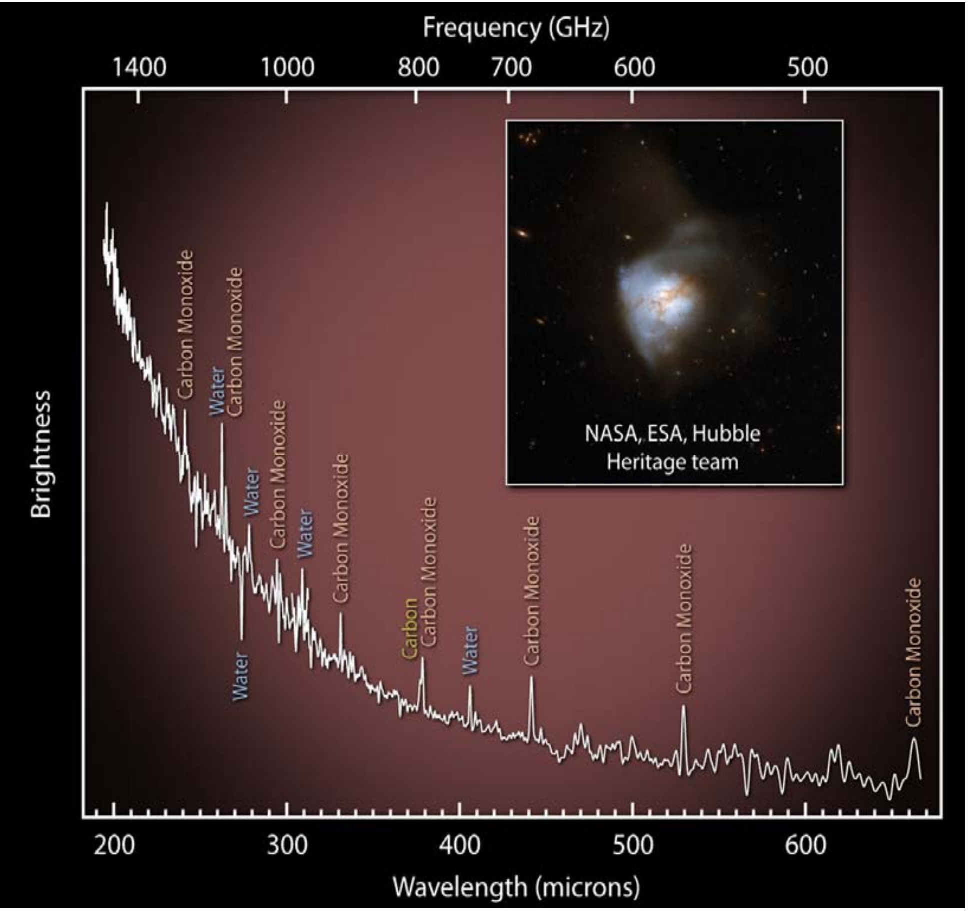


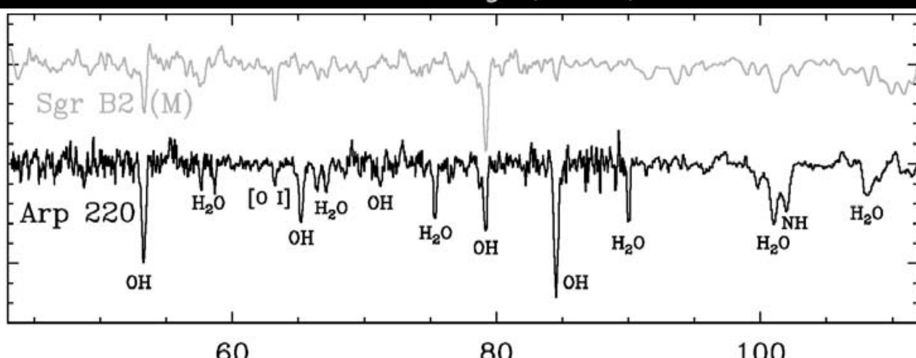
Fourier Transform Spectrometer (FTS) Layout and Optics



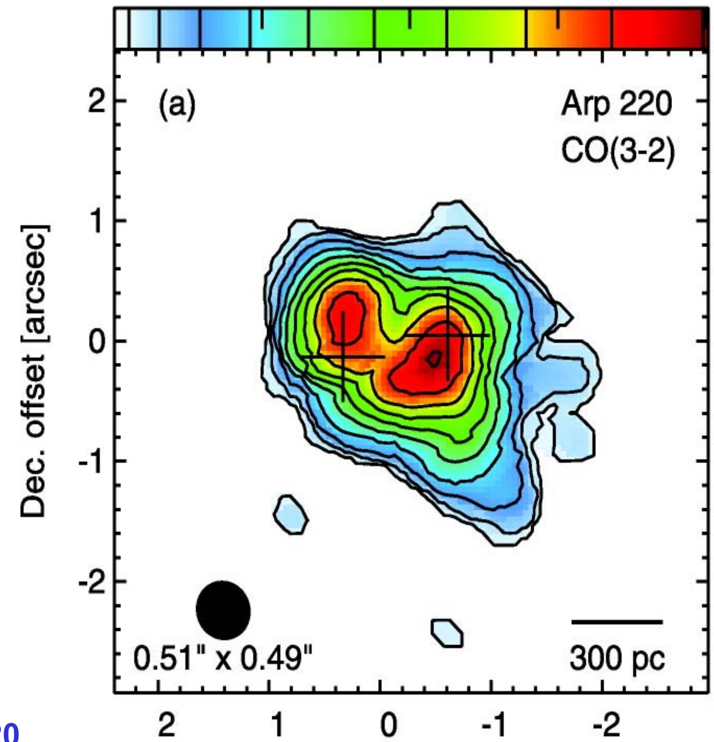


Spectroscopy of ULIRG Arp 220





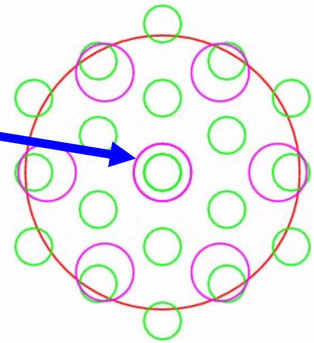
- **Detection of 7 of 8 water lines between 600 and 1210 GHz**
- **Blueshift suggests emission coming from the western nucleus**



Spectrometer Observing Modes
(all now released)

Point source spectroscopy:

Also provides a sparse map

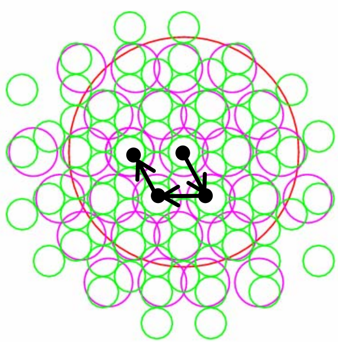


2 beam spacing

2’

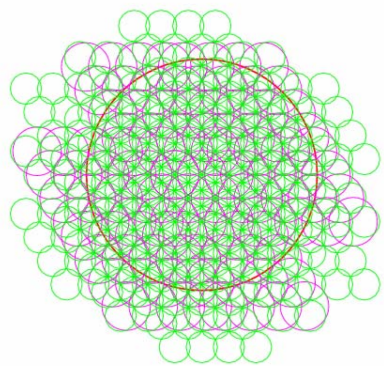
Spectral mapping:

Intermediate image sampling



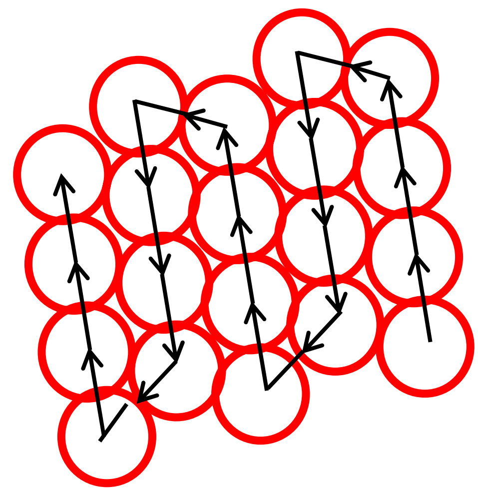
28” spacing
(4 jiggle positions)

Full image sampling



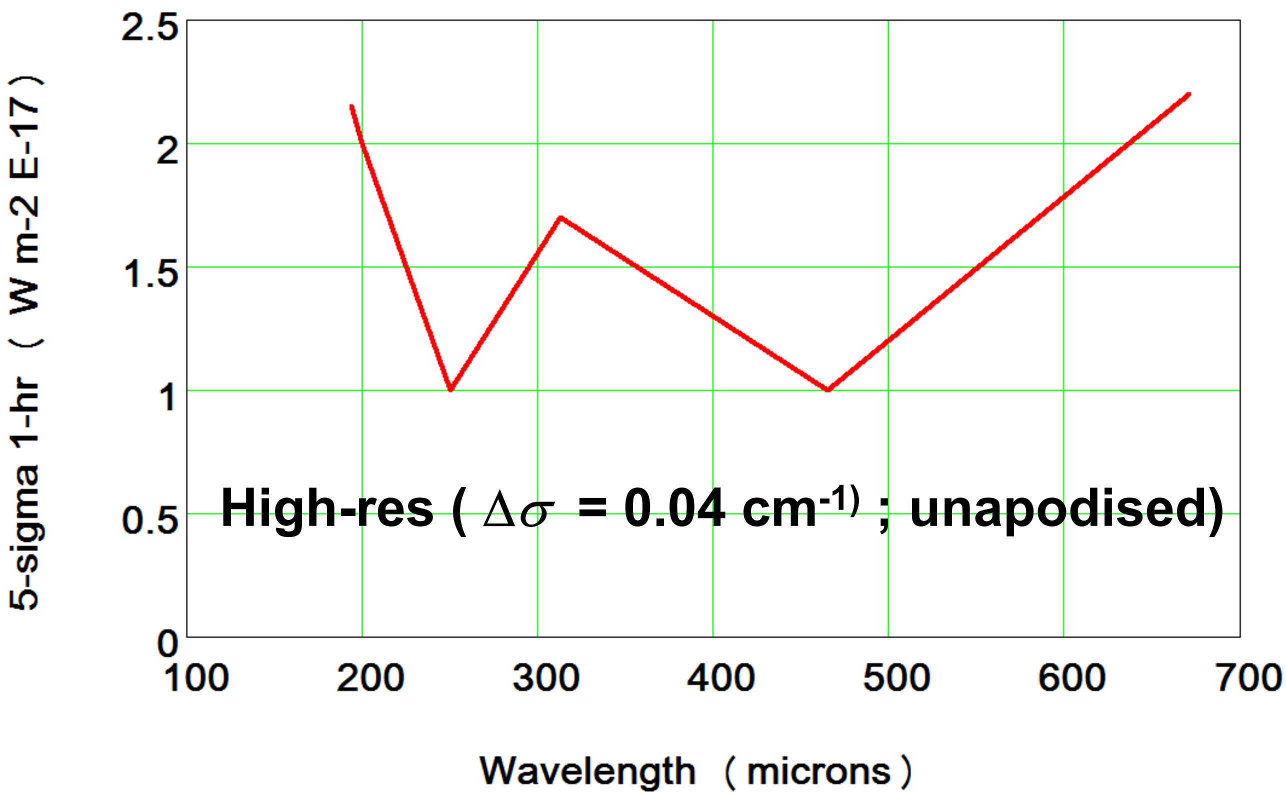
14” spacing
(16 jiggle positions)

Raster mapping for larger fields:



FTS Sensitivity

- **Typical high res. sensitivity (5-σ; 1 hour) achieved with new Uranus calibration:**
  - **1 – 2 × 10^{-17} W m^{-2} (0.8 – 1.7 Jy)**
  - **Better than pre-launch advertised performance (~ 3 x 10^{-17} W m^{-2} 5-σ 1-hr)**



Filaments permeate the ISM on all scales

Herschel

SPIRE 500 µm

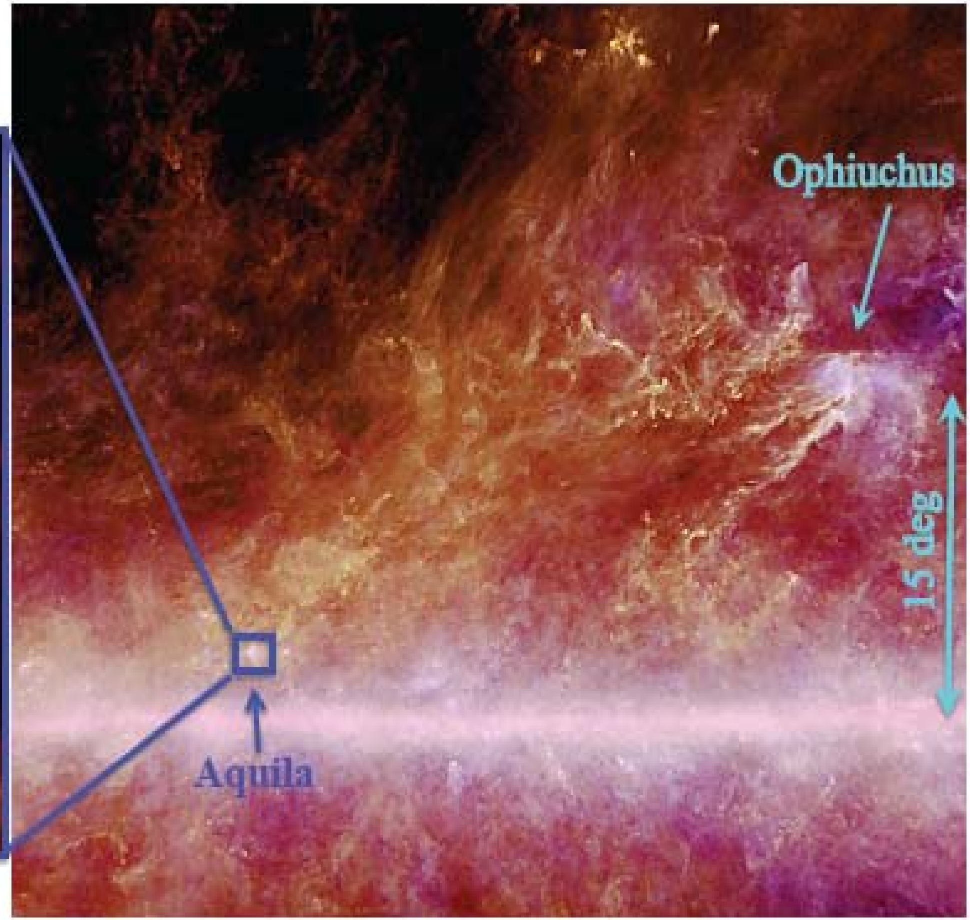
+

PACS 160/70 µm

ESA and the Gould Belt KP

Planck

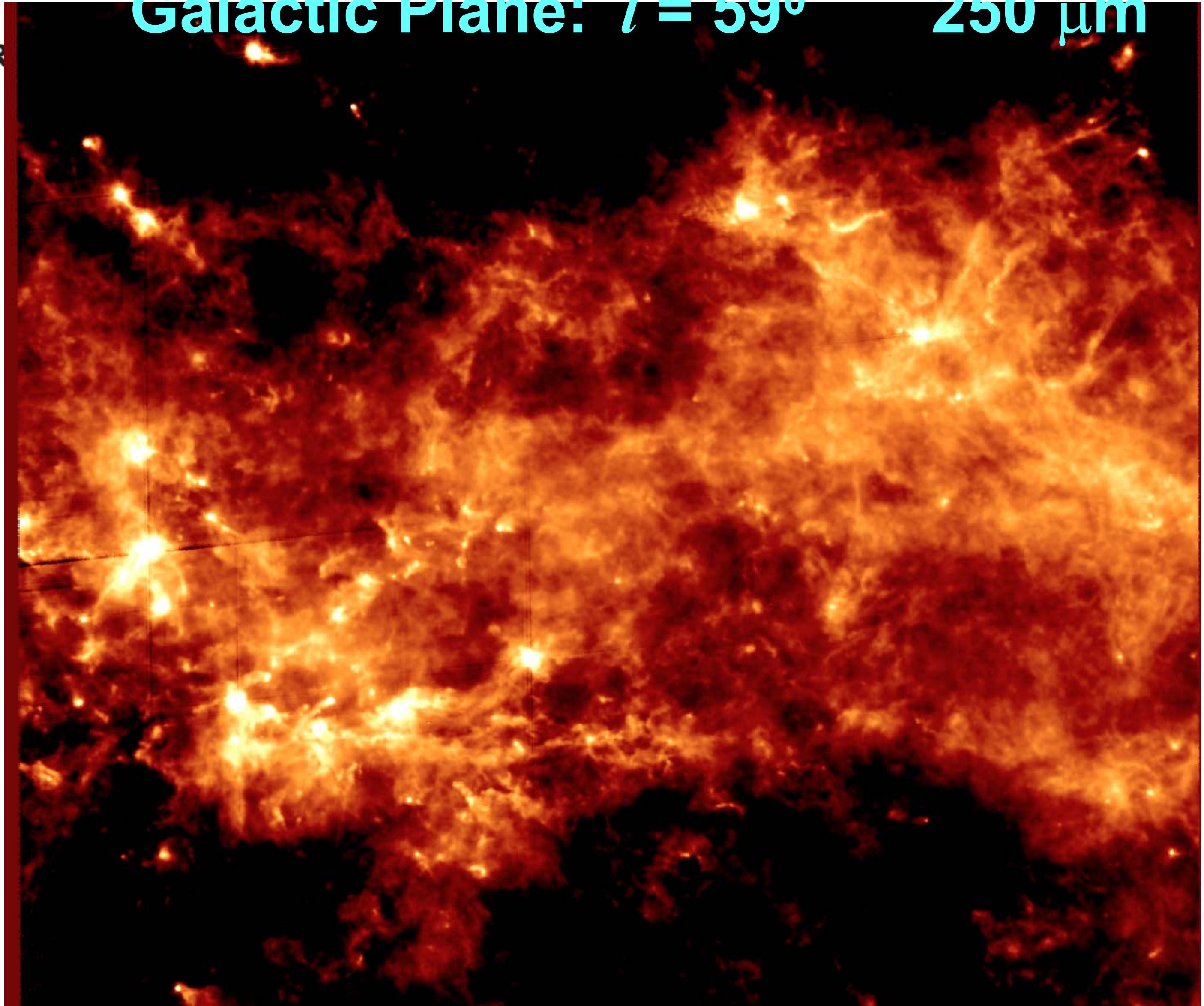
HFI 540/350 µm + IRAS 100 µm



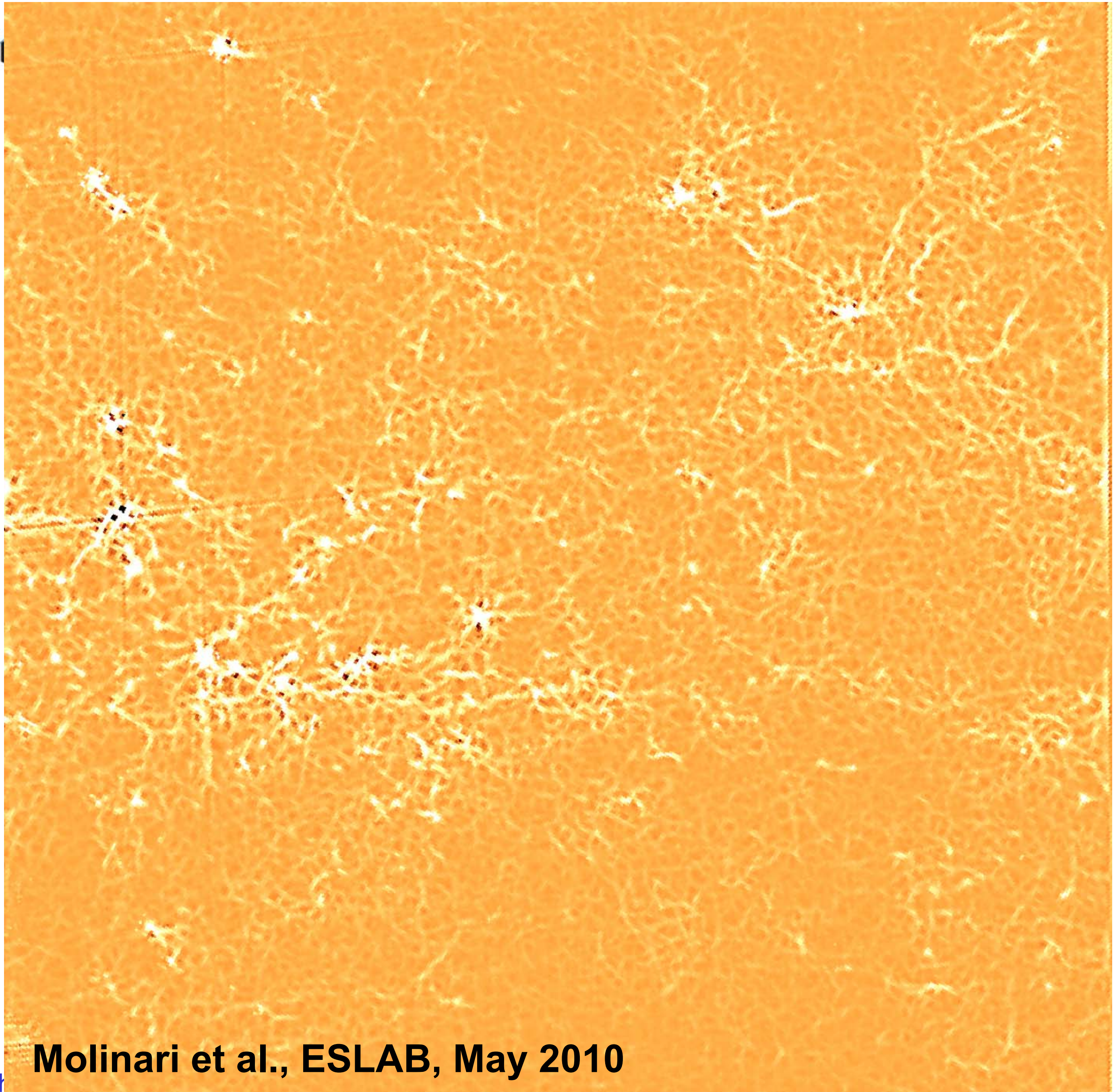
ESA and the HFI Consortium

André et al., ESLAB, May 2010

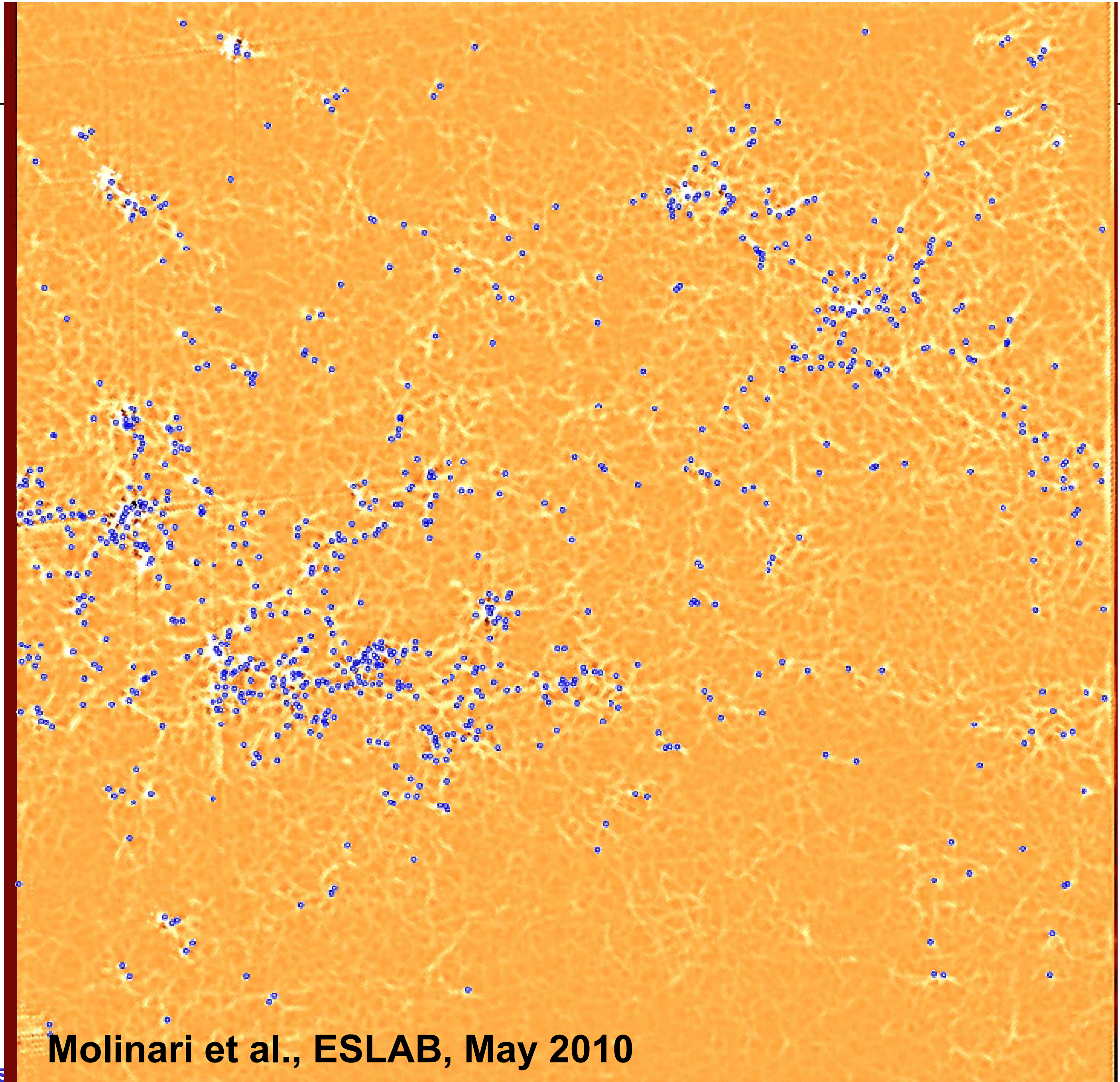
Galactic Plane: $l = 59^0$ 250 μm



Molinari et al., ESLAB, May 2010



Molinari et al., ESLAB, May 2010


Molinari et al., ESLAB, May 2010

Taurus in the optical (DSS)

- embargoed

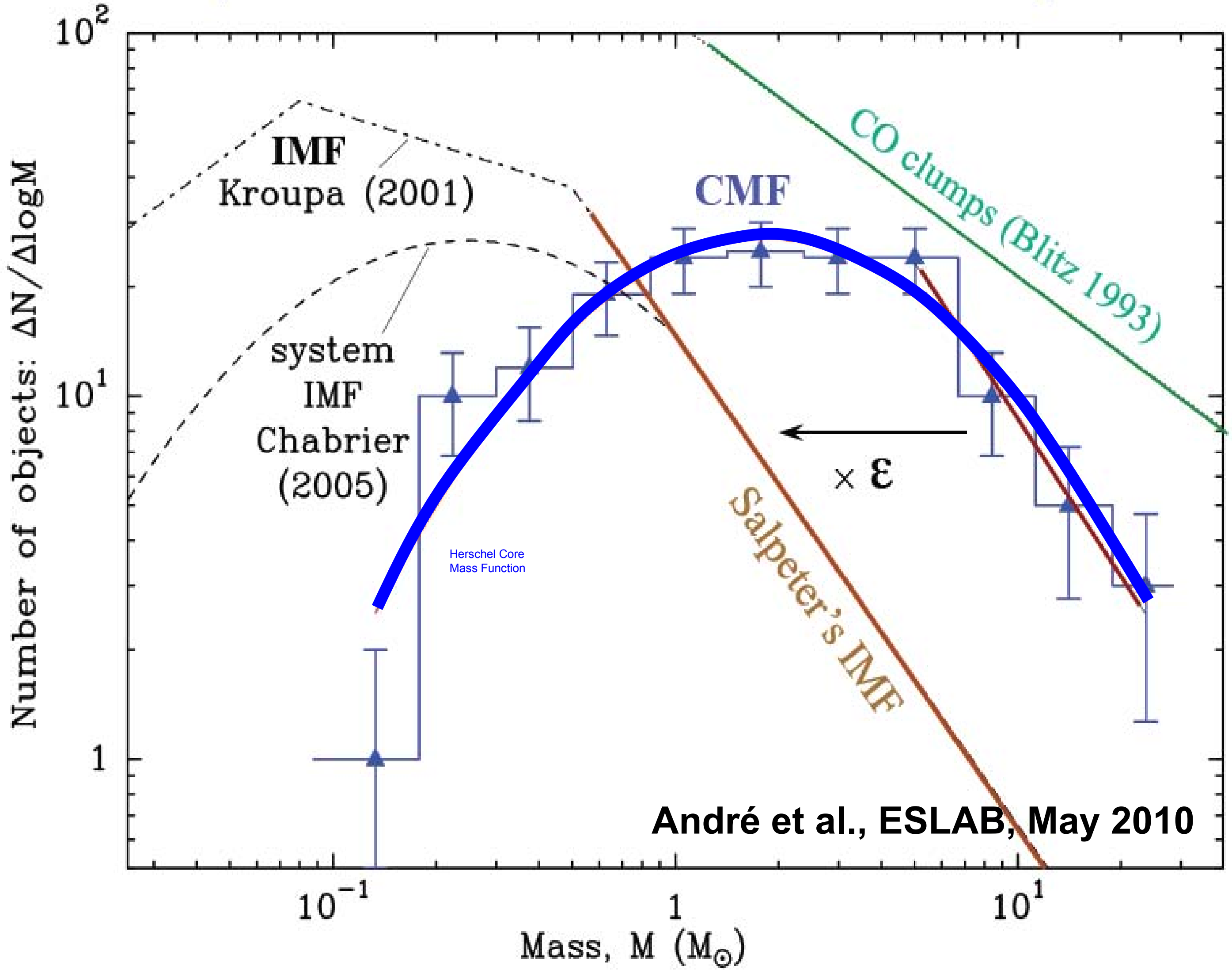
Taurus with Spire 250 overlaid

- embargo

Taurus larger region (b160,g250,r350)

- embargoed

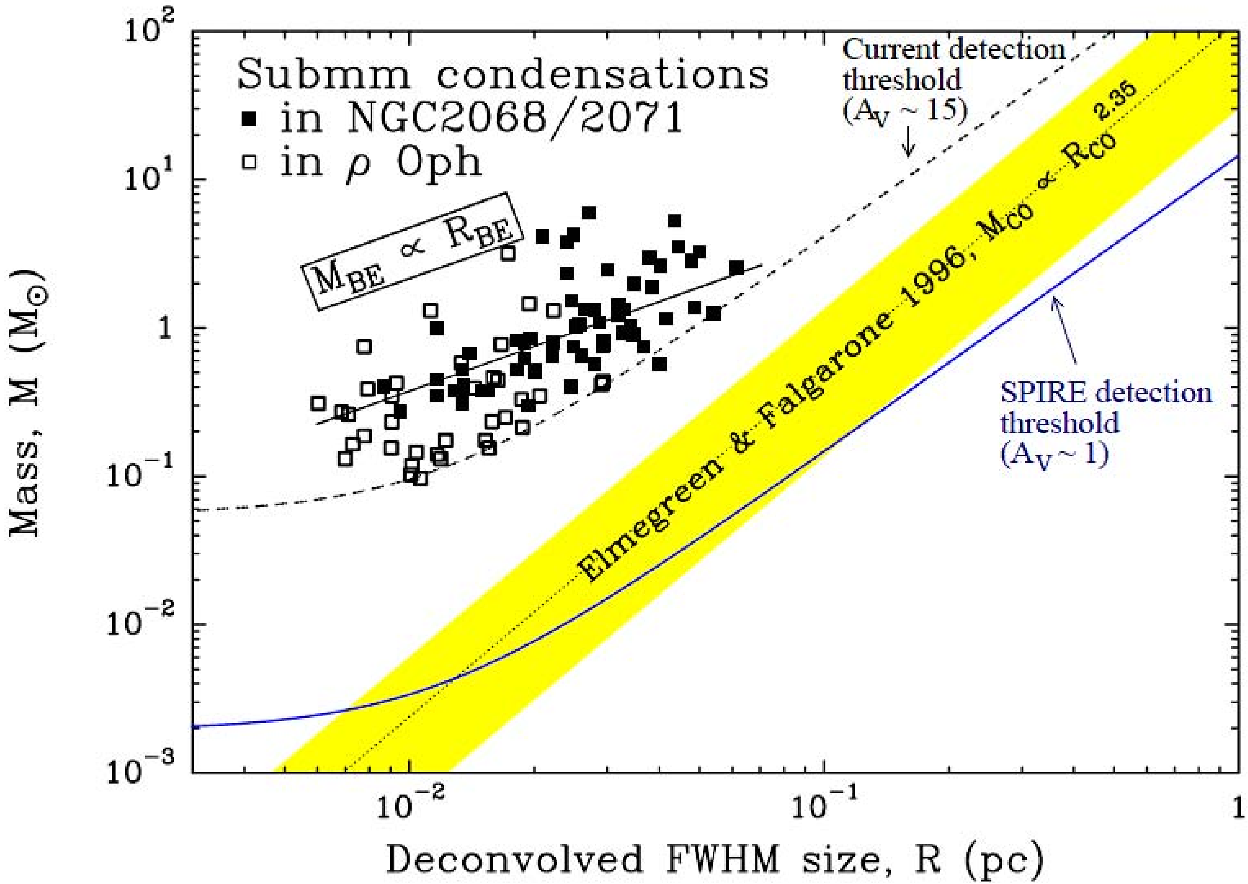
Pre-stellar Core Mass Function



Similarity between core mass and stellar mass spectra with $\varepsilon = M_*/M_{CORE} \sim 0.2$ in Aquila

The picture before Herschel

SCUBA cores (black) occupy different area from CO cores (yellow band)



Mass-size relation in Aquila

Mass-size relation in Polaris

Spire 250um of whole of Taurus

Taurus mass-size relation

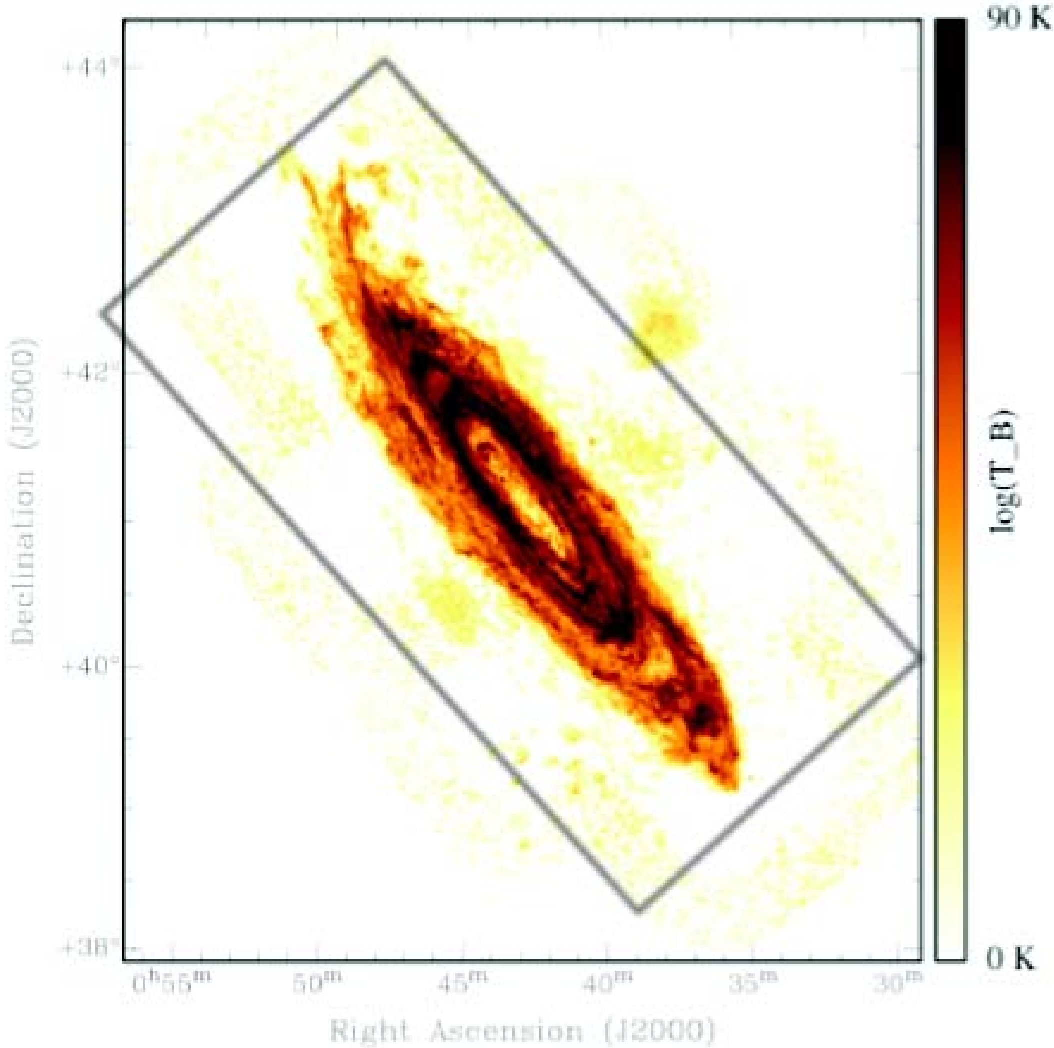
Fills in the gaps i.e. whole parameter space is now filled

Implications for CCAT

- The Herschel galactic plane surveys, and the statistics derived from them are confusion, NOT sensitivity limited
- Hence CCAT can resolve further down the low-mass range for pre-stellar and protostellar cores
- BUT really need FIR data at similar resolution, hence a strong case for using the 200 micron window that the high altitude of CCAT opens up (in best weather anyway !)

M31 (Andromeda)

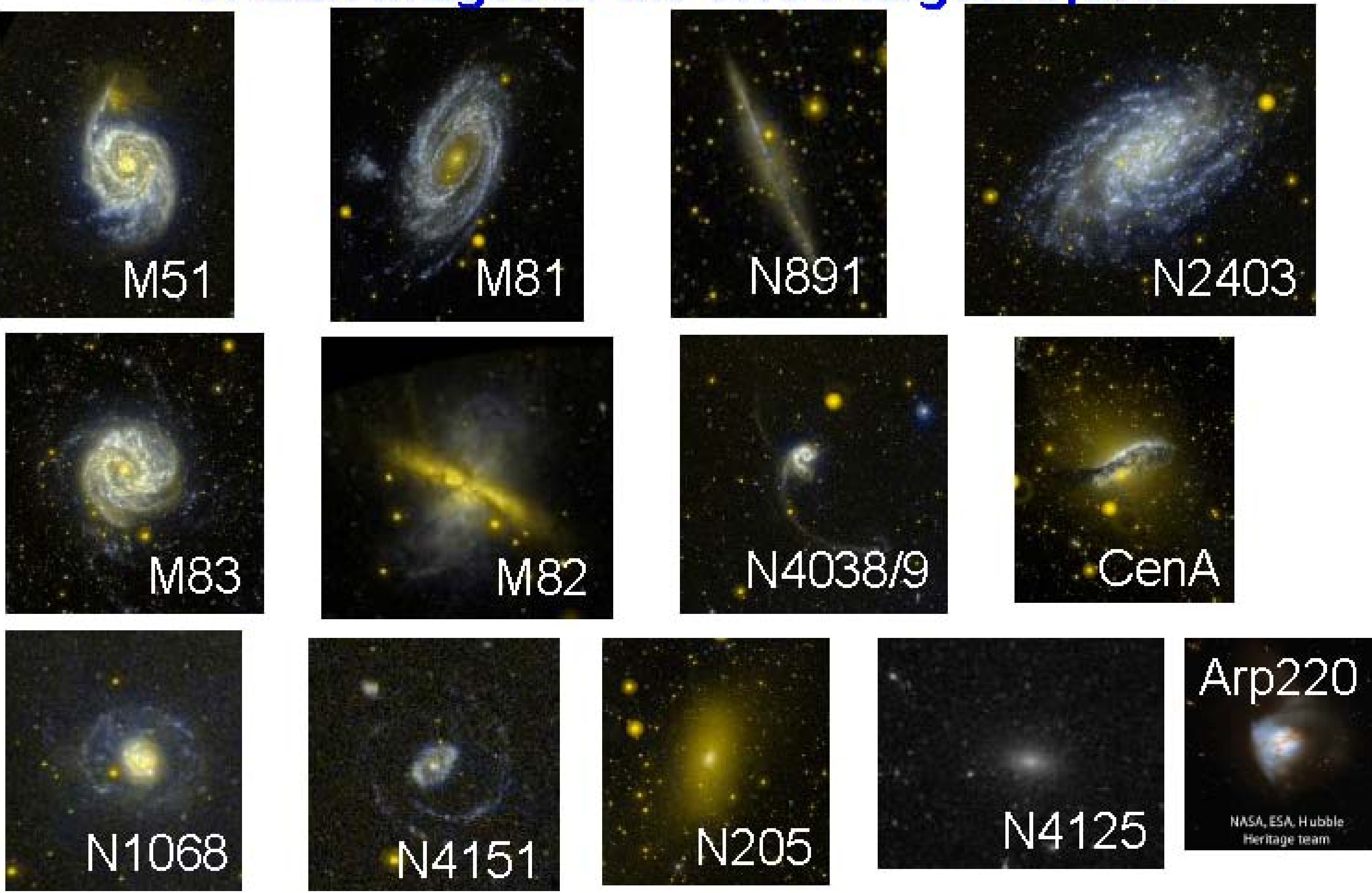
- We have a SPIRE GT project to make a 5.5x2.5 deg fast scan parallel mode map of M31 to study
  - Global distribution of star formation
  - Spiral structure
- PACS are also making a slow-scan parallel mode 3x1 deg map of the central region
- CCAT will be able to make a similar study but with a spatial resolution more like we see in the Herschel surveys of our own galaxy



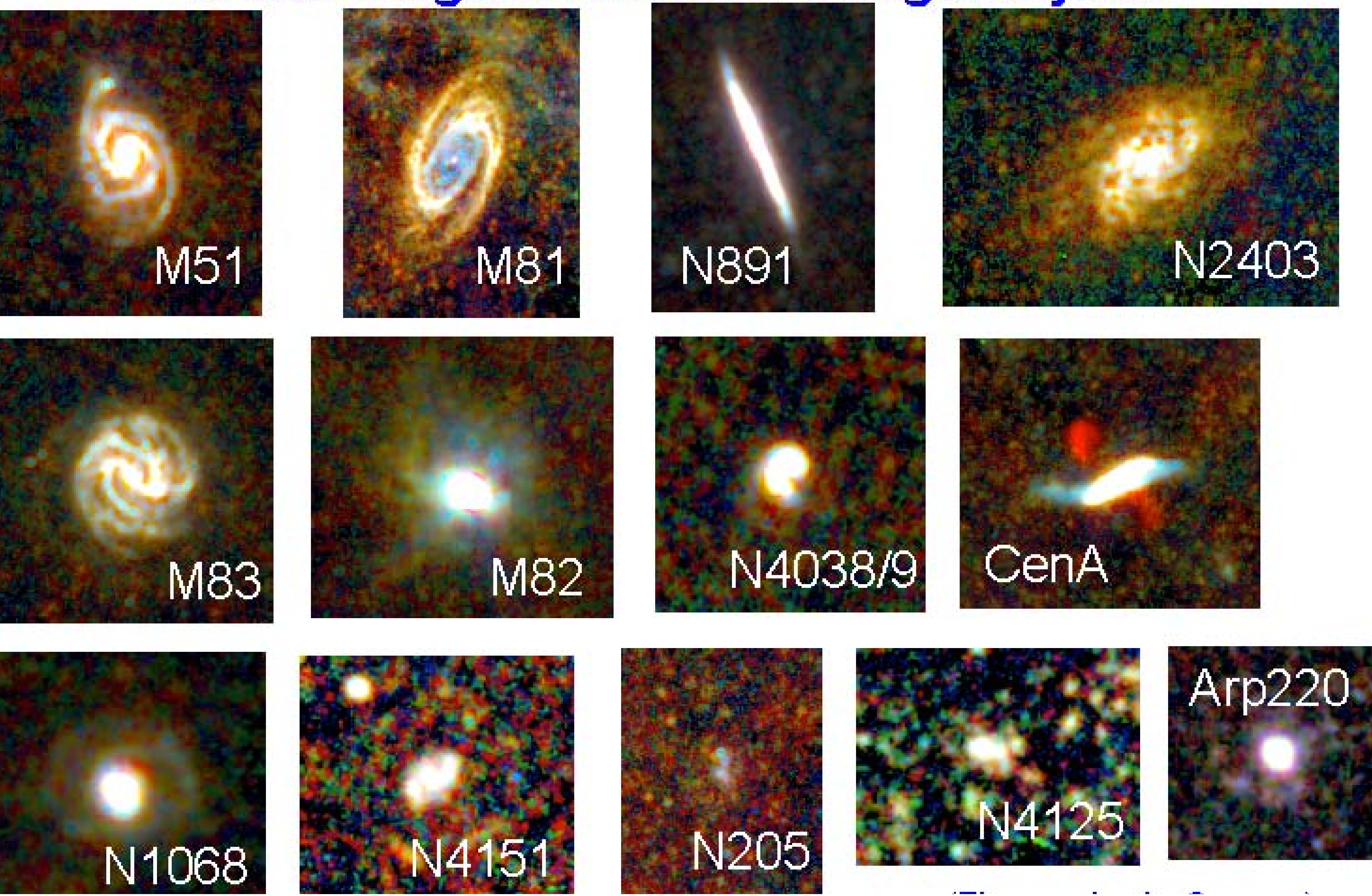
Nearby Galaxies

- VNGS is a SPIRE GT survey of 15 very nearby galaxies of various types
- Detailed studies of the gas and dust properties of the ISM at highest angular resolution yet made
- CCAT will resolve spatially on a scale much closer to that that Herschel sees in our own galaxy and M31.
- It will also be able to global detailed studies in a number of the nearest galaxies, more like the interferometric maps shown this morning by Kartik Sheth

GALEX images of the VNGS target objects

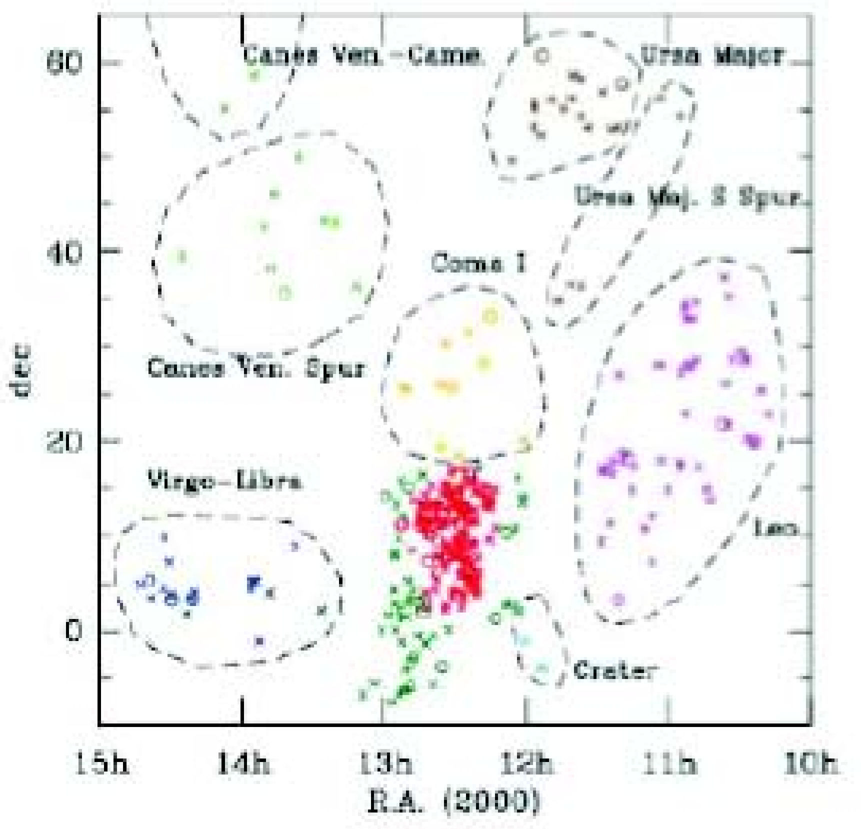


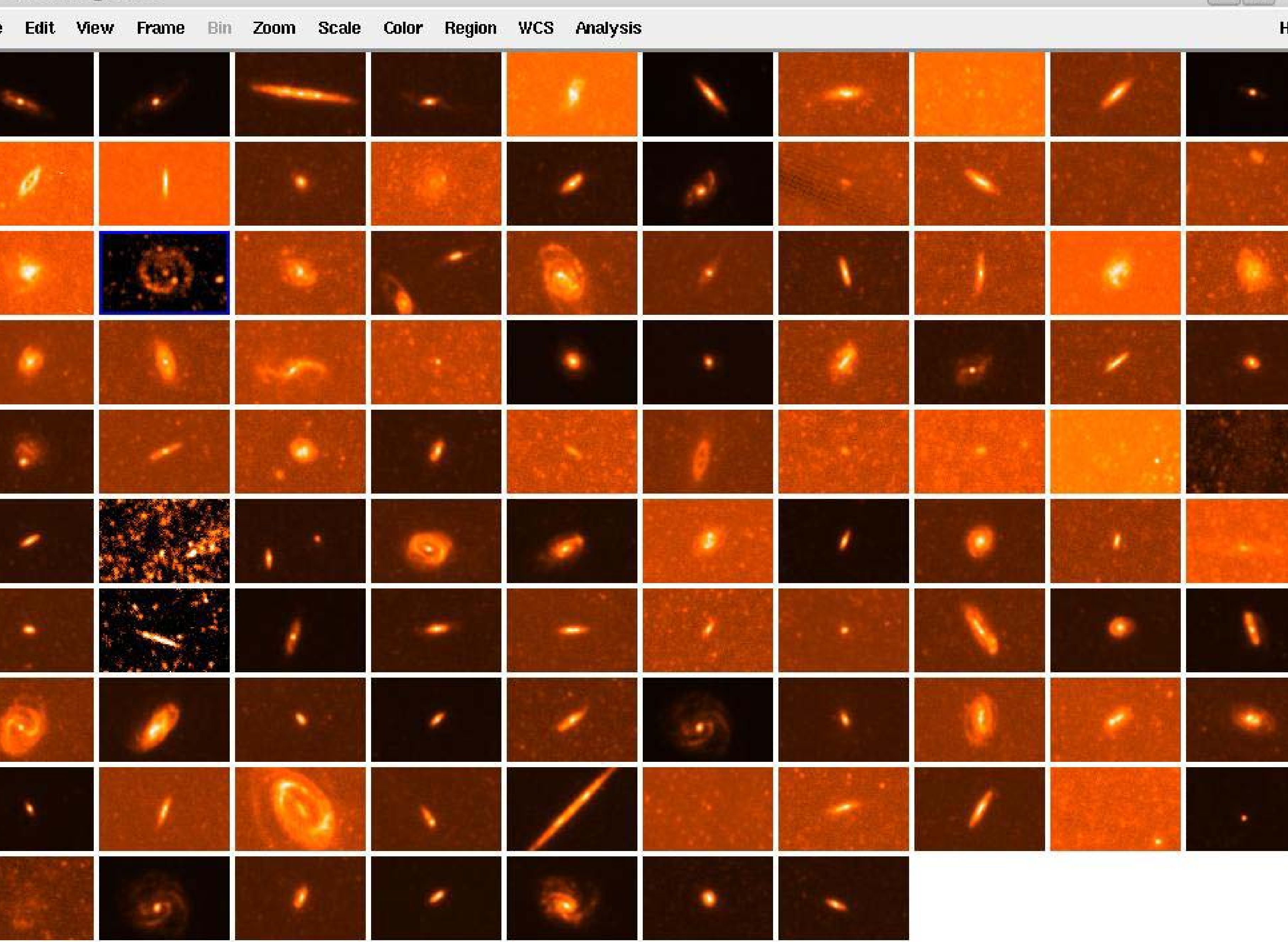
SPIRE images of the VNGS target objects



Nearby Galaxies

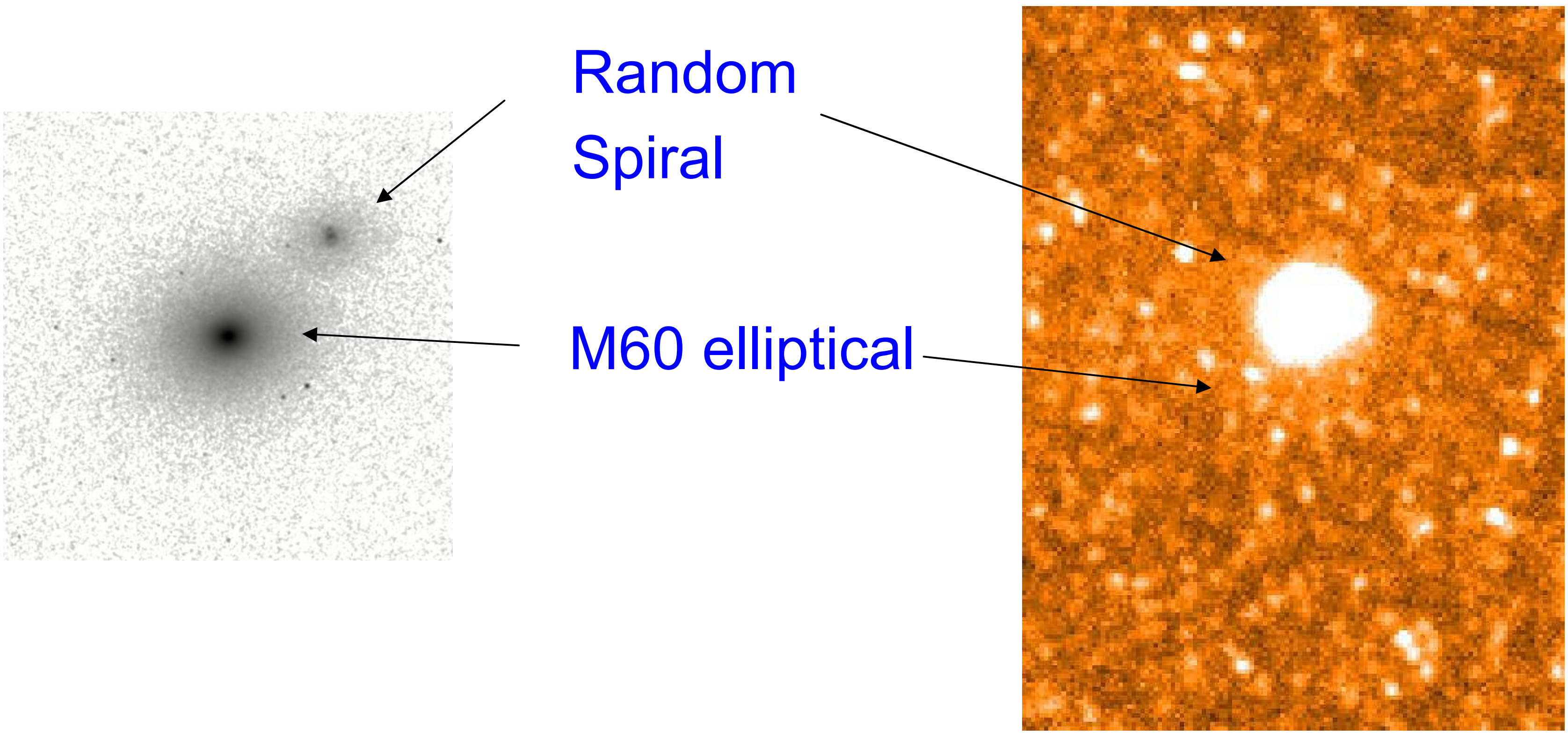
- **Herschel Reference Survey (HRS)**
  - **15 < D < 25 Mpc**
  - **b >55 deg**
  - **K < 8.7 for E, S0 & Sa, and < 12 for others**
- **323 Galaxies at 250, 350 & 500 um**
- **Acts as a z=0 reference study for high-z surveys**
- **See Boselli et al 2010 PASP 122, 261**




Edit View Frame Bin Zoom Scale Color Region WCS Analysis

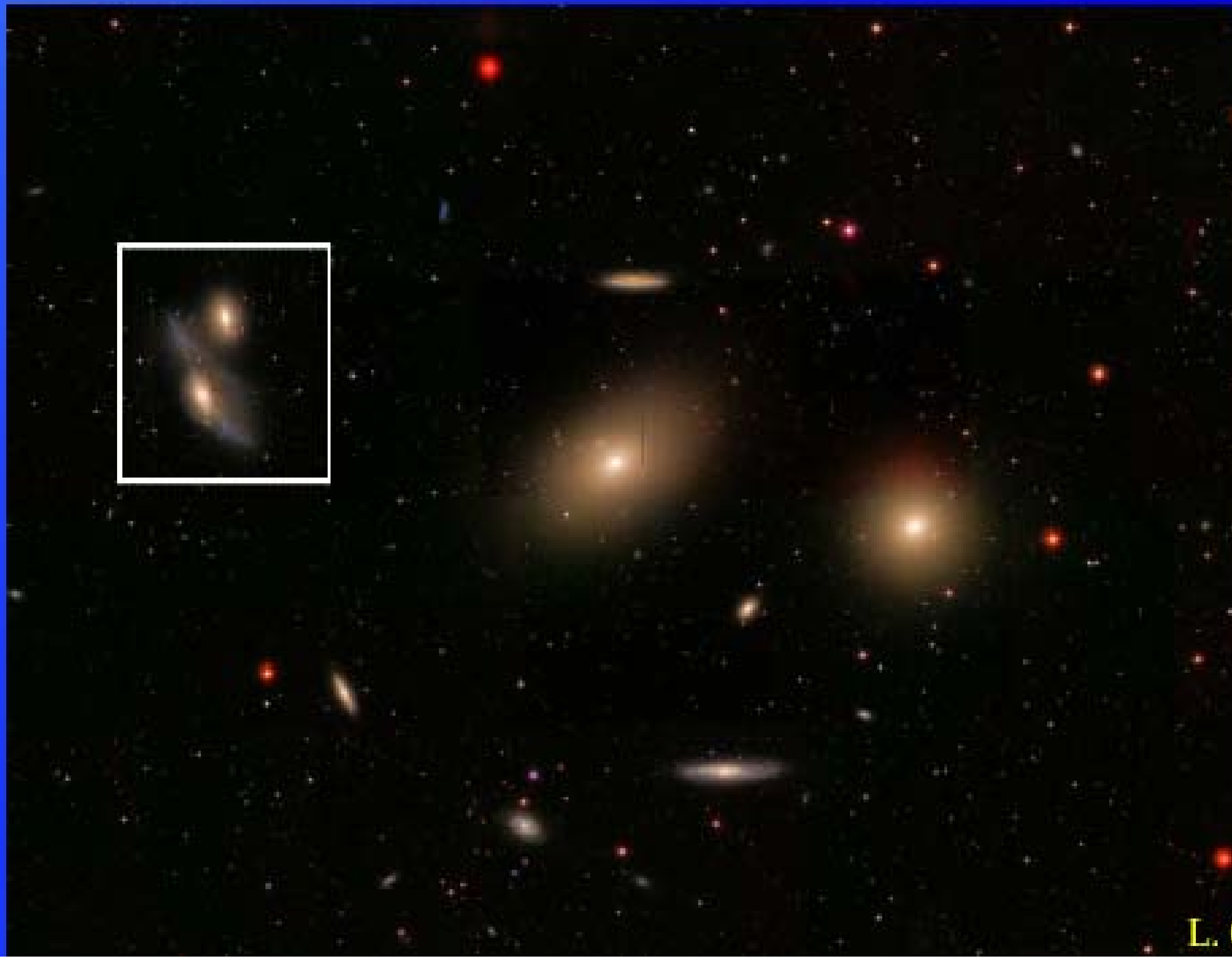
HRS Science

- **Quote from Steve Eales**
- **"ellipticals really do contain bugger-all dust and are a separate population form other galaxies"**

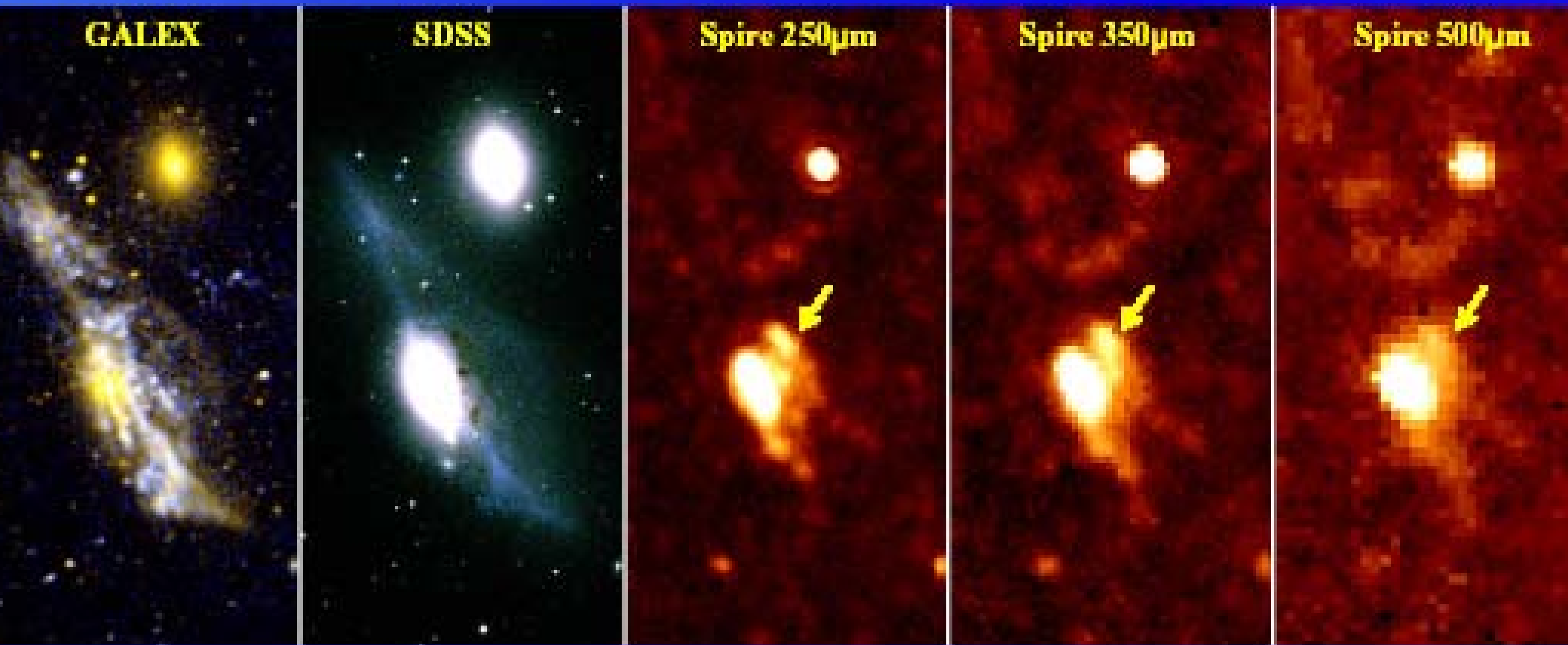


HRS Science

Dust Stripping in the Virgo Cluster: the case of NGC4438



Dust Stripping in the Virgo Cluster: the case of NGC4438



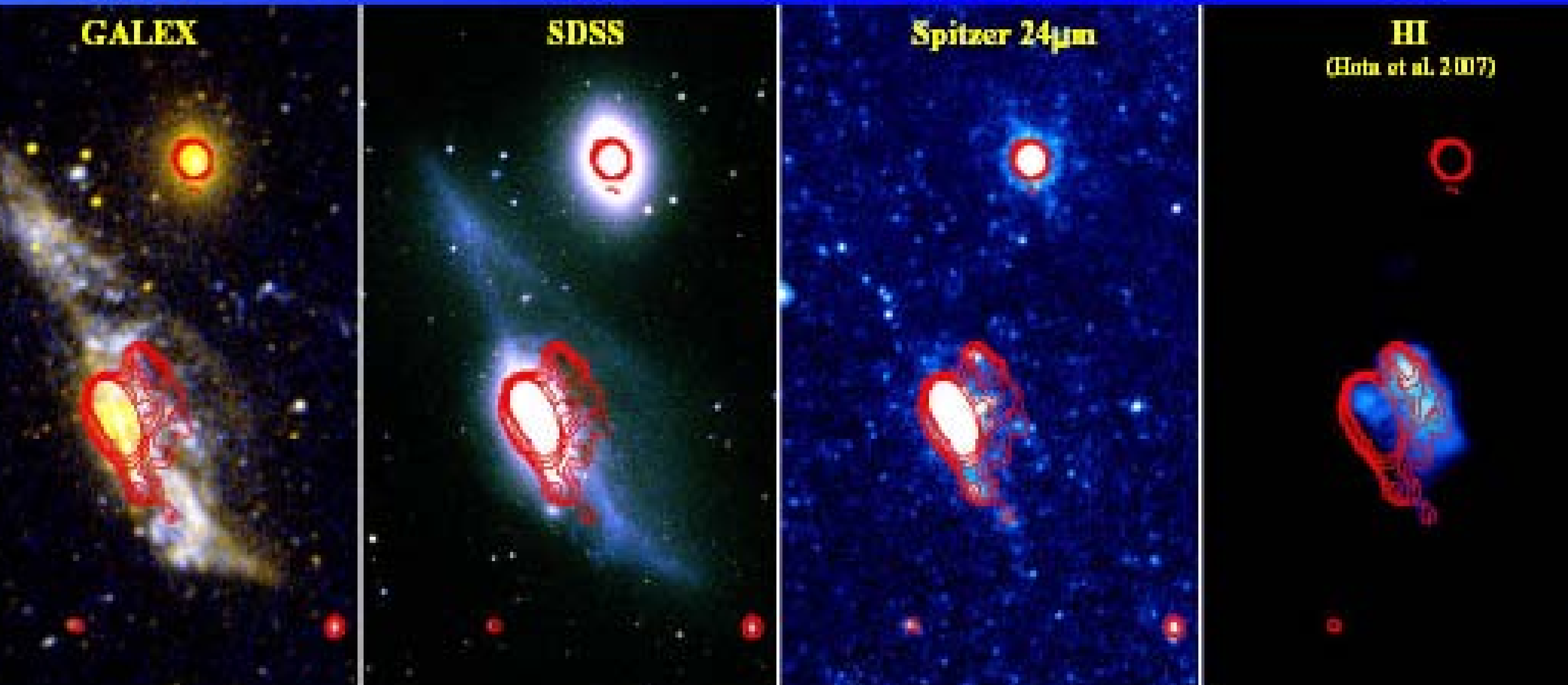
Extra-planar cold dust, stripped by the cluster environment

3 scan-map

L. Corte

Dust Stripping in the Virgo Cluster: the case of NGC4438

Spire 250μm contours onto:

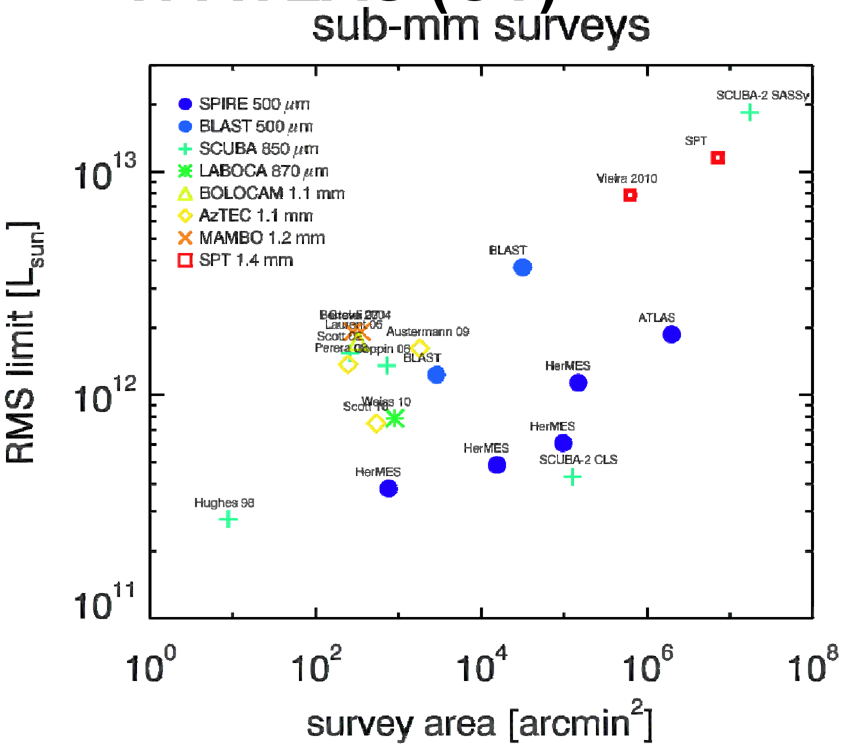


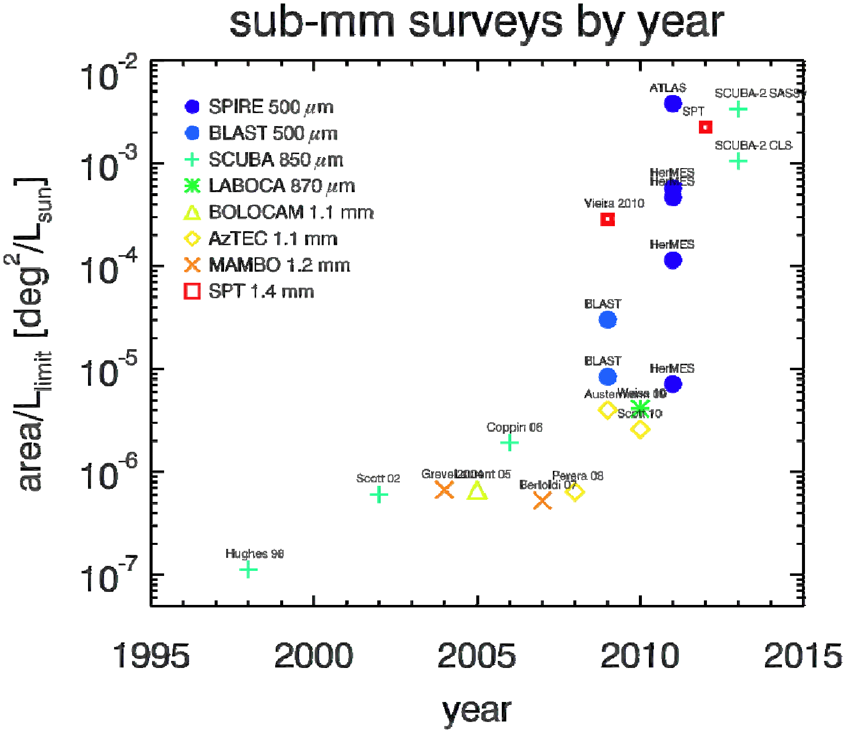
Stripped cold dust associated with stripped hydrogen

L. Corte

Cosmological Surveys

- **HERMES (SPIRE-GT)**
- **H-ATLAS (OT)**





HERMES

Clusters

Level1 0.11 □°

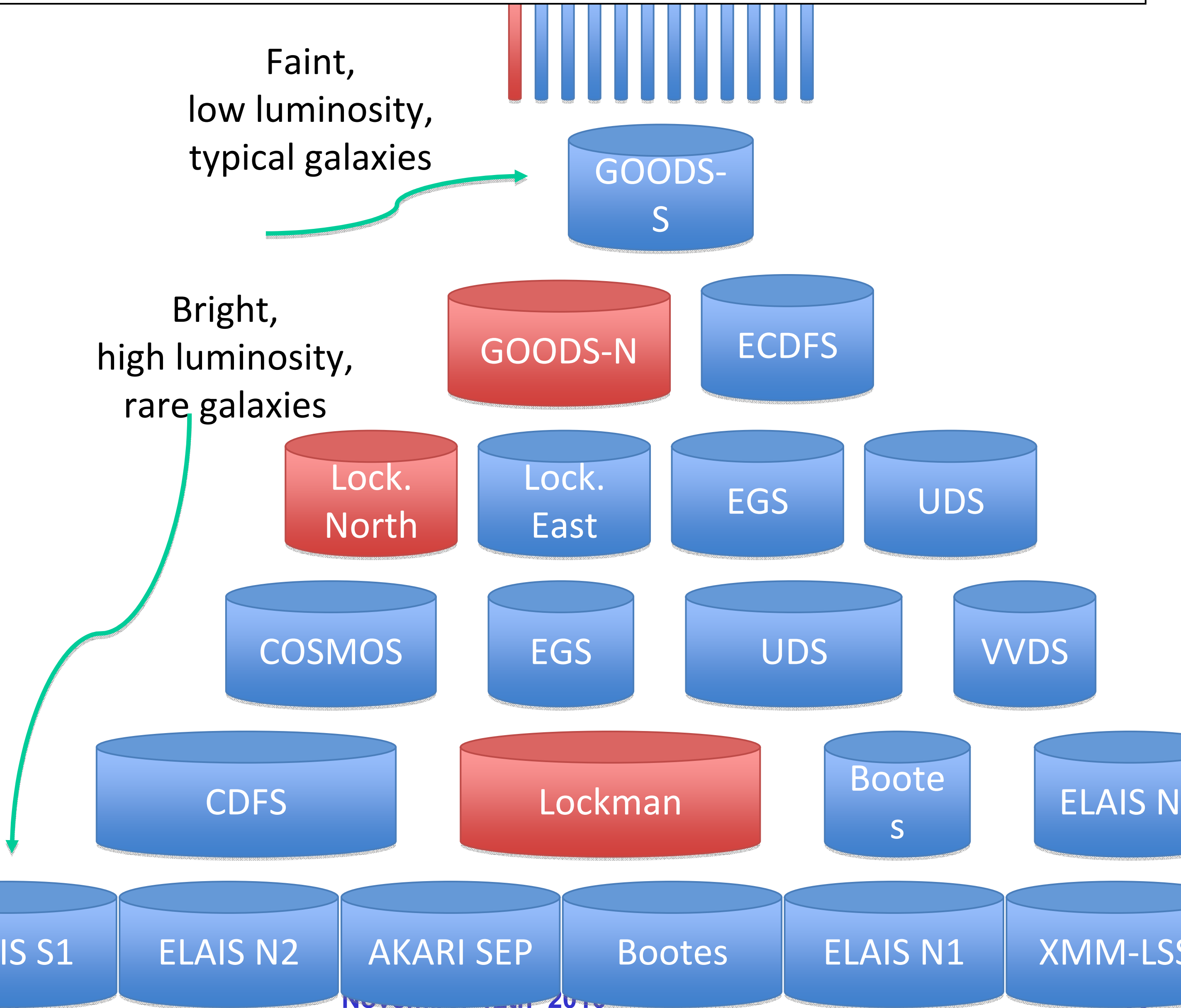
Level2 0.36 □°

Level3 1.25 □°

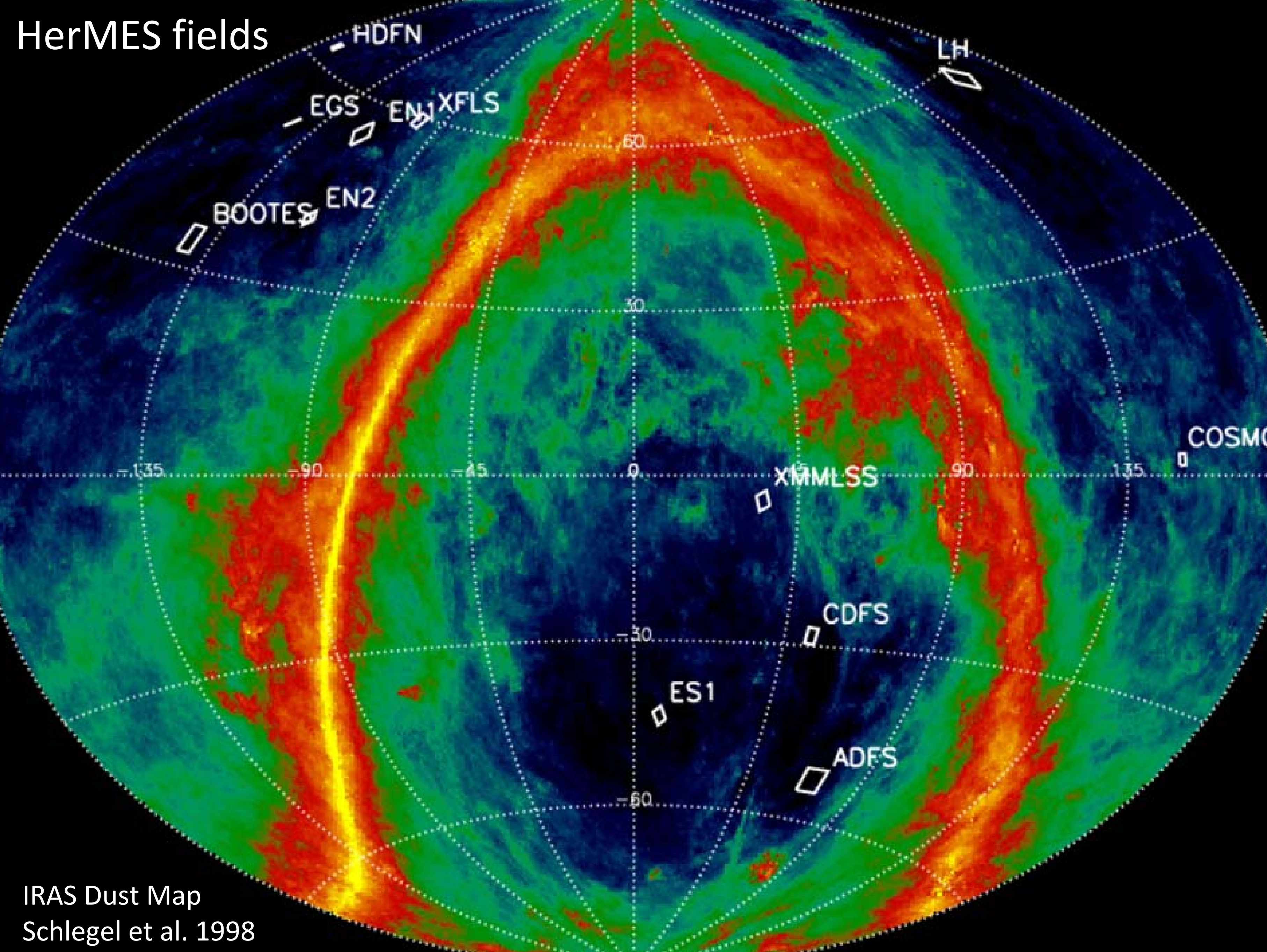
Level4 ~4 □°

Level5 ~30 □°

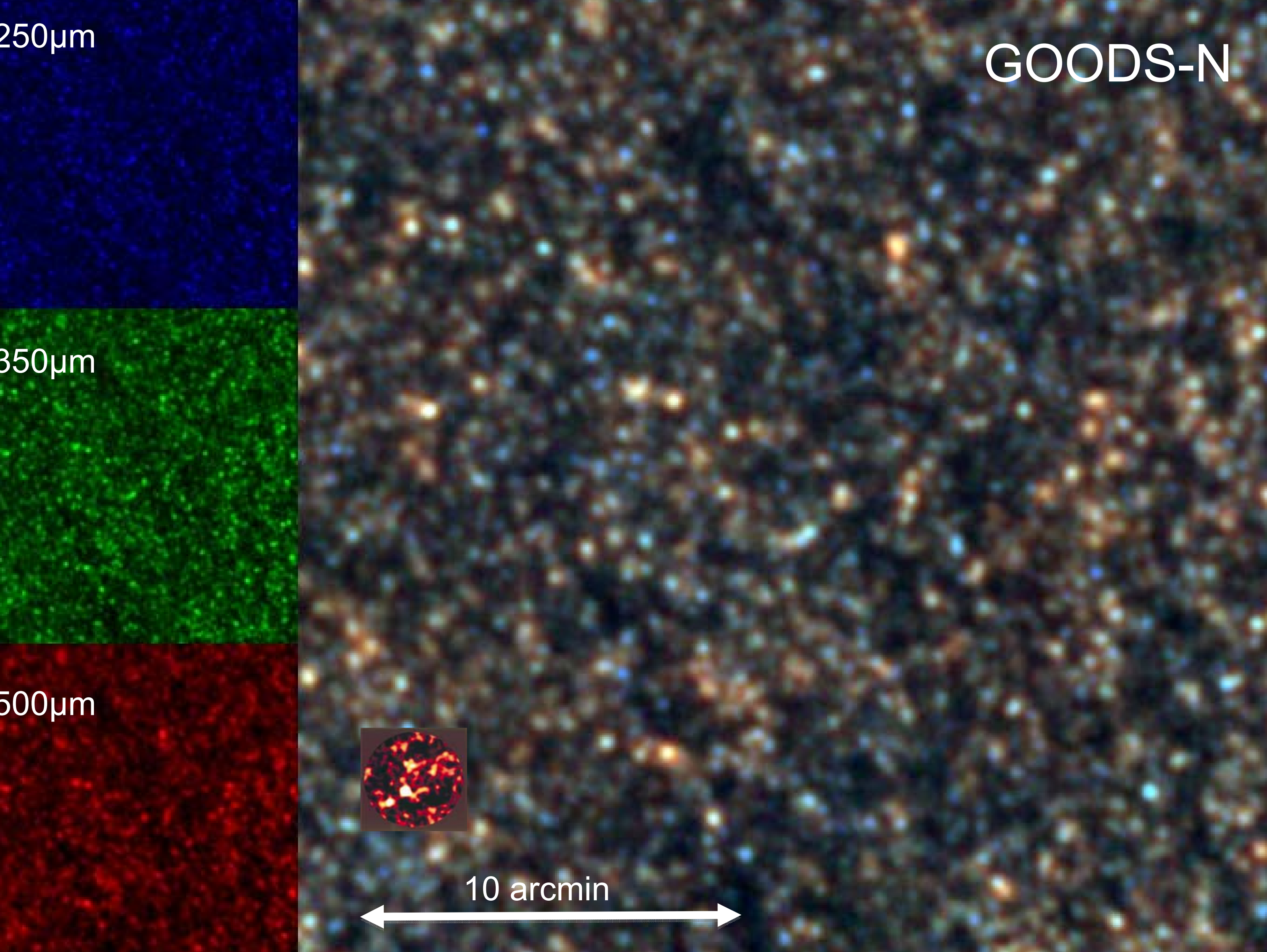
Level6 ~40 □°

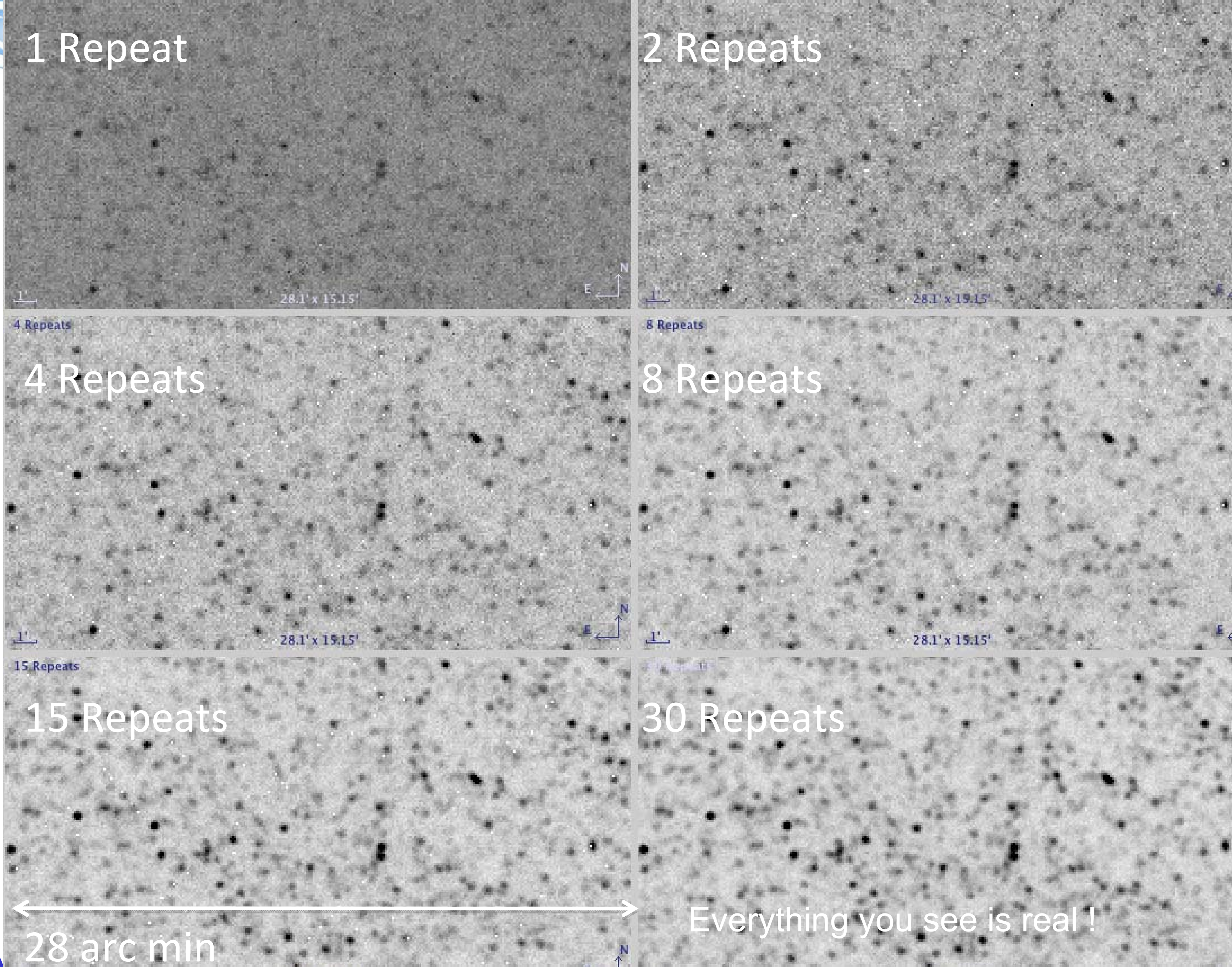


HerMES fields



IRAS Dust Map
Schlegel et al. 1998


250μm
350μm
500μm
GOODS-N
10 arcmin



1 Repeat
28.1' x 15.15'
2 Repeats
28.1' x 15.15'
4 Repeats
4 Repeats
28.1' x 15.15'
8 Repeats
8 Repeats
28.1' x 15.15'
15 Repeats
15 Repeats
30 Repeats
28 arc min
Everything you see is real !

CCA

The Herschel ATLAS

Astrophysical Terahertz Large Area Survey

The widest area survey with Herschel (~ 550 sq deg)

Consortium of 150+ astronomers worldwide led by Cardiff and Nottingham (Eales, Dunne)

Covering 5 bands with PACs and SPIRE (110 – 500 microns) in fast parallel mode

5 sigma sensitivities of 132, 126, 33, 36 and 45 mJy / beam from 110-500μm

Detect ~10^5 sources to z~3

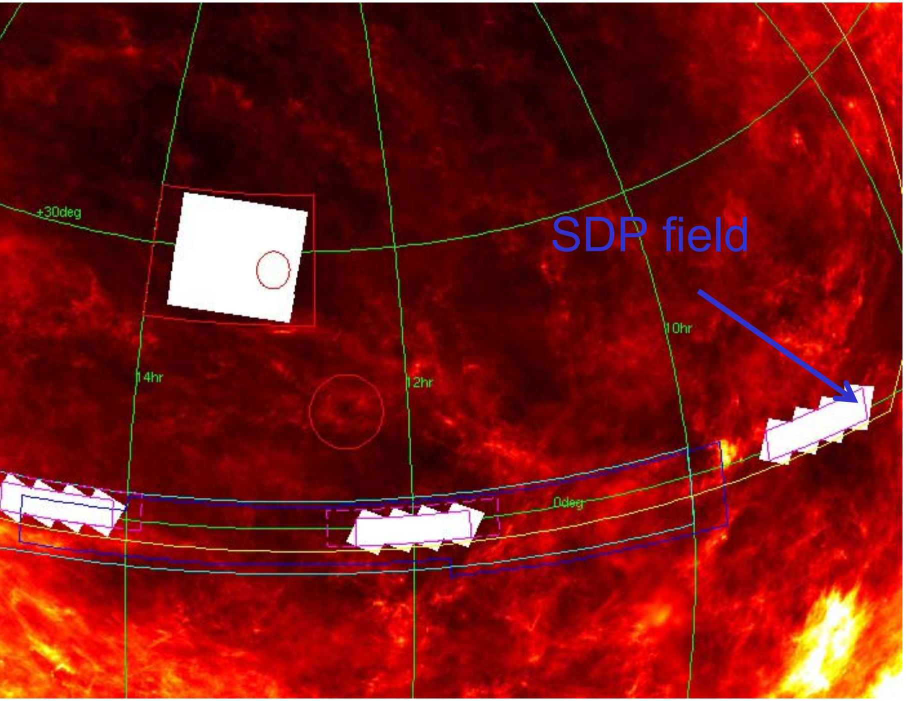
Primary Aim: to provide the kind of leap 2Df/SDSS made in the optical for the FIR/sub-mm

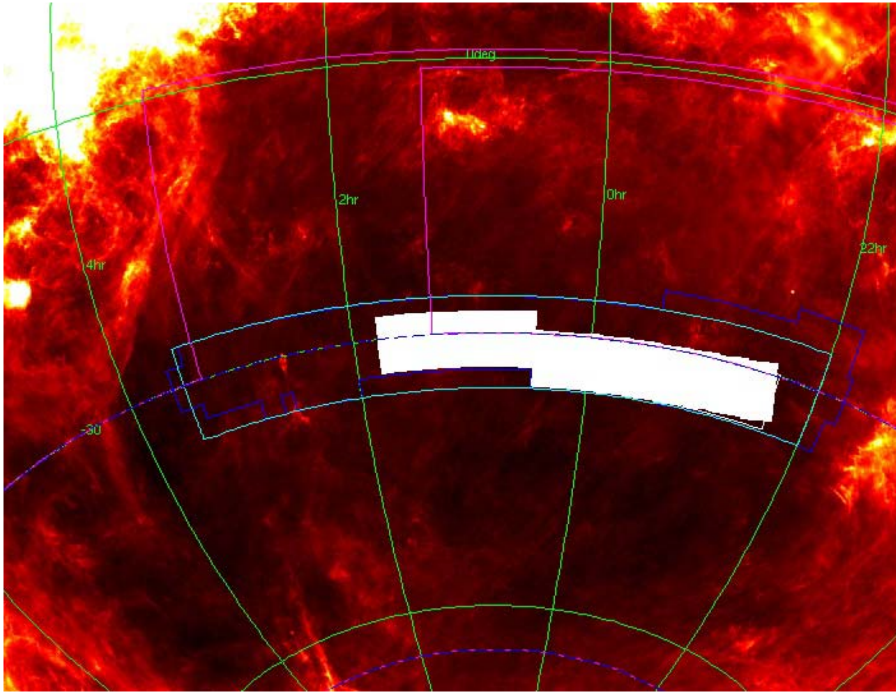
SDP 4x4 deg 1/40 th whole survey

There are 7000 galaxies in this image !!

NGP and Equatorial

SGP





Fields chosen to allow maximum overlap with existing and planned surveys
GALEX, 2dF, SDSS, GAMA, UKIDSS, KIDS, VIKING, PanSTARRS, DES, SPT, SASS

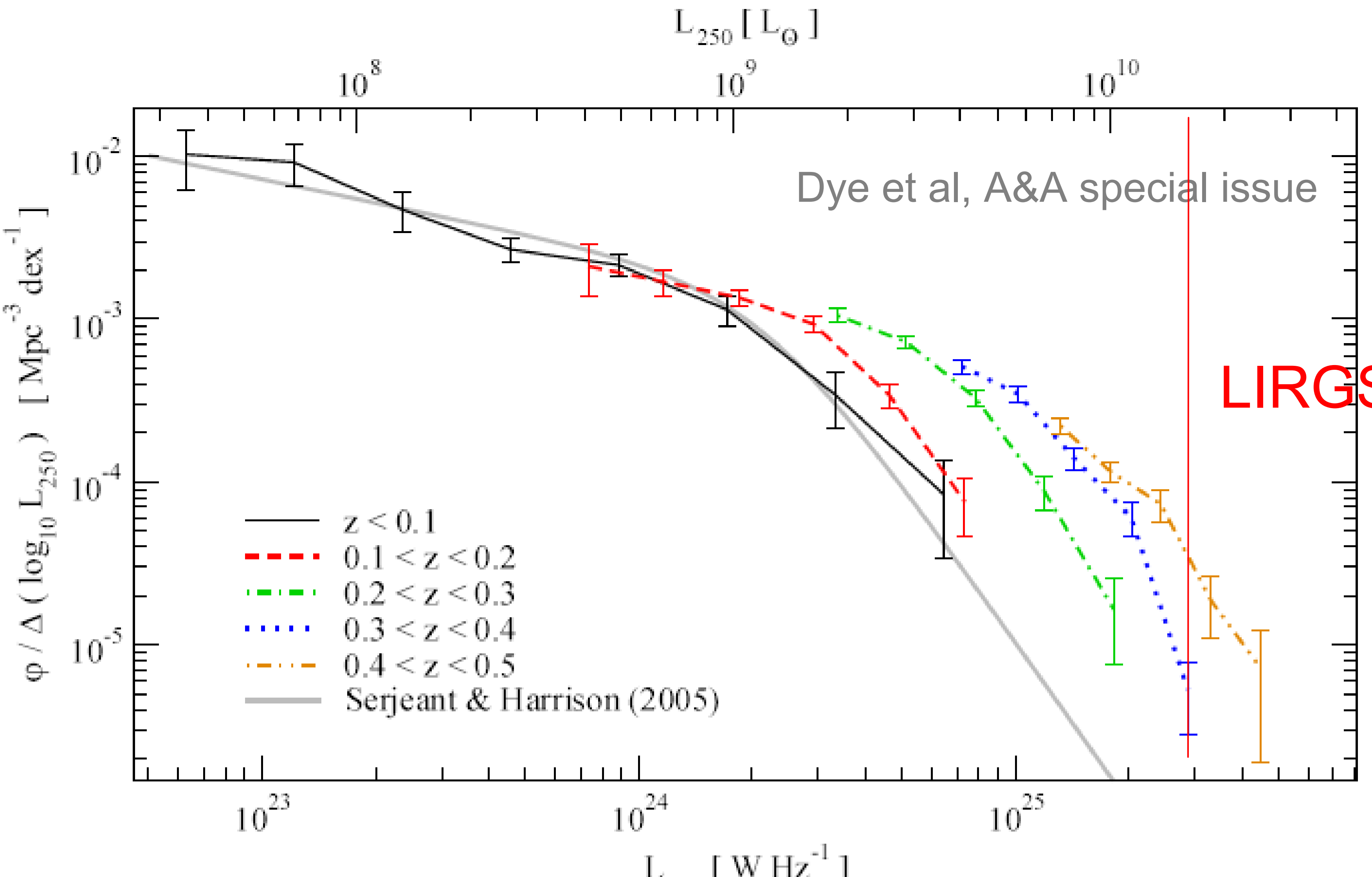
and to be accessible to new facilities which will be valuable for follow-up
ALMA, SKA and prototypes, SCUBA2, LOFAR, e-MERLIN

Key Science Themes in ATLAS

1. Local Universe Survey
2. Synergies with Planck
3. The Herschel Lens Survey
4. AGN and rare objects
5. Large scale structure and High-z galaxies
6. Galactic star and planet formation

>20 papers already published or submitted

Evolution of the 250μm Luminosity Function



What is causing the evolution?

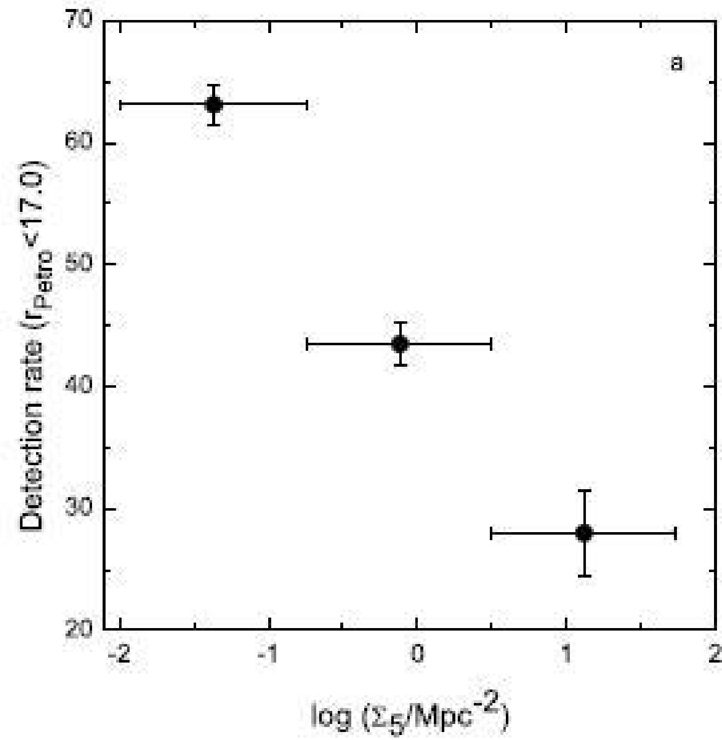
- Increasing number of starbursts? Or…
- Gradual depletion of interstellar medium?
- Current CO and HI telescopes do not have the sensitivity to measure the gas reservoirs in thousands of high-redshift Herschel sources
- Only way at present is to estimate the mass of the ISM directly from the dust emission
- Can CCAT fill this niche ?

The Environment of the H-ATLAS galaxies

Dariush et al. have quantified the density of the environment of each galaxy in the H-ATLAS optical catalogue.

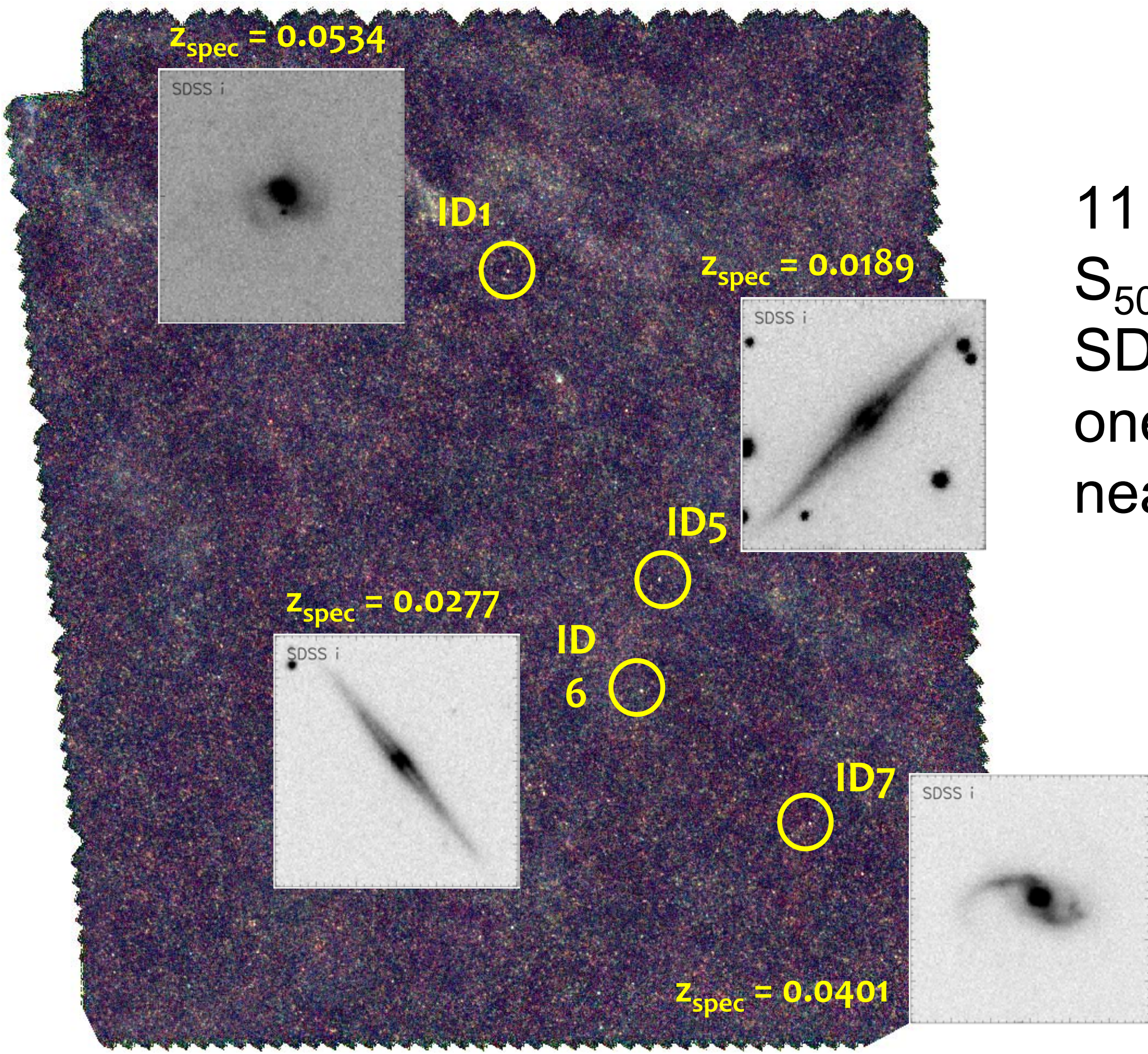
Strong inverse relation between the fraction of galaxies that are detected by Herschel and the density of the environment

i.e. Herschel galaxies are more likely to be found in low-density fields than clusters



But exactly the same as the relation between optical colour and environment!

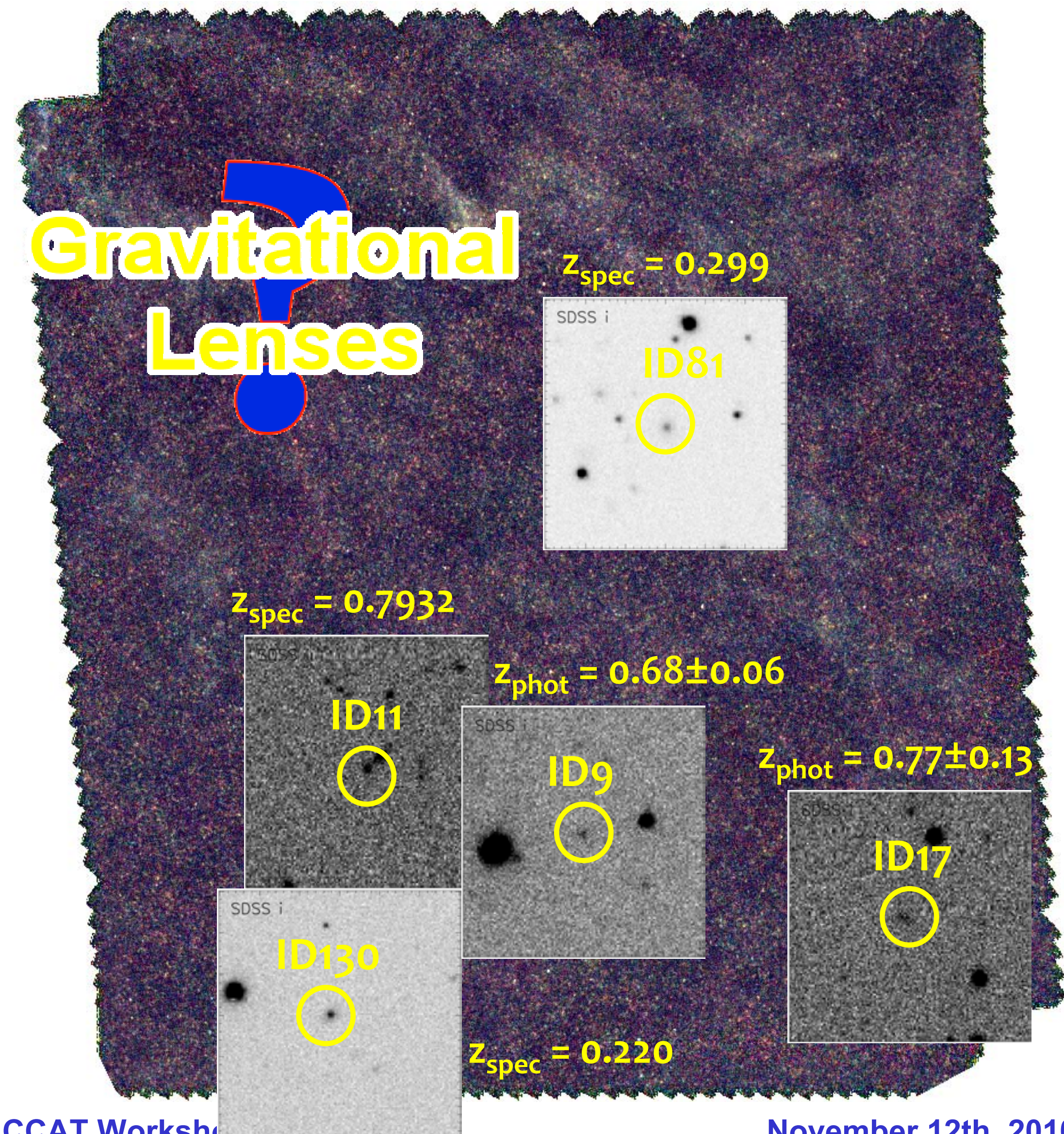
Brightest galaxies in SDP field



11 sources with $S_{500\mu m}$ > 100 mJy in SDP field – the blob, one blazar and four nearby galaxies

SPIRE

The other sources



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

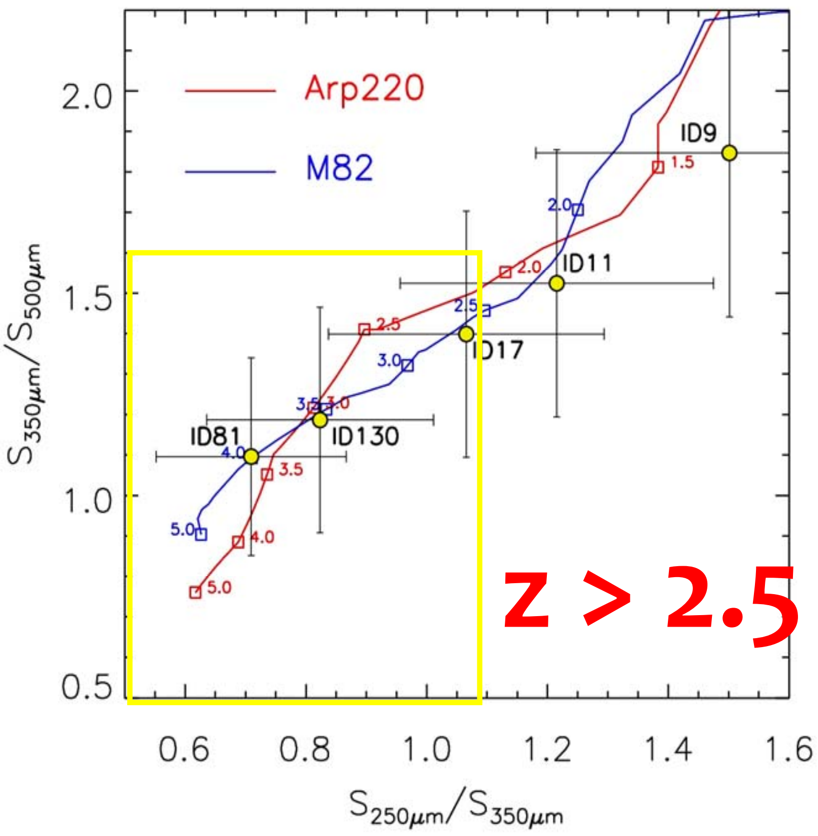
…

what about the sub-mm SED?

ID81 - ID130:

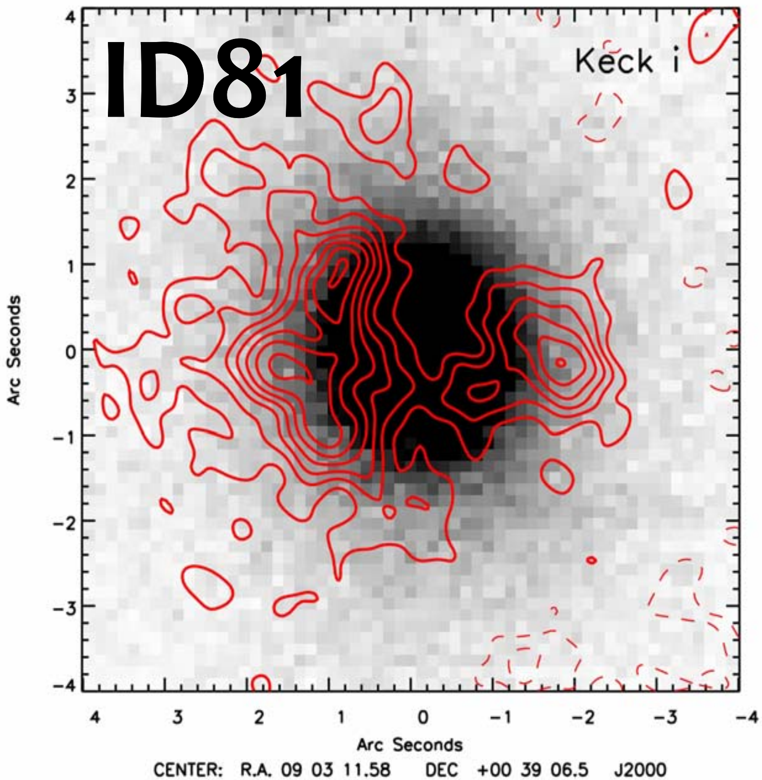
UV/optical/near-IR SED inconsistent with sub-mm SED !

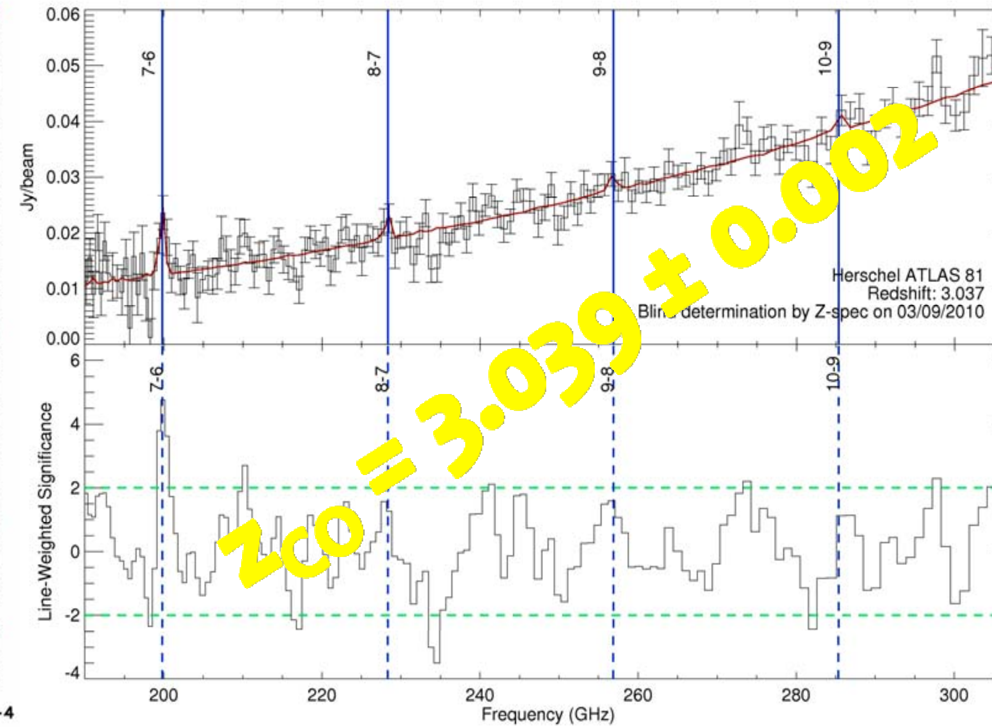
best lens candidates for DDT follow-ups



GRAVITATIONAL LENS CANDIDATES ID81

CSO/Z-spec blind redshift determination for **ID81** (March 09 2010) from observations of the **CO ladder**

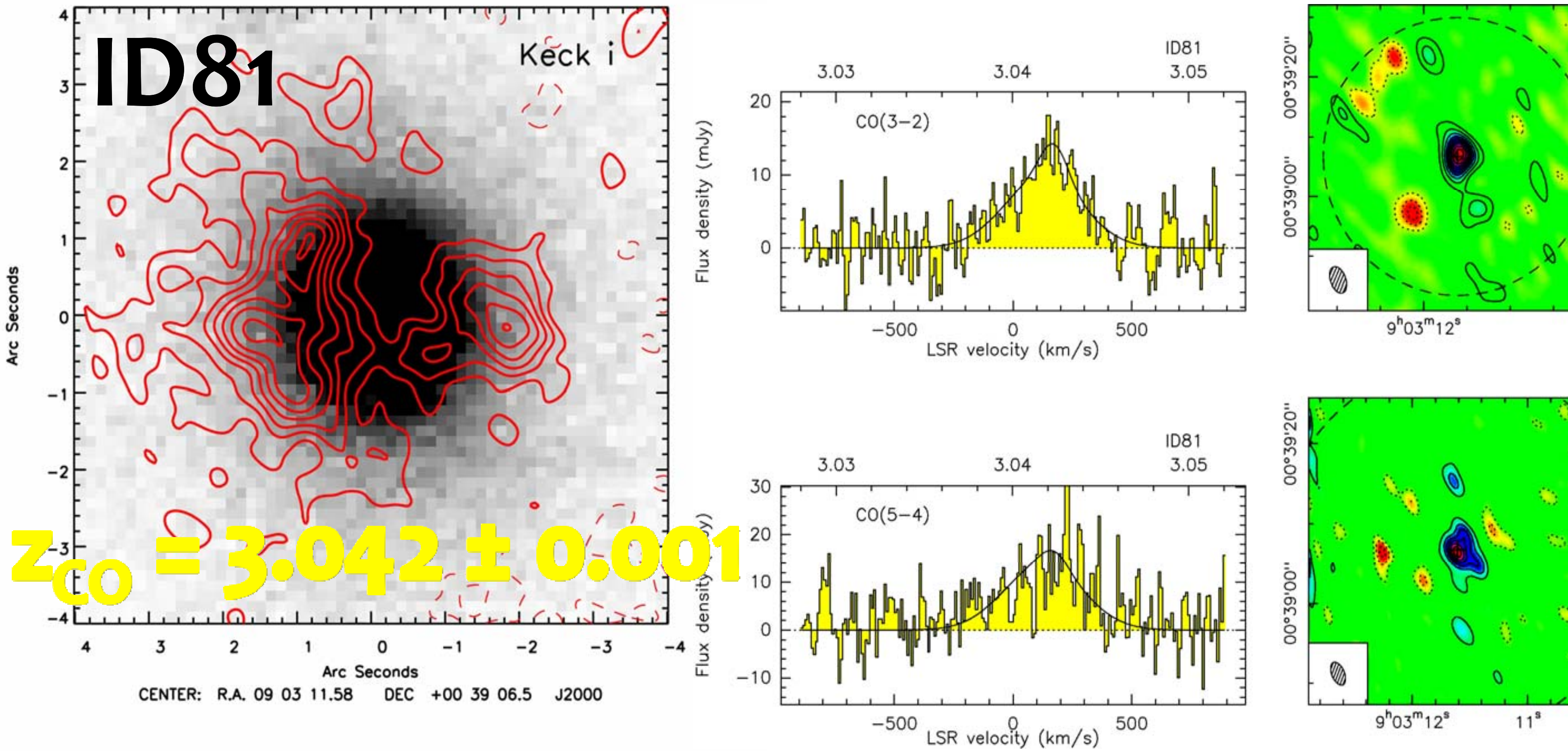




Credit: The

Gravitational Lens candidates ID81

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



$z_{CO} = 3.042 \pm 0.001$

Credit: R. Neri, P. Cox, A. Beelen, H. Dannerbauer, F. Bertoldi

The First Five Candidates

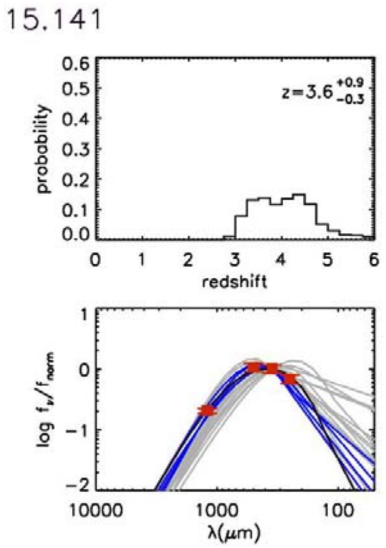
Source	Optical redshift	CO redshift
9	**0.679**	**1.577**
11	**0.72**	**1.786**
17	**0.77 (photo-z)**	**0.942+2.308**
81	**0.334**	**3.037**
130	**0.239**	**2.625**

→ ***100% success rate for finding lenses!***

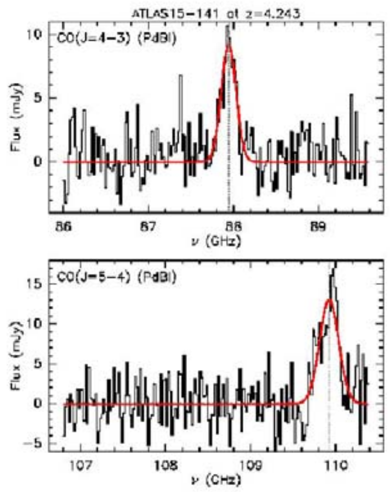
Negrello et al. accepted by Science

Pushing to even higher redshifts

- **H-ATLAS sources that are brighter at 500 microns that at 350 microns are likely to be at z>3**
- **First one looked at is at z=4.2**



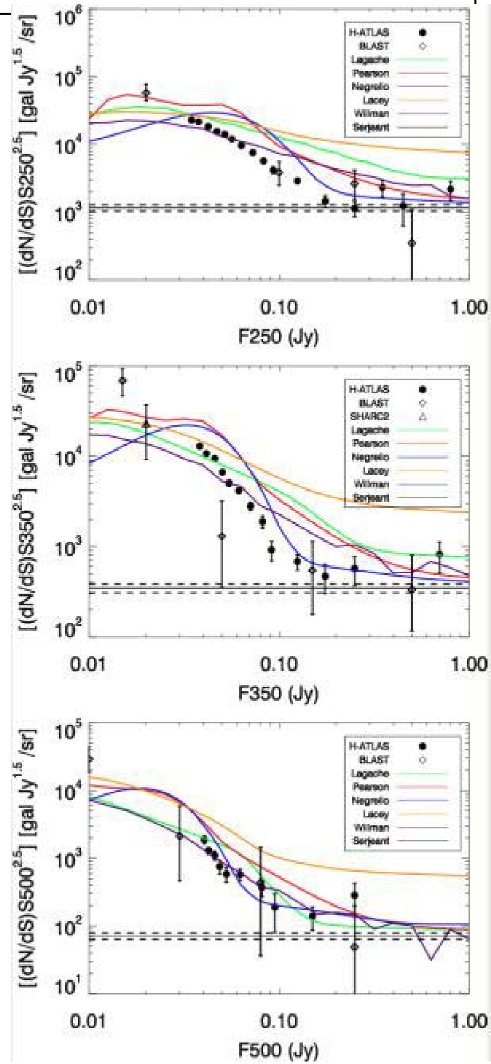
Follow-up photometry at 1.1 mm with IRAM to refine the redshift estimate, then spectroscopy with WIDEX on PdeB to measure the redshift – Krips et al. in prep.



How many Herschel sources are lensed?

- A calculation based on an evolving population of dark-matter halos implies that the probability of a source at z=3 being magnified by a factor of >2 is 0.0027 (Pearson et al. in prep).
- The steep Herschel source counts imply the fraction of sources in any sample that are lensed is ≈ 5%

→ 1.2×10^4 lensed source in survey



Implications for CCAT

- 5 objects can be handled in DDT for multi-wavelength IDs and spectroscopic follow-up for z
- Herschel surveys will produce ~10^5 galaxies
- Unlike optical surveys photometric redshifts do not easily pop out of this data
- CCAT could produce catalogs with millions of Submm-selected galaxies !

CCAT follow-up

- CCAT beam a factor ~7 smaller than Herschel so confusion much less of an issue for ID purposes
- 200 um would be extremely useful but the sensitivity is unlikely to be feasible….
- Spectroscopic follow-up very hard
- ALMA can do a high-z SMG in ~5 mins but one at a time is no use except for special cases
- Wide-field spectroscopic imaging is the only way forward!

SUMMARY

- HERSCHEL-SPIRE is working even better than predicted (is this unique in a space instrument?!)
- Fantastic science results from surveys of the galaxy, nearby galaxies and cosmology
- CCAT will overcome most of the confusion problems that limits Herschel observations
- BUT for galactic work a 200 um channel would really boost the science
- For cosmology surveys wide-field multi-object spectroscopic imaging capability should be a very high priority in the development process