Observing opportunities with SPIRE: an overview of the instrument and of the SPIRE GT programme

Ismael Pérez-Fournon
IAC, Tenerife
on behalf of Matt Griffin and the SPIRE team

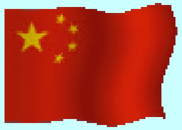
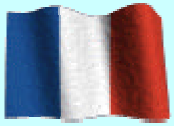
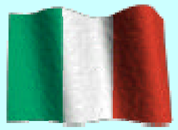
- **INSTRUMENT DESCRIPTION**
- **OBSERVING MODES**
- **PERFORMANCE ESTIMATES**
- **GT Key Projects (introduction)**
- **OT Key Projects (introduction)**
- **Future FIR missions**

Herschel

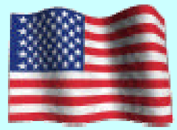
- The first large space mission in the FIR and submm
- The largest space telescope, 3.5m
- Three instruments to explore the FIR and submm
- Spanish participation in the three instruments consortia (funded by Plan Nacional del Espacio):
- HIFI (OAN, IEM)
- PACS (IAC)
- SPIRE (IAC)
- One Spanish Mission Scientist: J. Cernicharo (IEM)

The SPIRE Consortium

Canada China France Italy Spain Sweden 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**
- **Università di Padova, Italy**
- **University of Lethbridge, Canada**

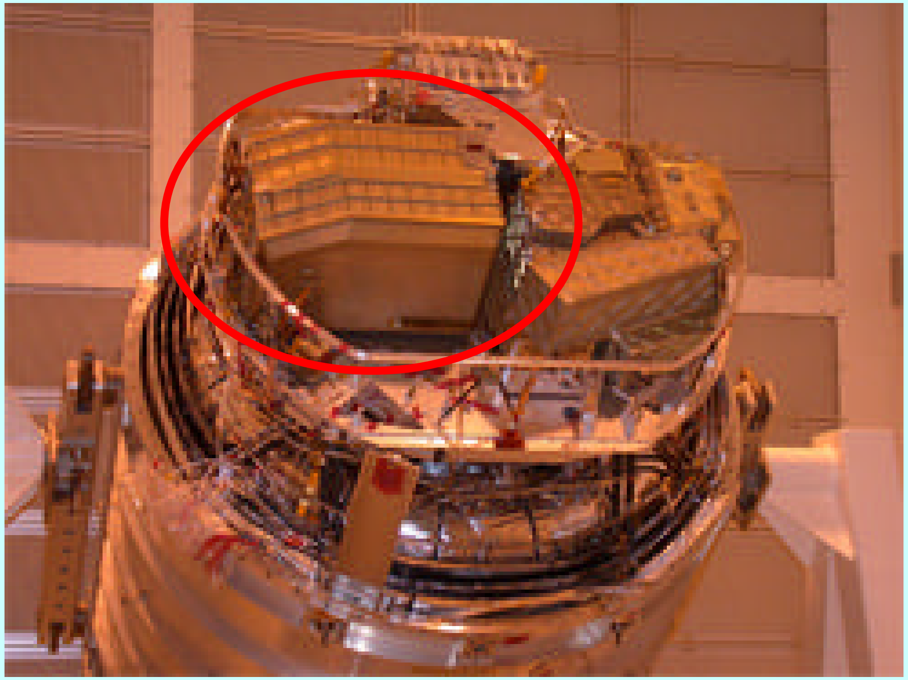
http://www.spire.ral.ac.uk/

SPIRE SAG 1 (Hi-z) and SAG 2 (Lo-z) Teams extragalactic part of the GT KP

Asier	Abreu	Erica	Ellingson	Alain	Omont
Rick	Arendt	Alberto	Franceschini	Mat	Page
Hervé	Aussel	Mark	Frost	Pasquale	Panuzzo
Tom	Babbedge	Frederic	Galliano	Ismael	Perez Fournon
George	Bendo	Ken	Ganga	Michael	Rowan-Robinson
Andrew	Blain	Walter	Gear	Marc	Sauvage
Jamie	Bock	Jason	Glenn	Richard	Savage
Alessandro	Boselli	Matt	Griffin	Bernhard	Schulz
Véronique	Buat	Bruno	Guiderdoni	Douglas	Scott
Jordi	Cepa	Mark	Halpern	Luigi	Spinoglio
Pierre	Chanial	Martin	Harwit	Jason	Stevens
Sarah	Church	Evanthia	Hatziminaoglou	Mattia	Vaccari
Dave	Clements	George	Helou	Laurent	Vigroux
Asantha	Cooray	Kate	Isaak	Ian	Waddington
Jon	Davies	Rob	Ivison	Tim	Waskett
Fred C.	Dobbs	Guilaine	Lagache	Christine	Wilson
Darren	Dowell	Glenn	Laurent	Kevin	Xu
Gianfranco	De Zotti	Suzanne	Madden		
Eli	Dwek	Bruno	Maffei		
Simon	Dye	Phil	Maloney		
Steve	Eales	Hien	Nguyen		
David	Elbaz	Seb	Oliver		

Spectral and Photometric Imaging Receiver

- **3-band imaging photometer**
  - **250, 360, 520 μm (simultaneous)**
  - **$\lambda/\Delta\lambda$ ~ 3**
  - **4 x 8 arcminute field of view**
  - **Diffraction limited beams (17, 24, 35”)**



- **Imaging Fourier Transform Spectrometer**
  - **200 - 670 μm (complete range covered simultaneously)**
  - **2.6 arcminute field of view**
  - **$\Delta\sigma$ = 0.04 cm^{-1} ($\lambda/\Delta\lambda$ ~ 20 - 1000 at 250 μm)**

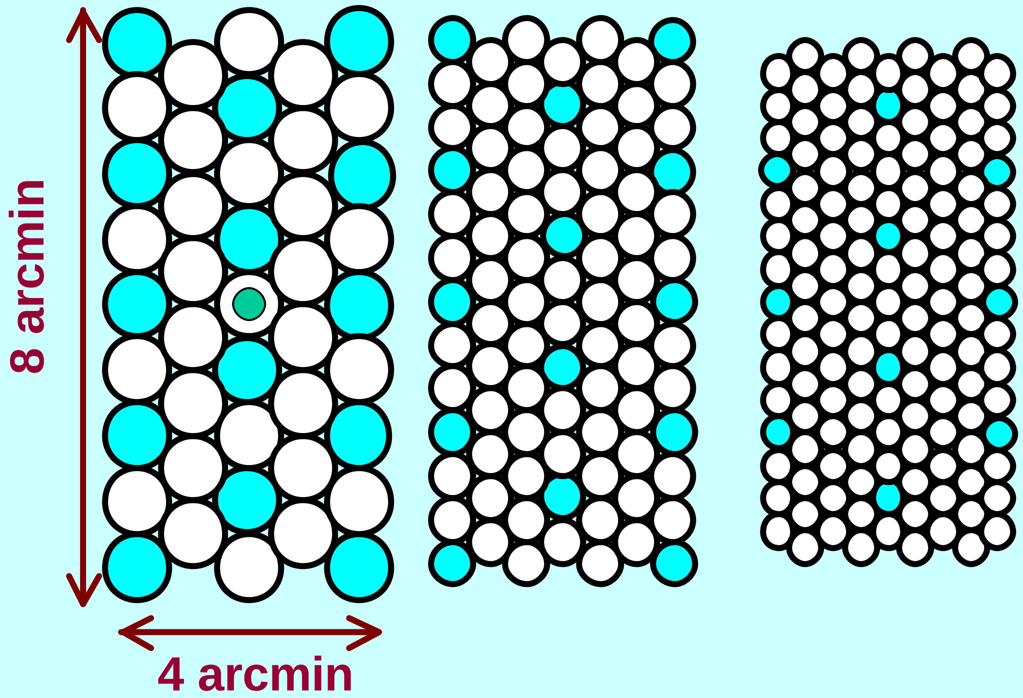
SPIRE Detector arrays

Photometer

500 μm
43 detectors

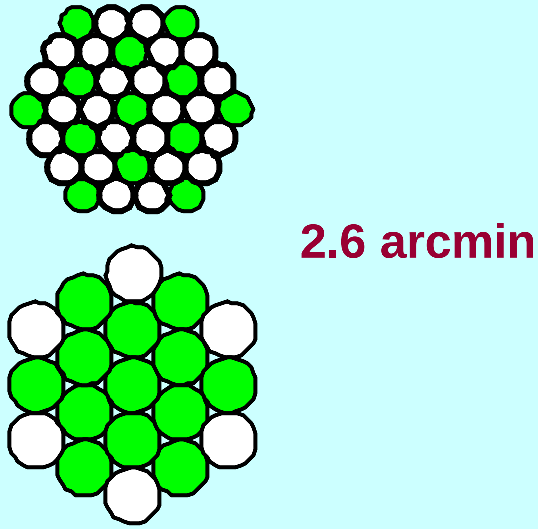
350 μm
88 detectors

250 μm
139 detectors



Spectrometer

200 – 325 μm
37 detectors

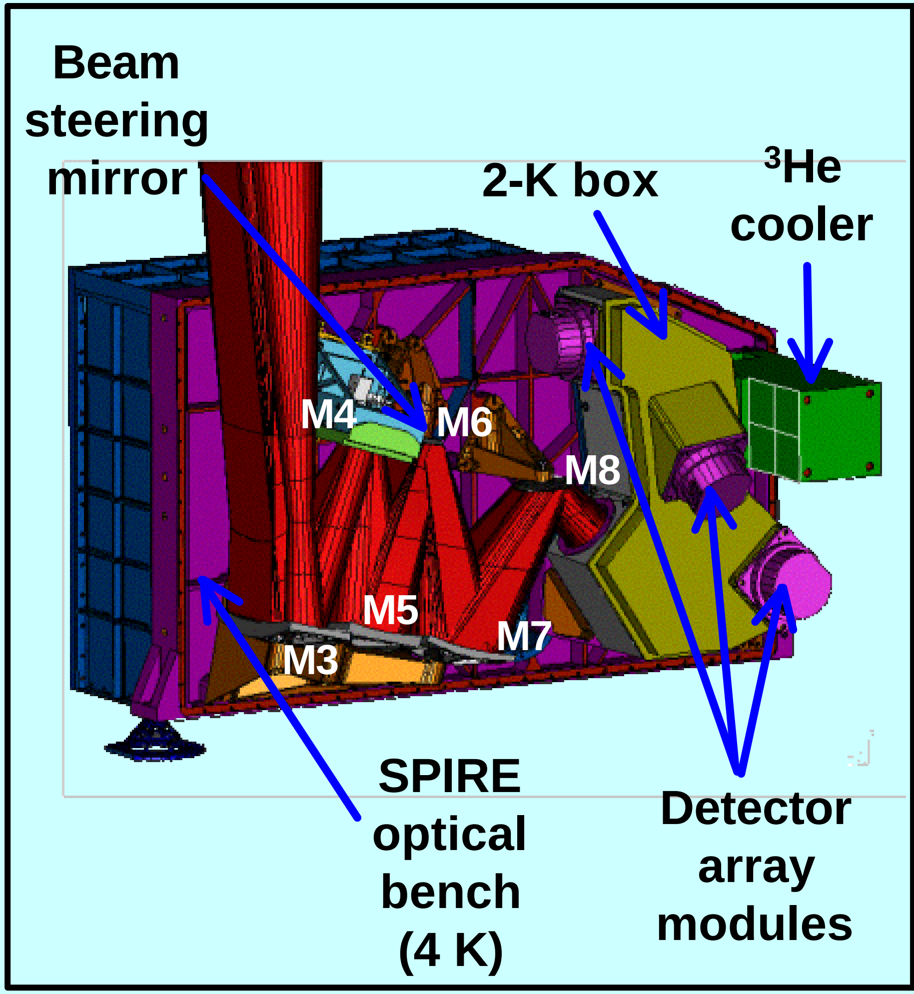


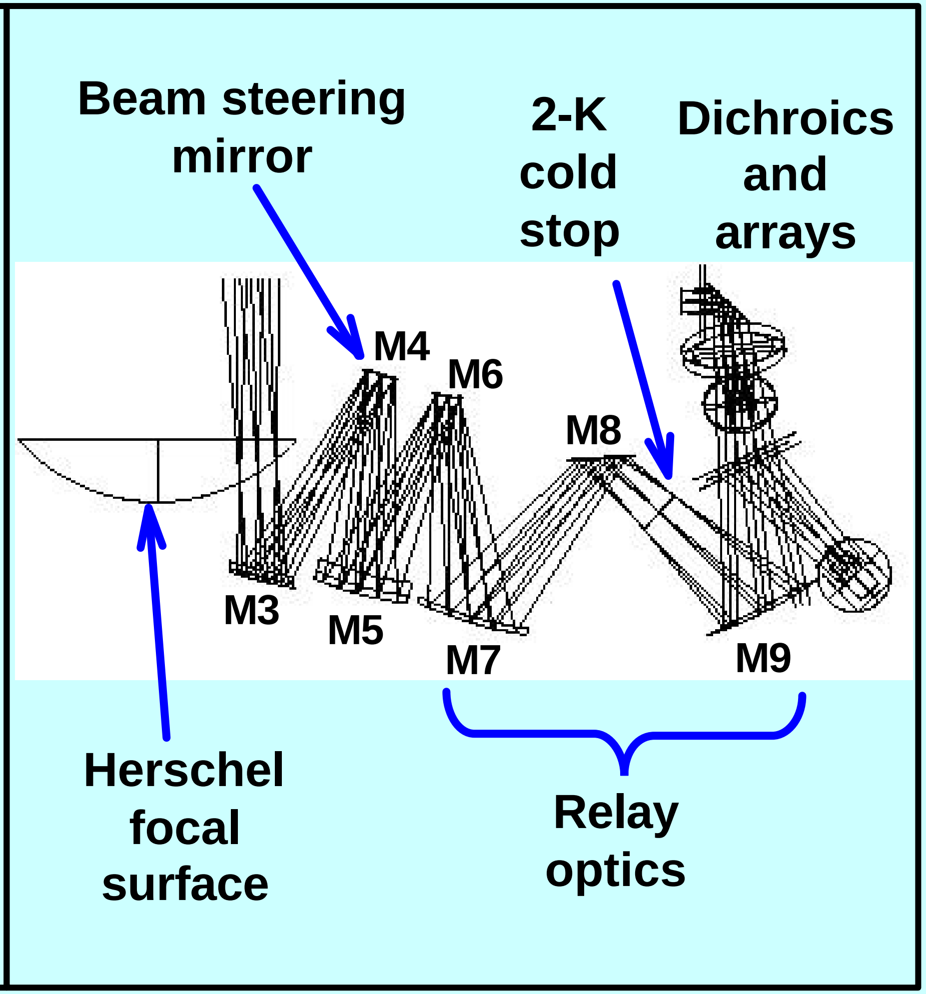
315 – 670 μm
19 detectors

⇒ **Sets of detectors with exactly overlapping beams on the sky**

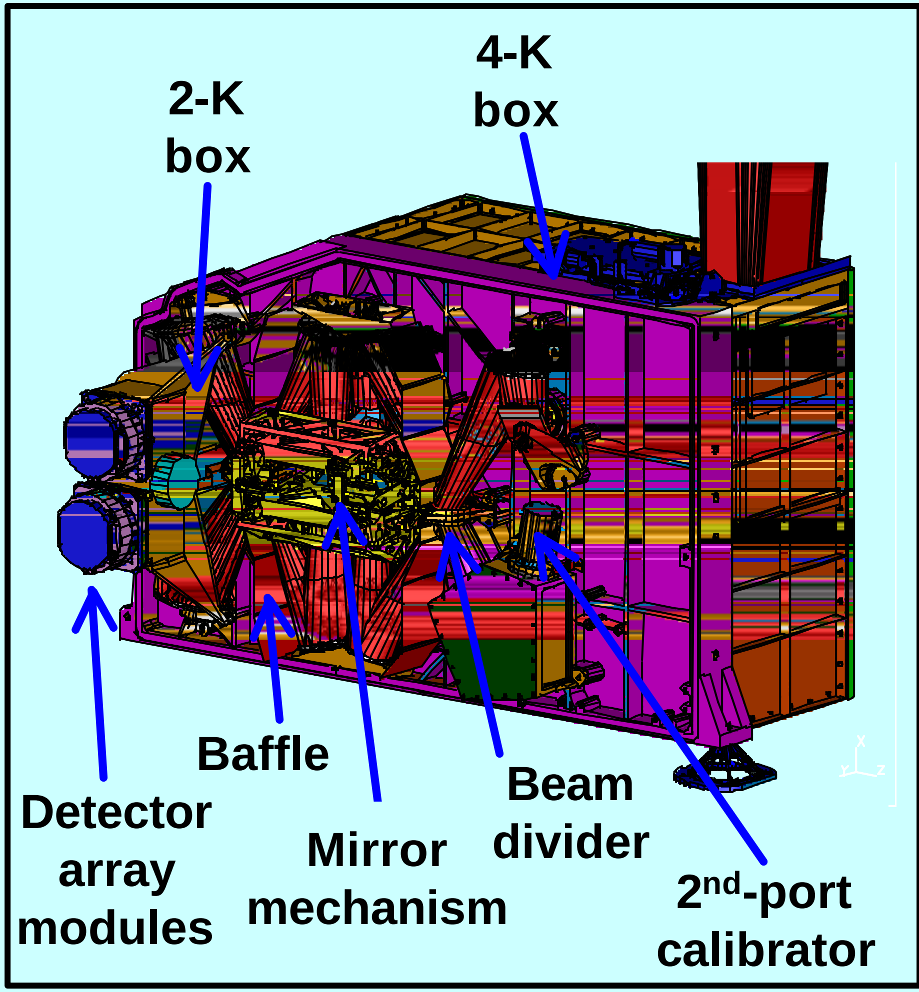
⇒ **FWHM of beam (2fλ feedhorns)**

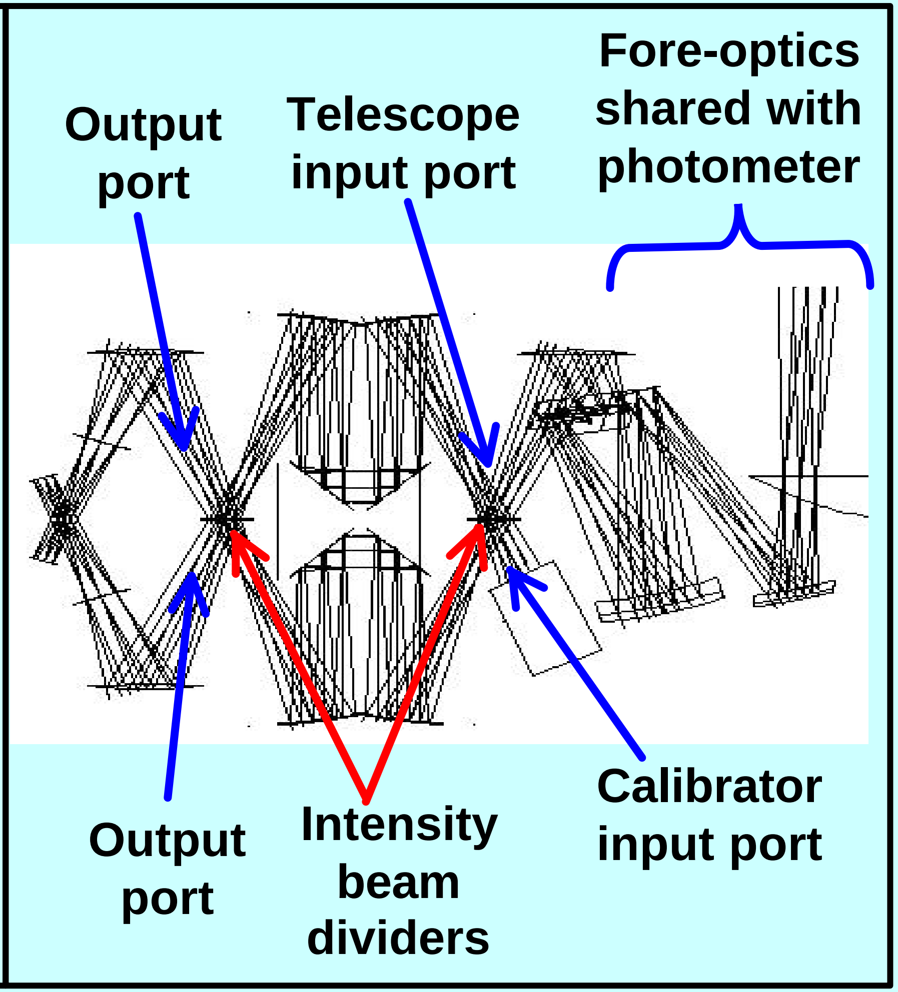
Photometer Layout and Optics





FTS Layout and Optics

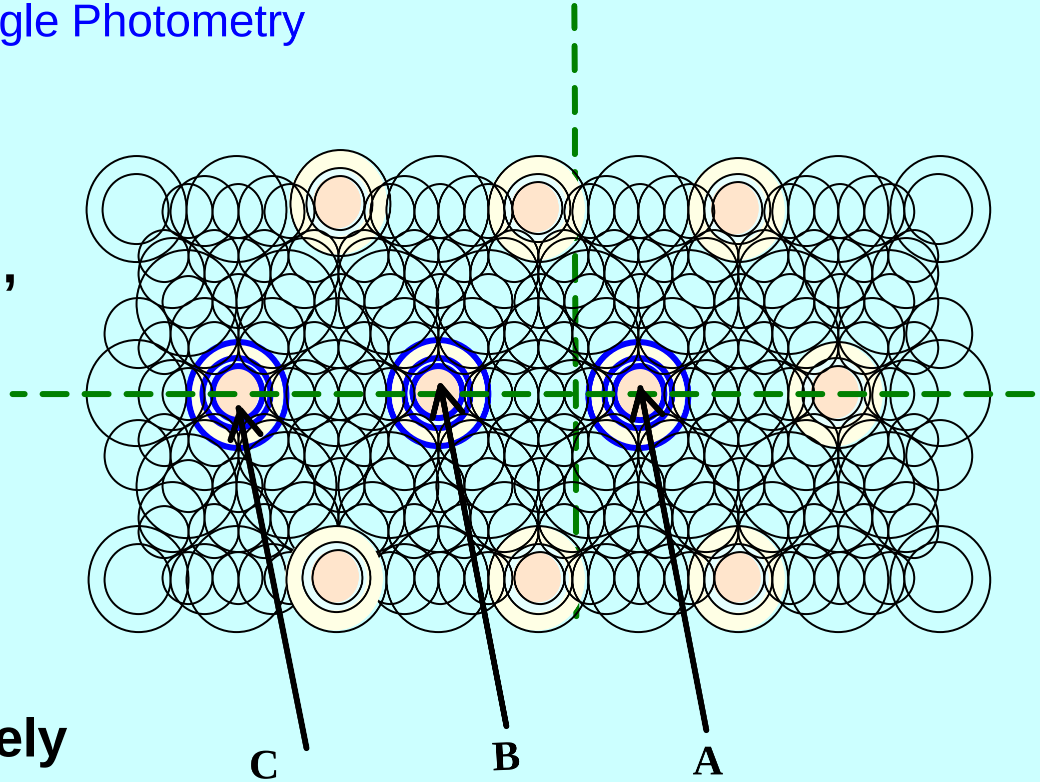


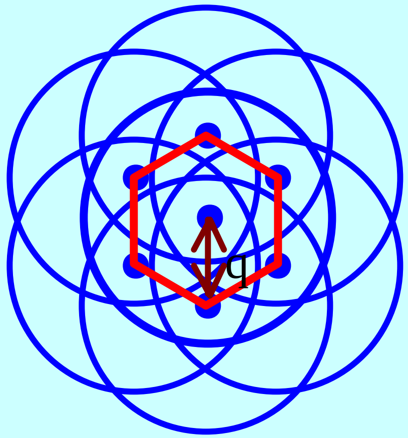


Photometer Observing Modes:
Seven-point Jiggle Photometry

- **Chopping 126” and nodding, using detector sets A, B, C**
- **7-point map**
- **Angular step θ ~ 5”**
- **Total flux and position fitted**
- **Compared to single accurately pointed observation, S/N for same total integration time is only degraded by**

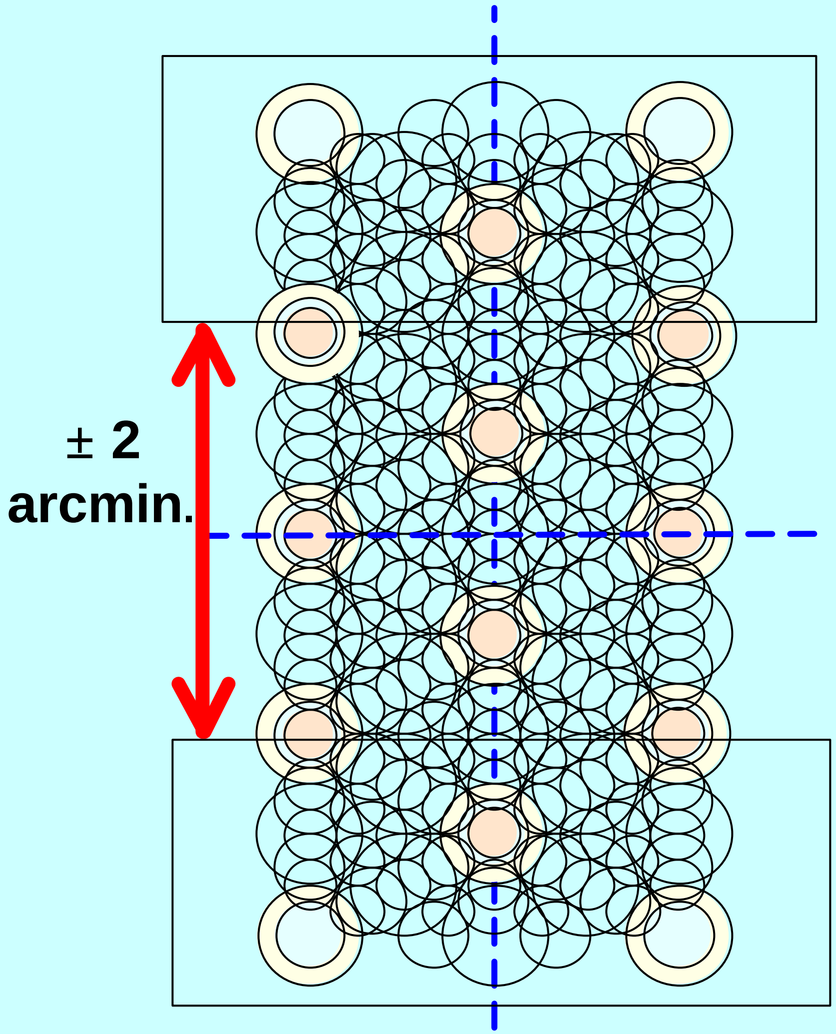
~ 20%	**at**	**250 μm**
~ 13%	**at**	**360 μm**
~ 6%	**at**	**520 μm**





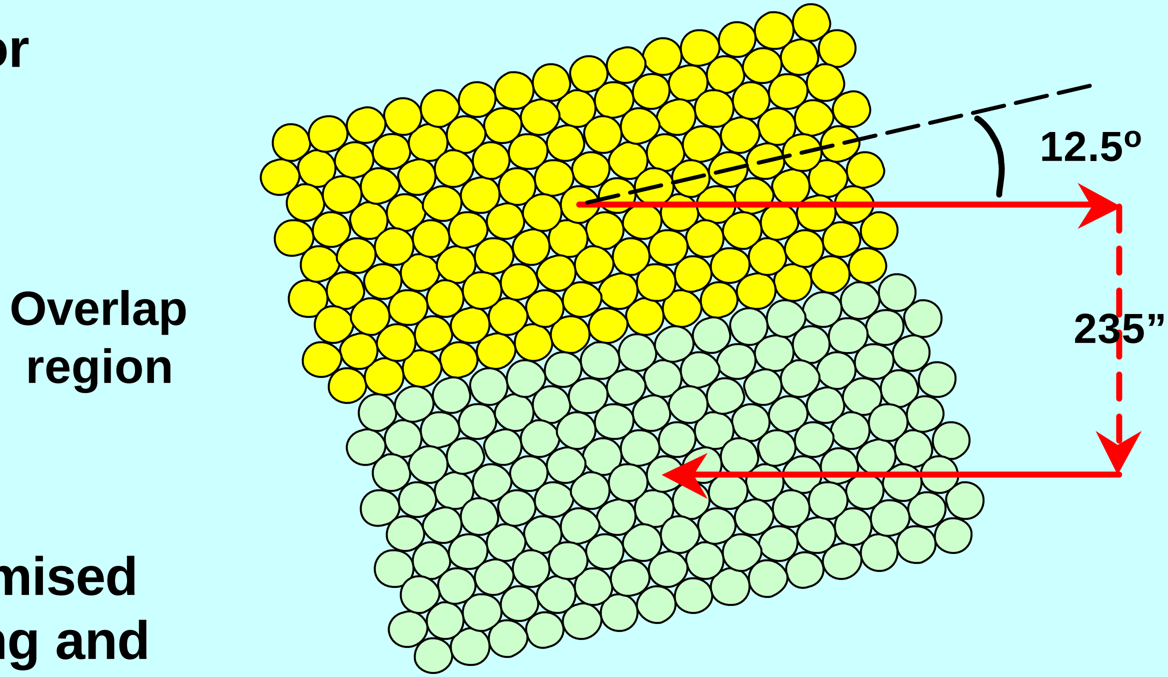
Field (Jiggle) Map

- **Telescope pointing fixed or in raster mode**
- **Chopping ± 2 arcmin**
- **64-point "jiggle" pattern for full spatial sampling**
- **Available FoV = 4 x 4 arcmin.**



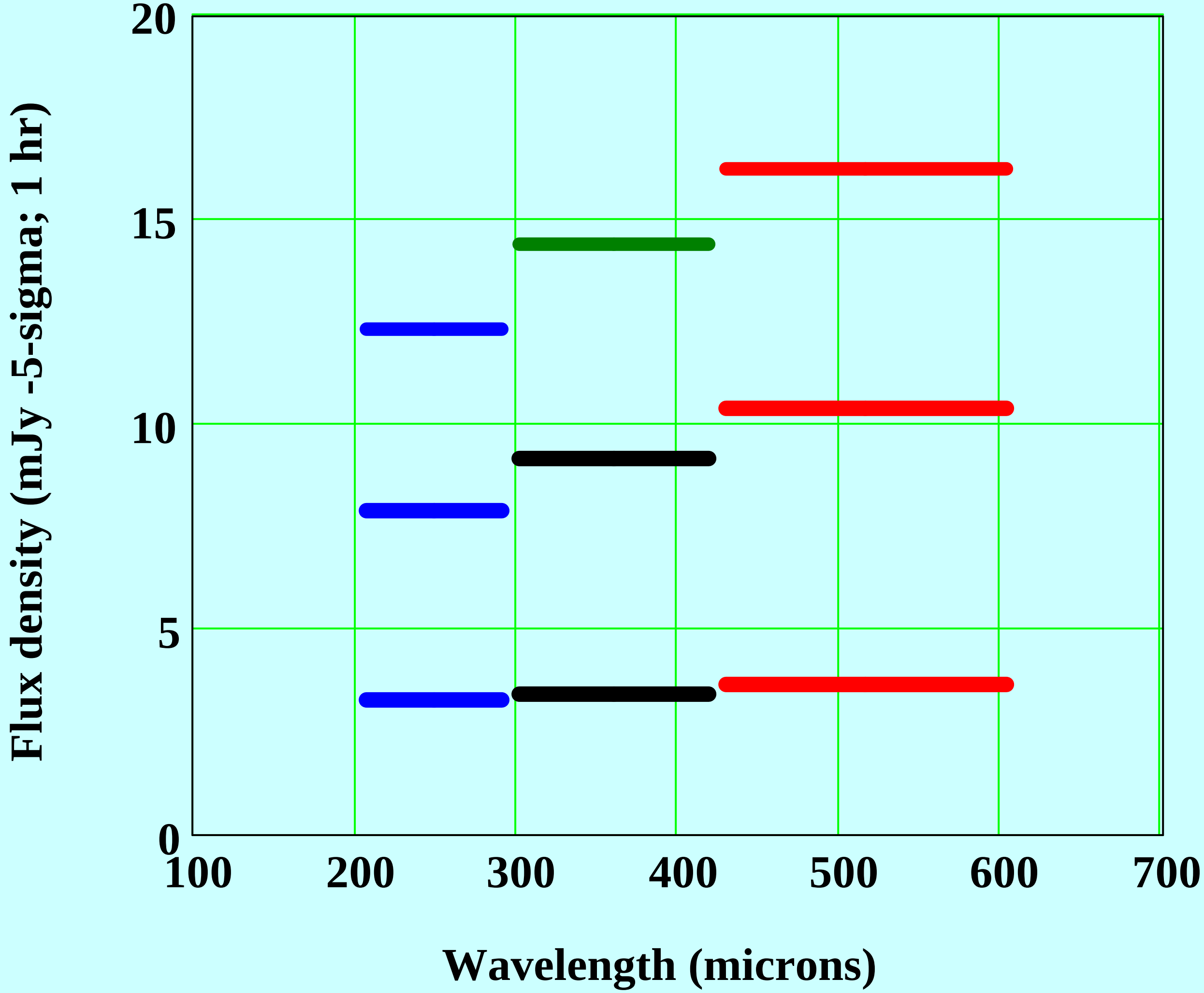
Photometer Observing Modes: Scan Map

- **Most efficient mode for large-area surveys**
- **Telescope scans continuously at up to 60"/sec.**
- **Scan parameters optimised for full spatial sampling and uniform distribution of integration time**
- **Map of large area is built up from overlapping parallel scans**



Estimated Sensitivity: Photometry

(5 s ; 1 hr)



Jiggle map

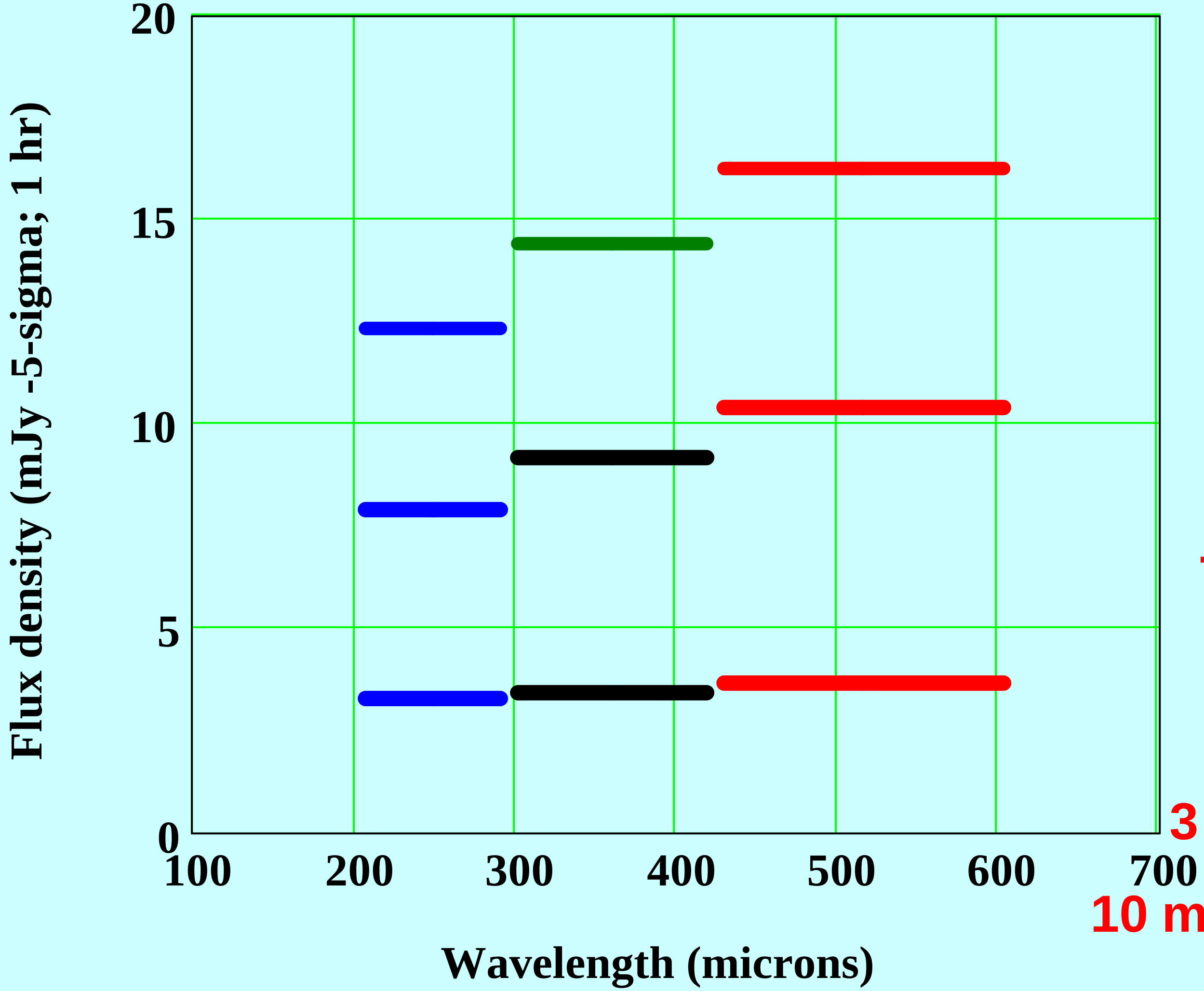
Scan map

Point source/ sparse map

(7-point)

Estimated Sensitivity: Photometry

(5 s ; 1 hr)



Jiggle map

Scan map

7-point jiggle photometry

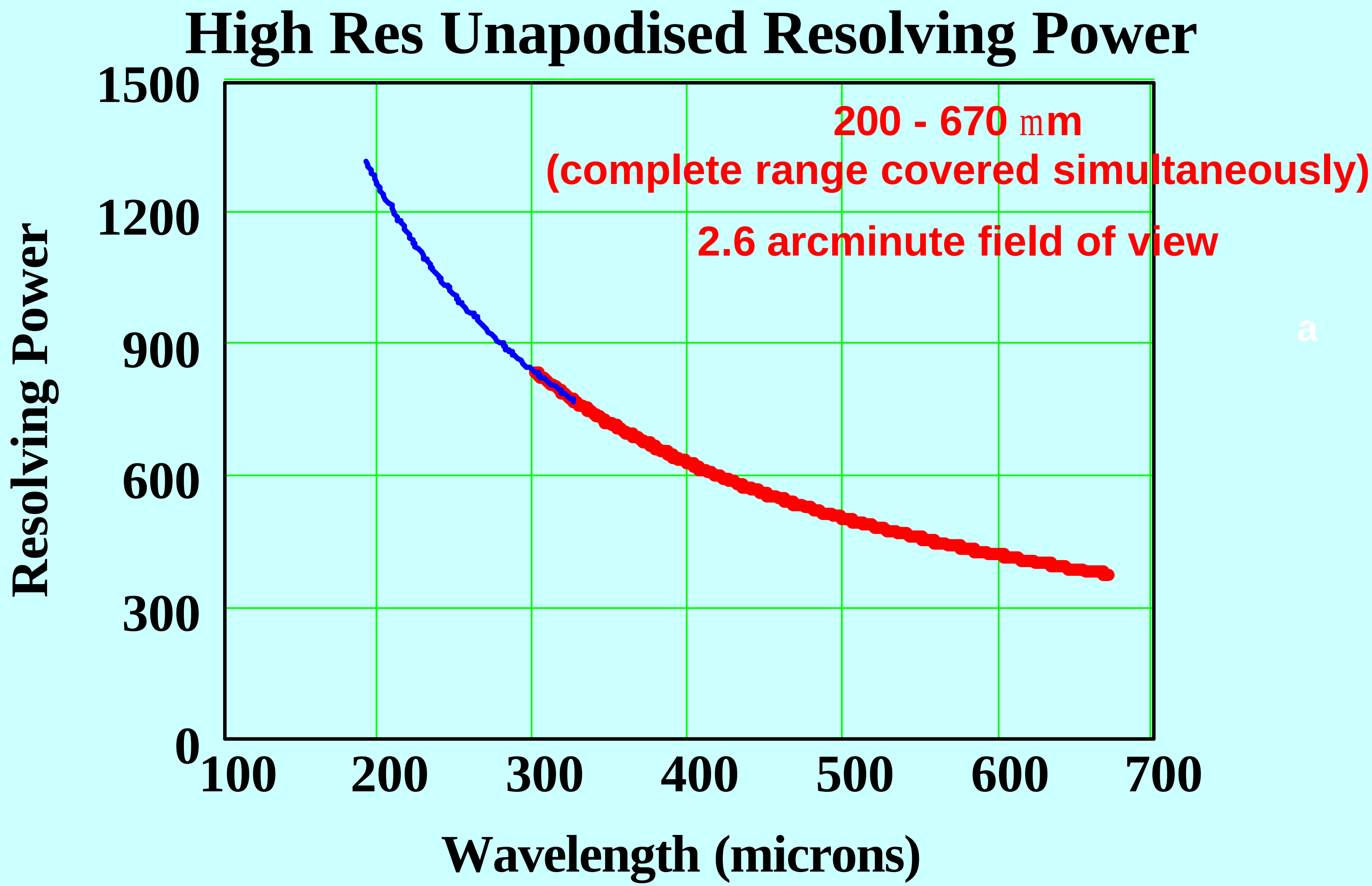
Quite fast

3 mJy in 1 hour

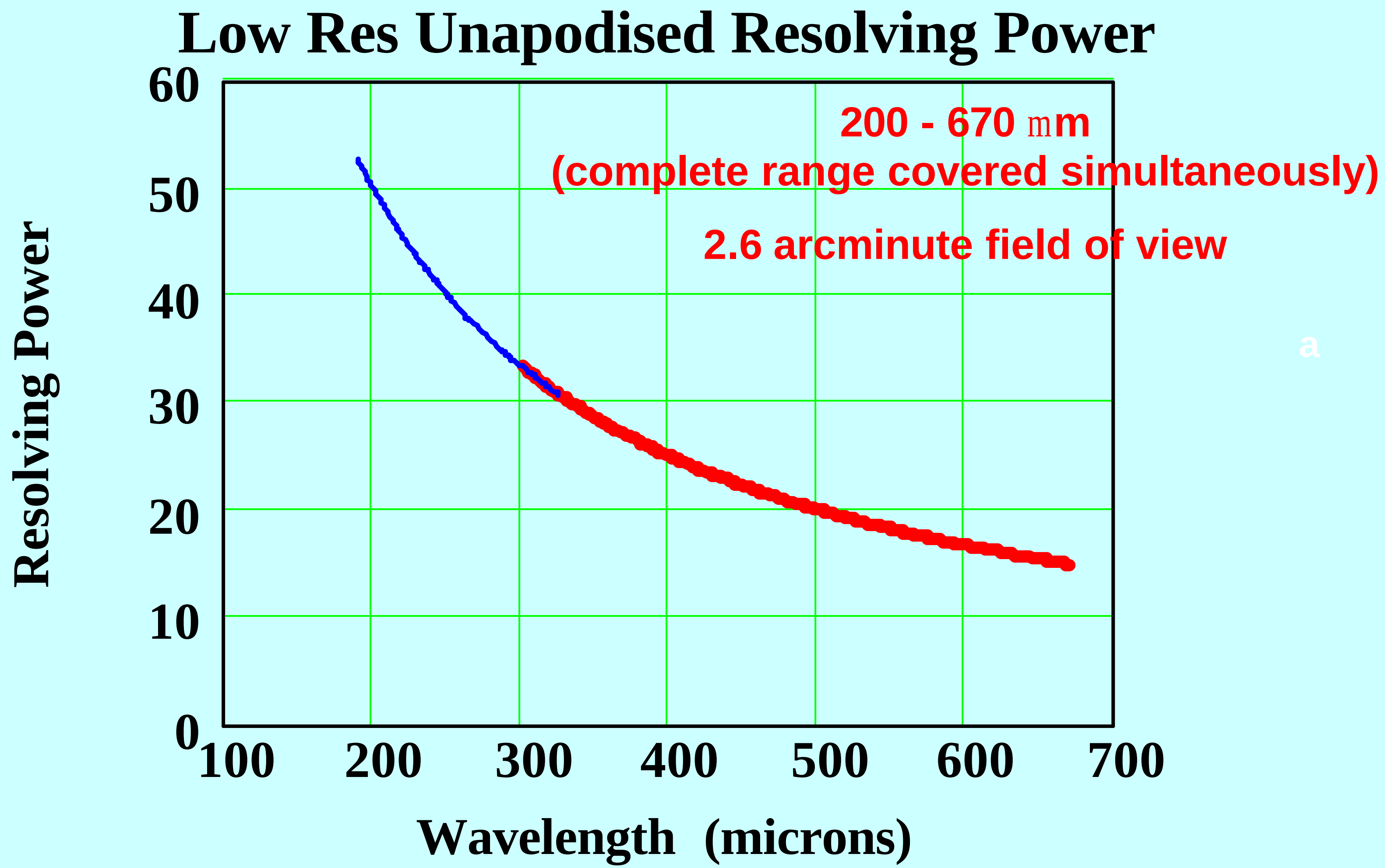
10 mJy, in 6 minutes!!

(5 sigma)

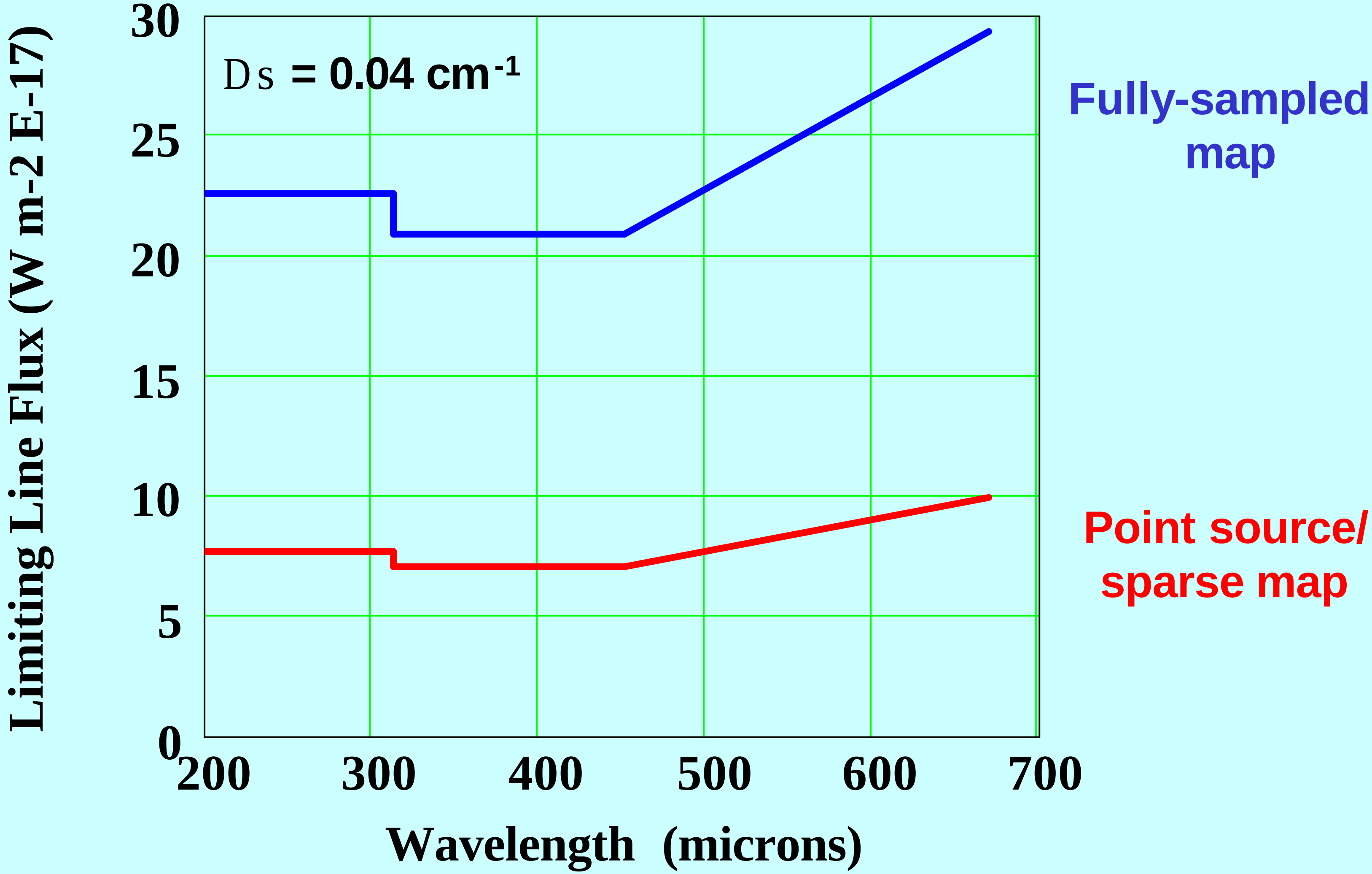
FTS Spectral Line Resolving Power
($\Delta\sigma$ = 0.04 cm^{-1})



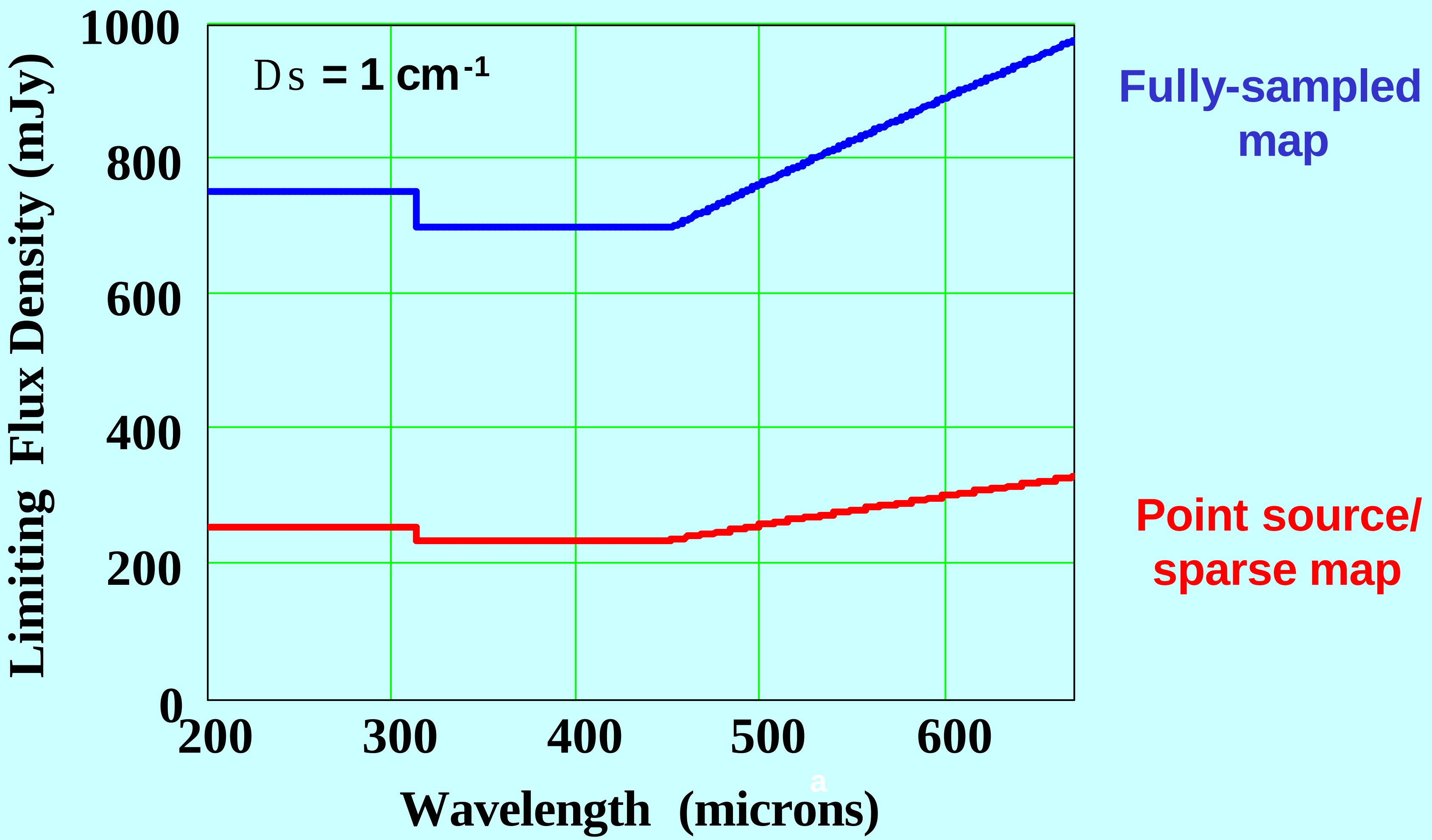
FTS Spectrophotometry Resolving Power ($\Delta\sigma$ = 1 cm^{-1})



Estimated Sensitivity: Line Spectroscopy (5 s ; 1 hr)

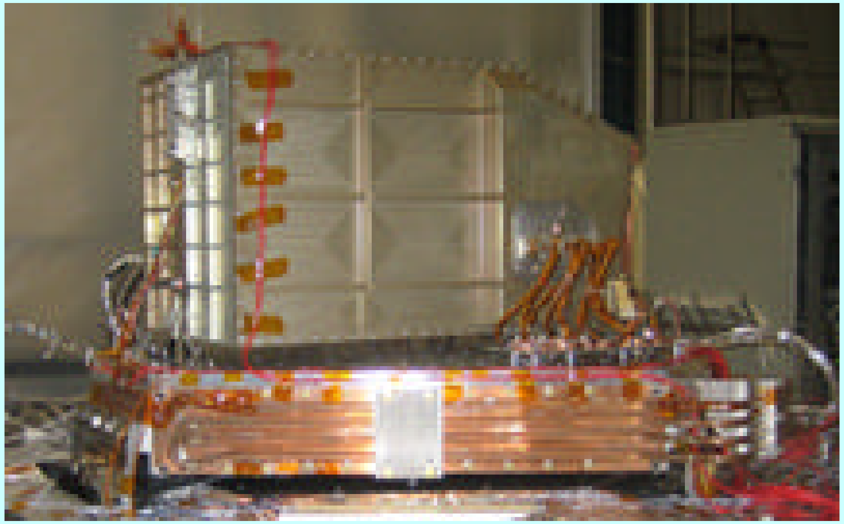


Estimated Sensitivity: Spectrophotometry (5 σ ; 1 hr)



Instrument Status (May 2006)

- Flight instrument is being built and tested in stages at Rutherford Appleton Laboratory, UK



- Test campaigns so far
  - 1. Spectrometer side (early 2005)
  - 2. Full instrument (Autumn 2005)
  - Qualification vibration (end 2005)
  - 3. Post-vibration cooldown (mid 2006)
- Future steps
  - Installation of the flight spectrometer mechanism
  - Final cold vibration
  - Extended instrument evaluation, calibration, observing mode testing
- Integration and test of flight spare
  - Use as a test-bed and for training after flight instrument delivery

Current Status (December 2006)

- Instrument currently undergoing its fourth cooldown at RAL
- This is for the first time with all flight equipment
- Instrument is working well (a few minor problems are being addressed)
- A fifth and final cooldown is planned for Jan/Feb 2007 for some final detailed calibration and testing
- Delivery for integration into the Herschel cryostat planned for March 2007

SPIRE Scientific Goals: GT Programmes as Examples

• High-redshift galaxies	850 hrs
• Local galaxies	300 hrs
• Star formation	320 hrs
• Galactic ISM	180 hrs
• Circumstellar matter	150 hrs
• Solar system	50 hrs

Herschel Key Projects Will . . .

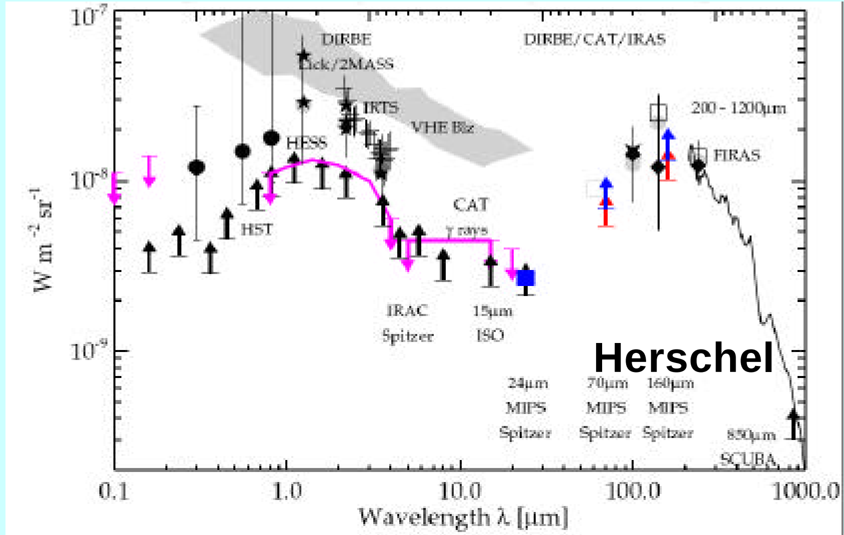
- exploit unique Herschel capabilities to address important scientific issues in a comprehensive manner
- require a large amount of observing time to be used in a uniform and coherent fashion
- produce well characterised and uniform datasets of high archival value
- occupy a large part of the mission
  - GT: ~ 90% will be in the form of Key Projects
  - OT: . . . . .
- be done mainly early in the mission:
  - core science done in case of mishap
  - allows for follow-up

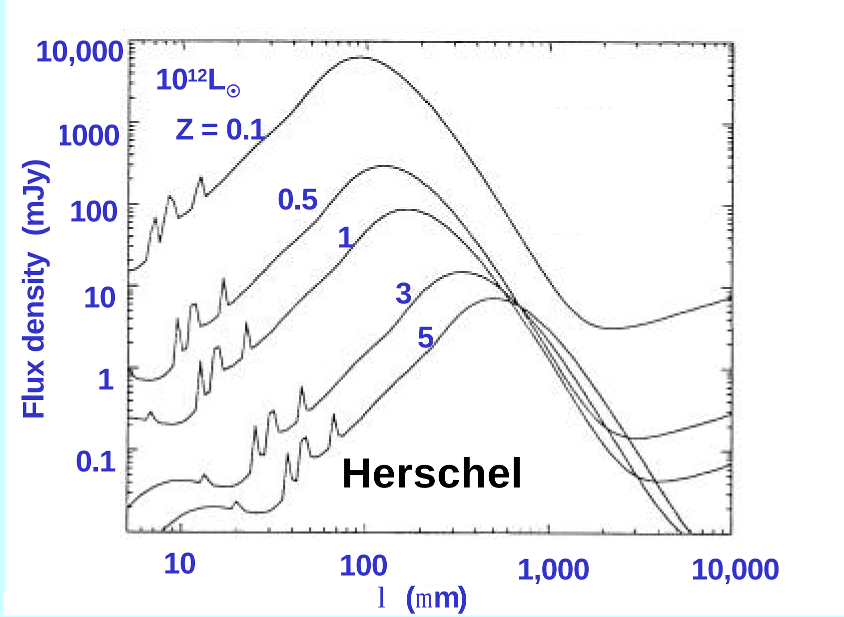
High-Redshift Galaxies

Herschel probes the rest-frame bolometric emission from galaxies as they formed most of their stars

- **History of star formation and energy production**
- **Structure formation**
- **Cluster evolution**
- **CIRB fluctuations**
- **AGN-starburst connection**
- **Planck synergy**

- **Follow up spectroscopy:**
  - **Redshifts**
  - **Physics and chemical properties**

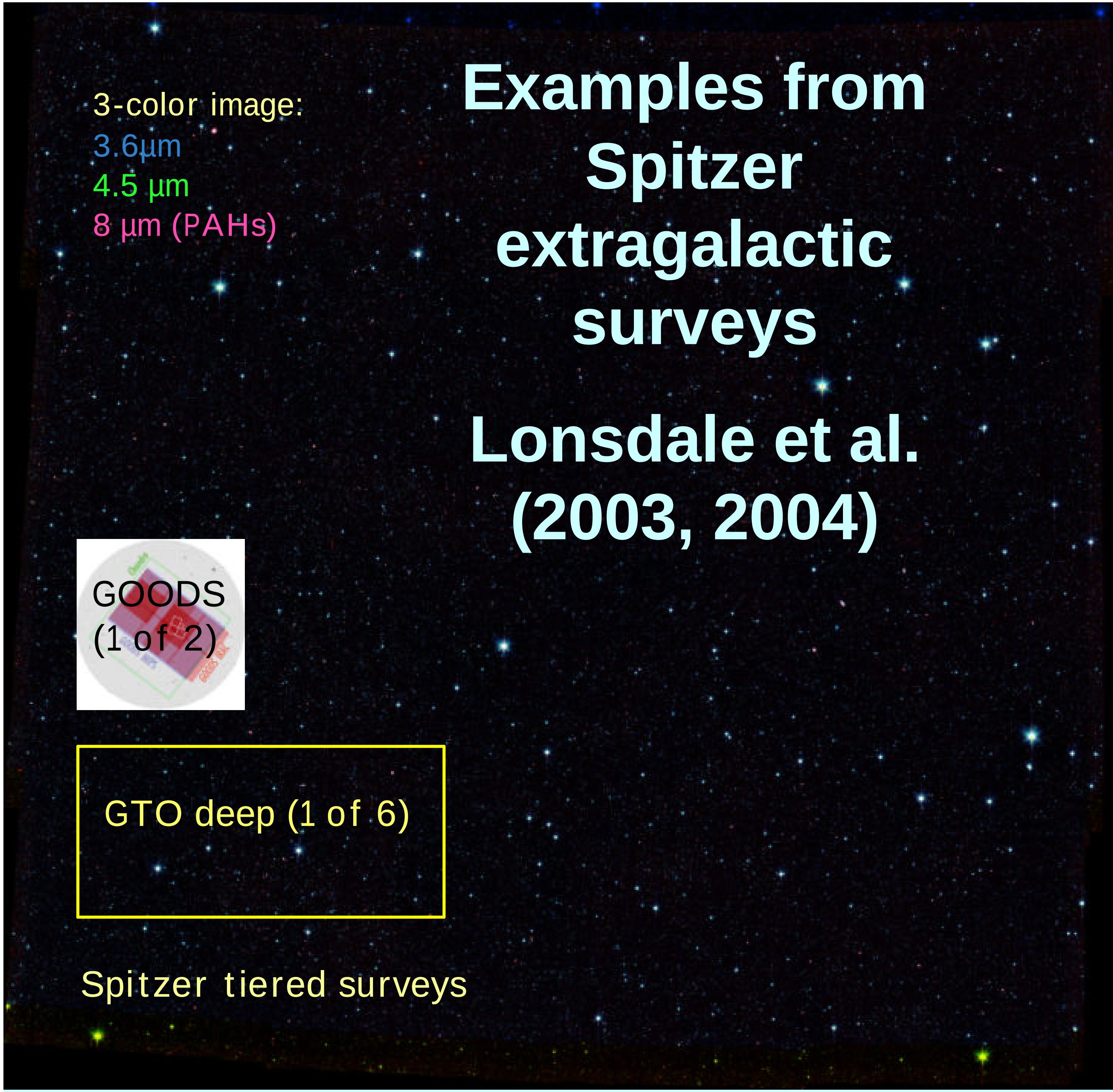




After Guiderdoni et al. MNRAS 295, 877, 1998

High-z GT Programme

- **Multi-band surveys (multi-tiered "wedding cake") covering the peak of the FIR background**
- **850 hrs of SPIRE GT (coordinated with 650 hrs of PACS GT)**
- **More in Open Time . . .**



Examples from Spitzer extragalactic surveys

Lonsdale et al. (2003, 2004)

3-color image:
3.6µm
4.5 µm
8 µm (PAHs)

GOODS
(1 of 2)

GTO deep (1 of 6)

Spitzer tiered surveys

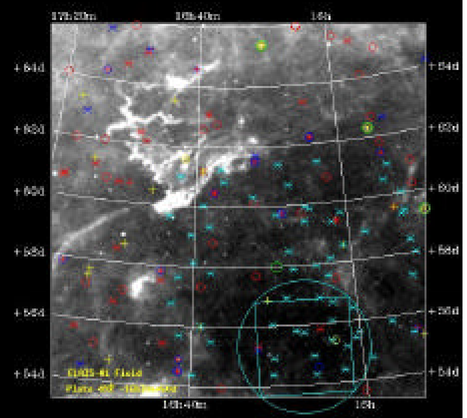
SWIRE ELAIS N1

9 sq deg in all 7 bands: 3.6 - 160 µm

~0.5 million galaxies

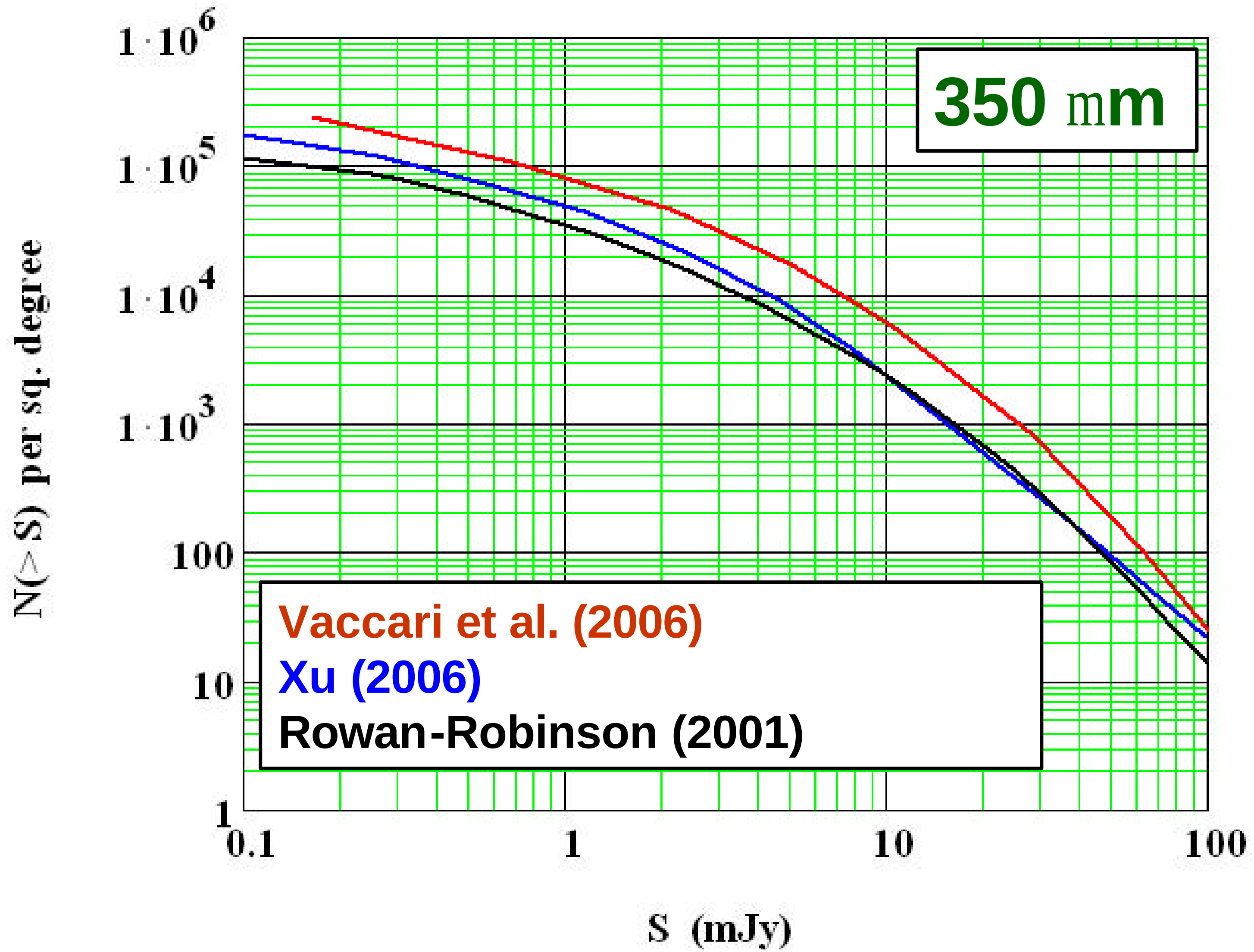
Low cirrus hole

white = 100µm IRAS

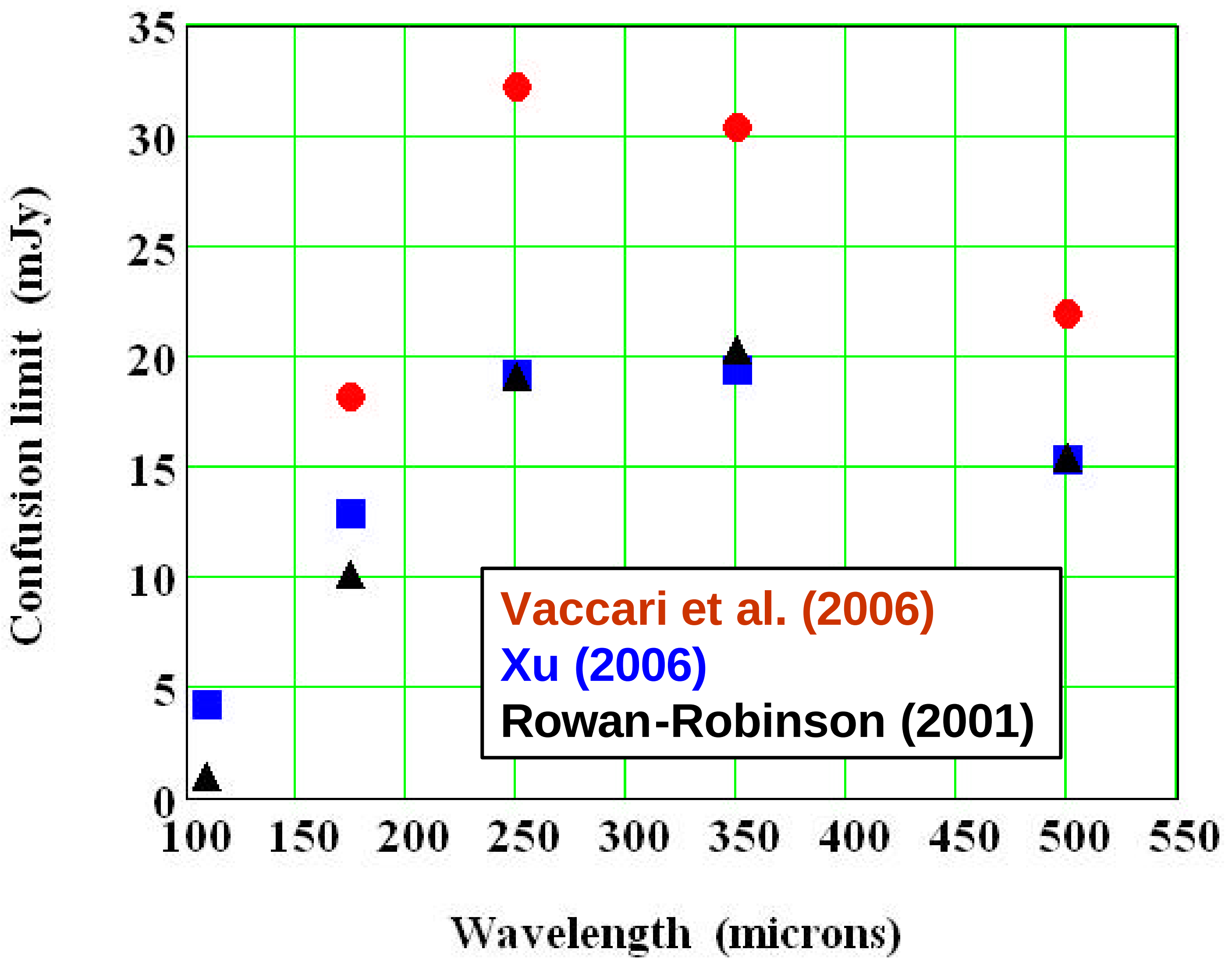



UGC10214, the “Tadpole” galaxy
Jarrett et al. (2006)

Source Count Models



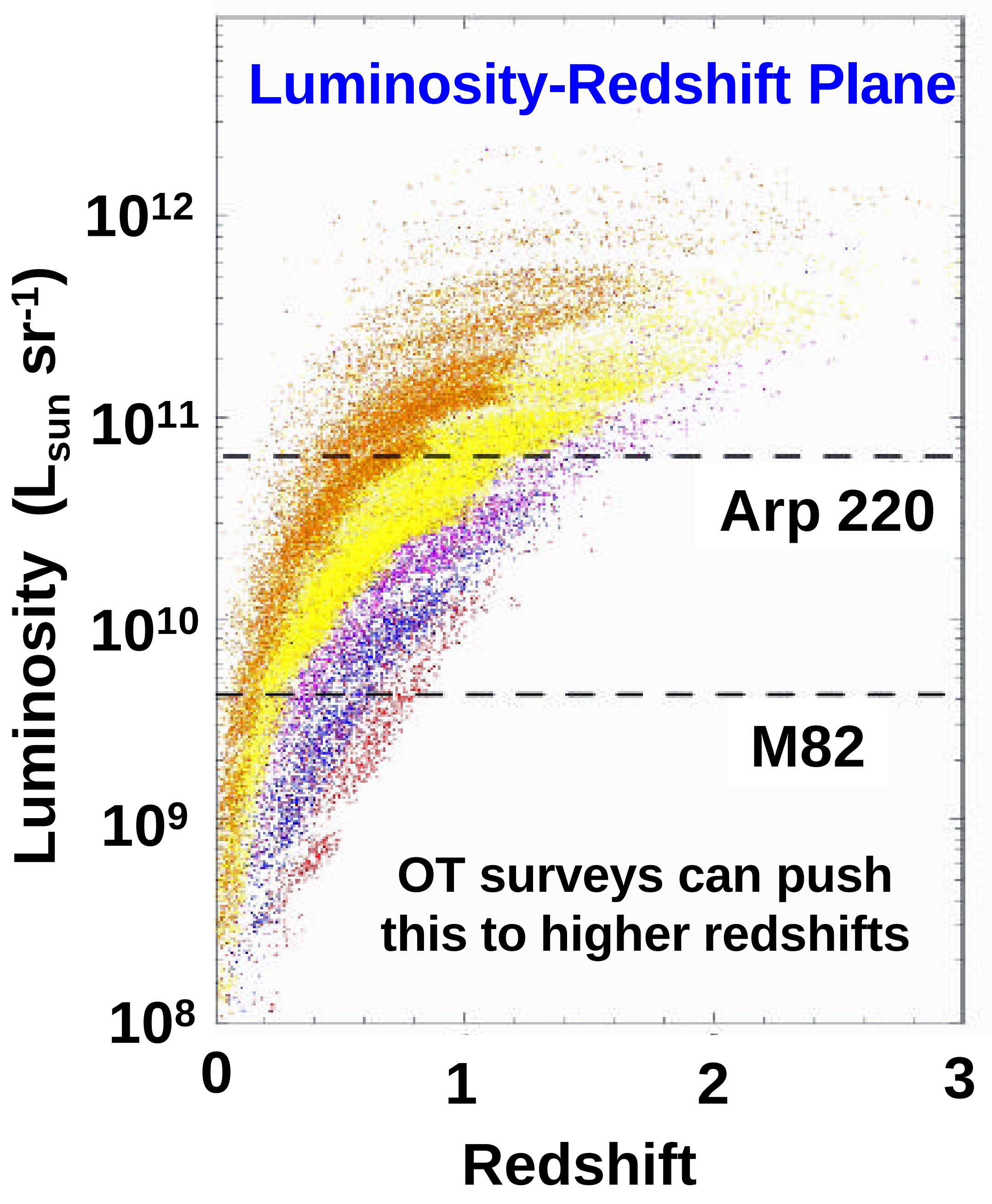
Confusion Estimates (40 beams/source)



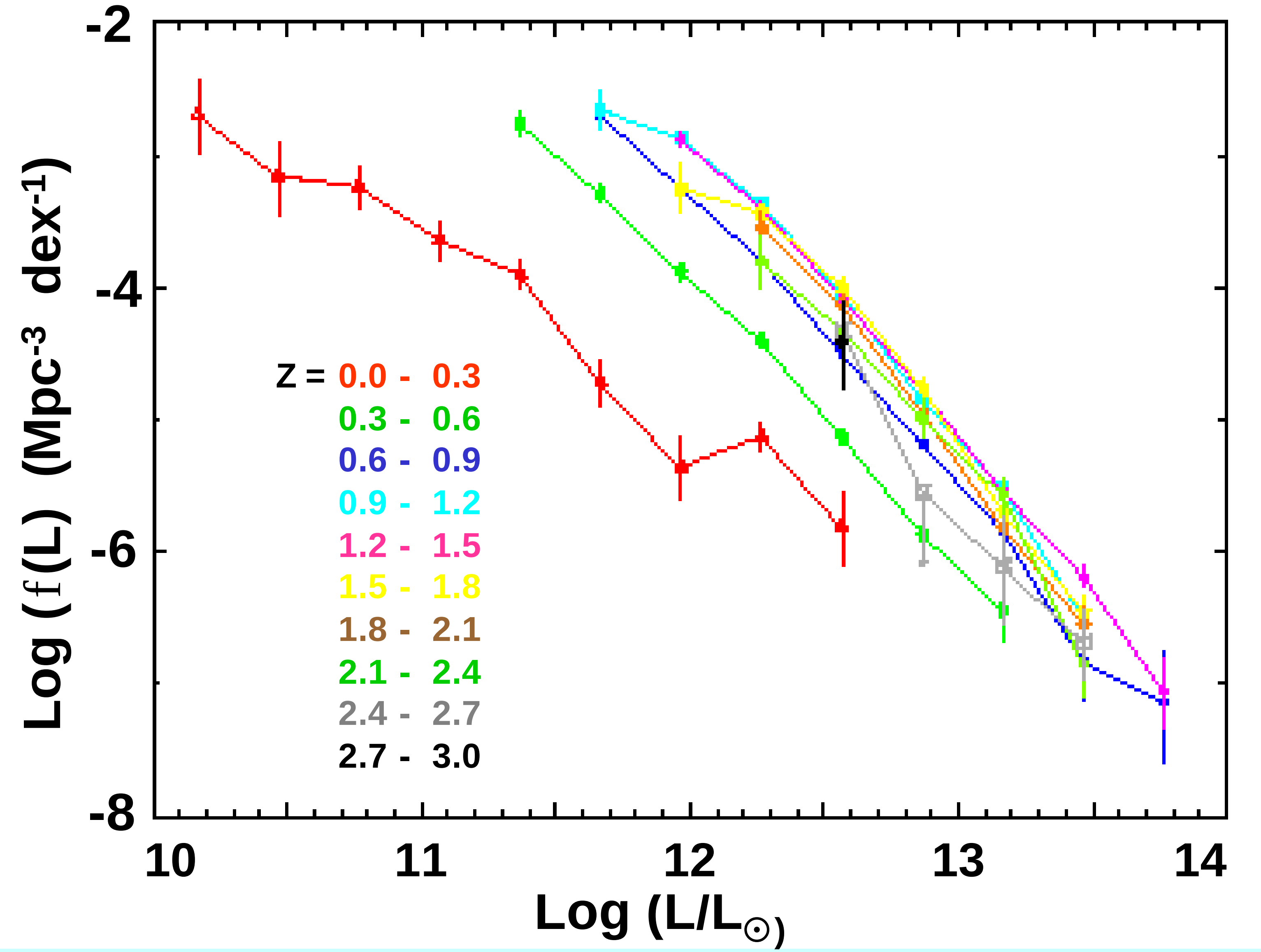
Wedding Cake Survey

will probe L_{Bol} over a wide redshift range

Level	A (Sq. deg.)	Fields
Level-1	0.04	GOODS-S
Level-2	0.04	GOODS-N
Level-3	0.25 0.25 0.25	GOODS-S Groth Strip Lockman
Level-4	2 2	COSMOS XMM-LSS
Level-5	10	Spitzer field(s)[4]
Level-6	50	Spitzer fields[6]

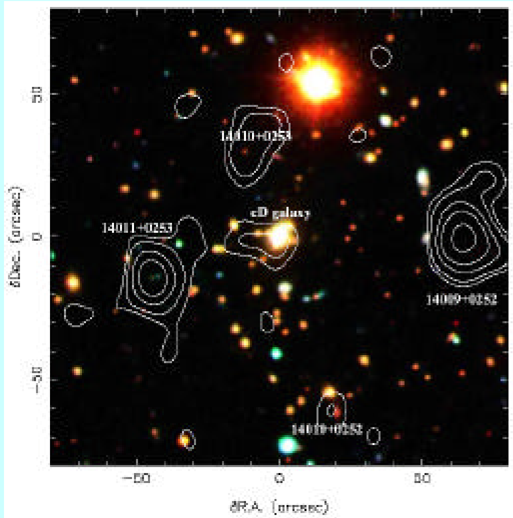


Reconstructing the Evolution of the Bolometric Luminosity Function

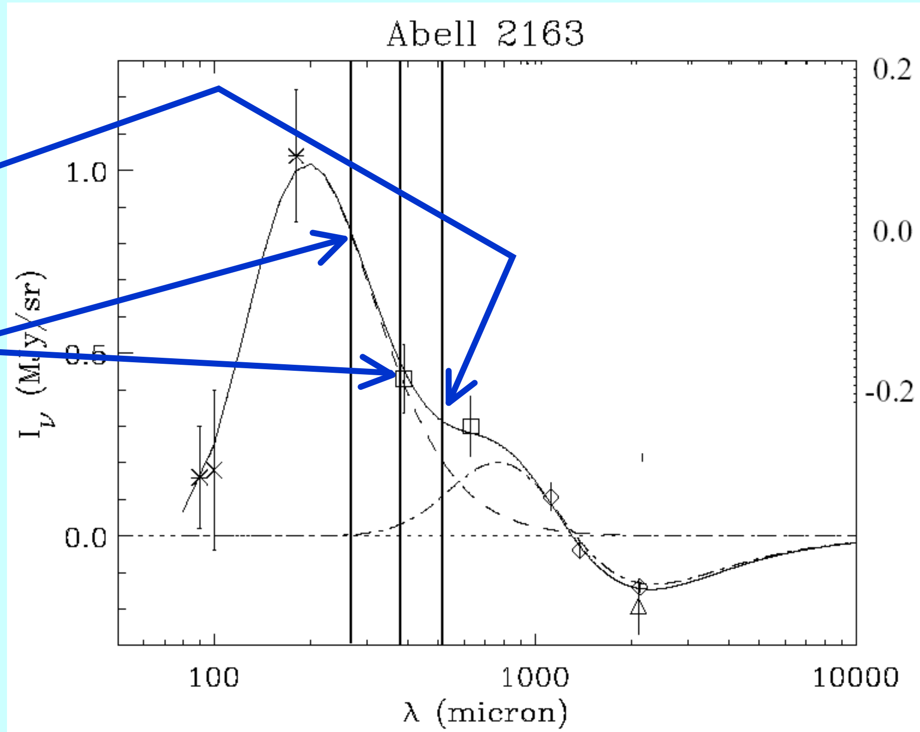


Cluster Imaging

- **15 rich clusters from z = 0.2 to > 1**
- **Lensing**
  - **Extend below blank field confusion limit to about 5 mJy**
  - **About 200 detections expected**

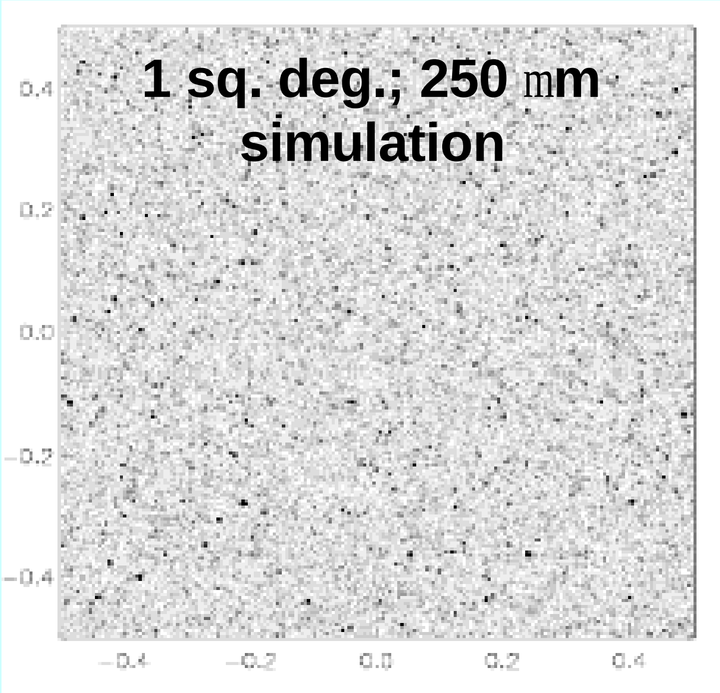


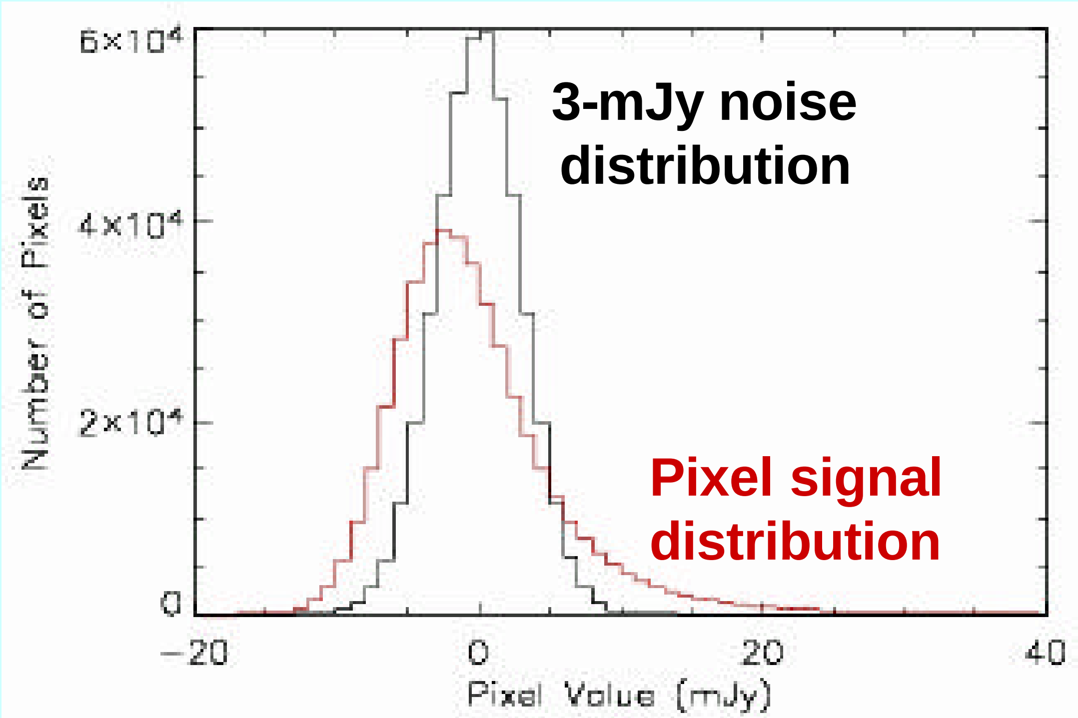
- **Sunyaev Zel'Dovich effect**
  - **Significant S-Z effect at 520 mm**
  - **Shorter wavelength bands will allow contribution from cluster galaxies to be subtracted**



P(D) Analysis

- Deep SPIRE observation of ~ 1 sq. deg.
- Fluctuations down to ~ 3 mJy (~ 1 source/beam)
- P(D) depends on beam profile and slope of number counts





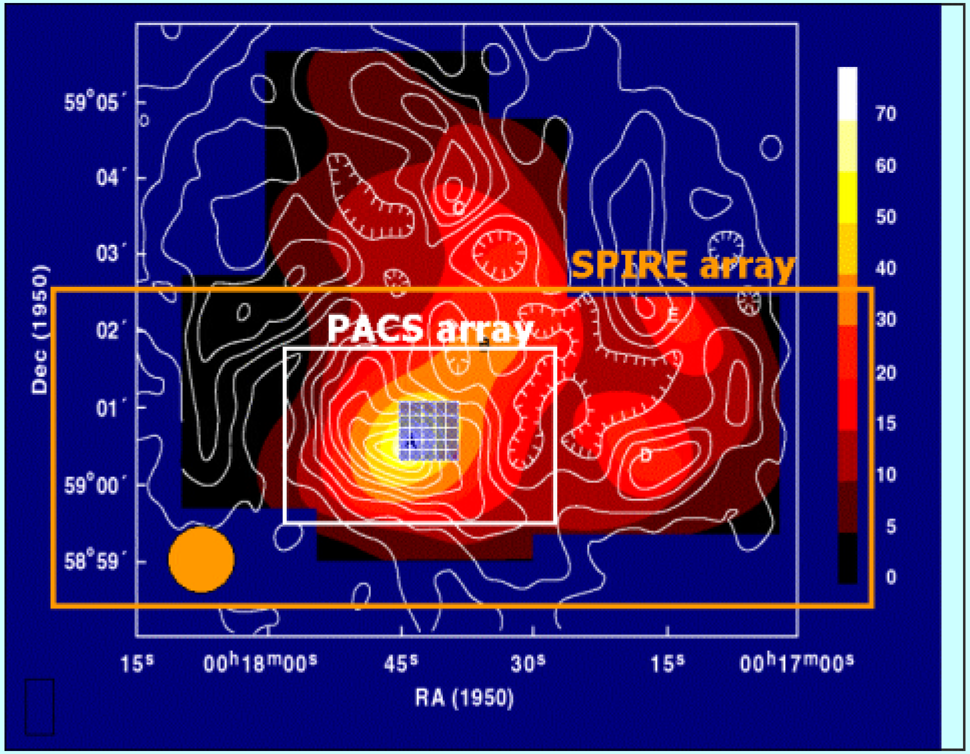
Local Galaxies GT programme

Three Key Projects

- **Physical Processes in the ISM of Very Nearby Galaxies**
  - **PACS + SPIRE + HIFI**
- **The ISM in Low Metallicity Environments**
  - **PACS + SPIRE**
- **The Herschel Galaxy Reference Survey**
  - **SPIRE only**

1. ISM in Nearby Galaxies

- **Sample of 15 nearby galaxies well-studied from X-ray-radio**
  - **Early & late type spirals**
  - **Low mass spiral**
  - **Edge-on spiral**
  - **Starburst spiral**
  - **Starburst galaxy**
  - **Quiescent dwarf**
  - **Starburst dwarf**
  - **Seyferts**
  - **Ellipticals**



Contours: HI; Color 158 mu CII Madden et al 1997

- **Spatially resolved photometry, spectroscopy with PACS, SPIRE, HIFI**
- **Detailed SEDs and dust properties**
- **Chemistry/metallicity variation and evolution**
- **Variations inside a galaxy as well as global properties**

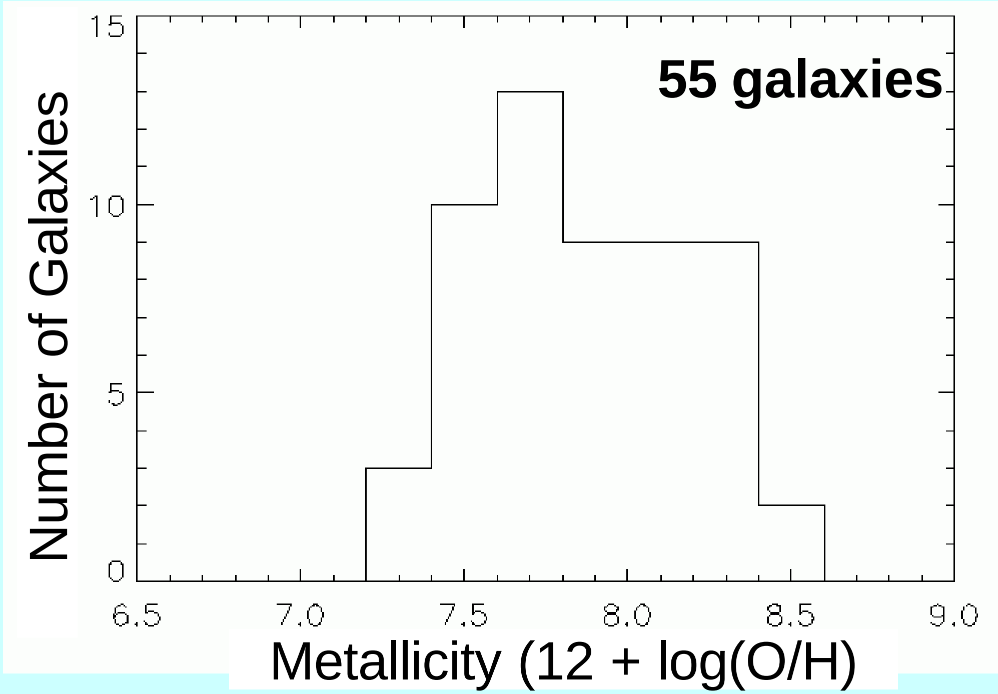
ISM in Nearby Galaxies

Galaxy	type	FOV
M51	late-type spiral	11' x 17'
M81	early-type spiral	27' x 14'
NGC2403	low mass spiral	22' x 12'
NGC891	edge on spiral	13.5' x 6'
M83	starburst spiral	13' x 12'
M82	starburst	15' x 15'
NGC6822	quiescent dwarf	16' x 14'
IC10	starburst dwarf	10' x 10'
Arp220	late-phase merger	2' x 1'
NGC4038/39	early-phase merger	6'x6'
NGC1068	Sy2	7' x 6'
NGC4151	Sy1	6' x 5'
CenA	closest E; agn	26' x 20'
NGC4125	normal E	6' x 3"
NGC205	dwarf E	22' x 11'

2. Low Metallicity Dwarf Galaxies

- **Cohesive programme of SPIRE/PACS/HIFI photometry and spectroscopy**

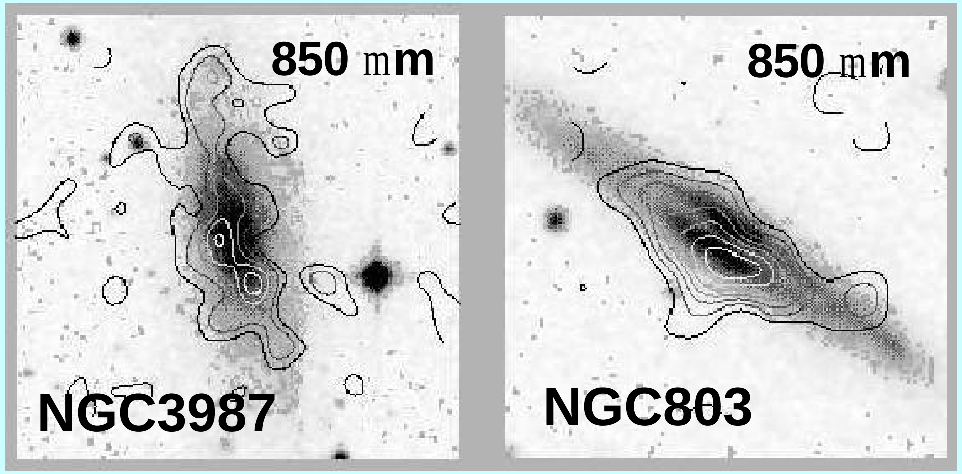
- **Analogues of high-z building blocks**
  - **ISM and SF in primordial galaxies**
- **Dust components and properties in metal-poor galaxies**
- **Influence of metallicity on ISM structure, radiation field, star formation activity**
- **Impact of super star clusters prevalent in dwarf galaxies on surrounding gas and dust**



- **0.5 – 1/50 solar metallicity**

3. Herschel Reference Survey of Dust in Galaxies

- **Statistical survey of dust in the nearby universe**
- **SPIRE photometry of sample of 320 galaxies**
- **Relate present-day galaxies to high-z ancestors**
- **How do dust mass and distribution depend on**
  - **Galaxy type?**
  - **Environment?**
  - **Luminosity?**

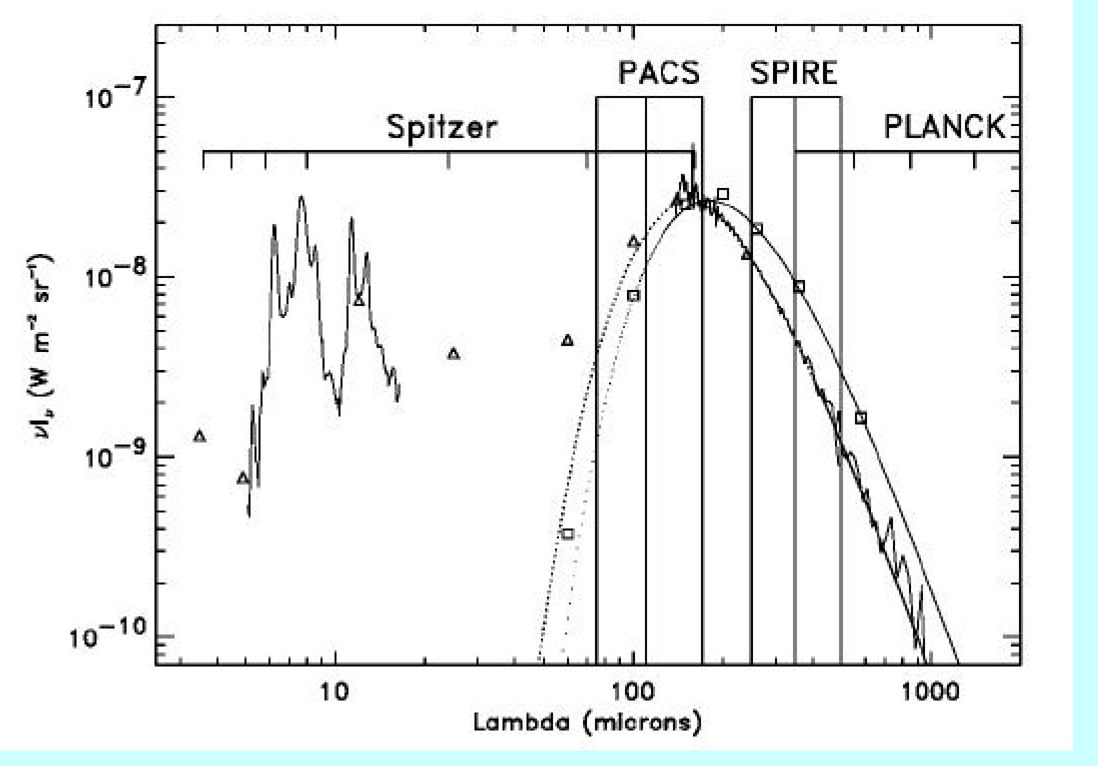


- **Primary sample: 155 galaxies**
  - **K(2MASS) < 9 (descendents of early universe luminous objects)**
  - **D = 15 - 25 Mpc (single pointing and spatially resolved)**
- **Secondary sample: K = 9 - 12 (extends mass range)**

A Relevant Galactic Programme: Physics and Evolution of Interstellar Dust

- **Unbiased surveys of regions with different A_v, illumination, density, history, star forming activity**
  - Dust SED and gas physics

- **Processes acting on dust particles**
  - Fragmentation
  - Coagulation
  - Condensation
  - Evaporation
  - Photo processing



- **In all environments:**
  - Shock processed dust
  - Cirrus
  - Molecular clouds
  - PDRs
  - Pre-stellar cores and protostars

Possible Open Time Extragalactic Programmes

Based mainly on EXTRAHOT (EXTRAgalactic Herschel Open Time projects) coordination meeting in Leiden, Oct. 2005

Open Time Programmes

1. **PACS deep survey of the COSMOS field/Chandra Deep Field South/ELAIS S1**
   - Extend in area the confusion-limited PACS surveys
   - Comprehensive investigation of galaxy evolution at z < 1.5
   - Coordinator: Eric Bell, MPIA

2. **SPIRE (+ PACS ?) survey of SCUBA-2/Laboca legacy areas**
   - Complement the GT confusion-limited SPIRE survey
   - Comprehensive investigation of star-formation/AGN activity as a function of environment and redshift
   - Coordinator: Eric Bell, MPIA

3. **Large-area shallow survey**
   - Few x 100 sq. deg. to ~ 20 mJy rms
   - Strongly lensed sources (halo mass function, dark energy)
   - High-z clustering
   - Rare objects
   - Planck foregrounds
   - Coordinator: Gianfranco de Zotti, Padua

Open Time Programmes

4. **High-redshift AGN**
   - Sample of AGN over a wide range of luminosity in a narrow redshift slice at z = 1
   - Coordinator: Matt Jarvis, Oxford

5. **High-mass cluster survey**
   - Survey 30 high-mass clusters; z = 0.4 - 1.2
   - Evolution of infall/star formation in rich environments.
   - Coordinator: Eelco Van Kampen, Innsbruck

6. **Herschel survey of local-universe activity: AGN vs. starbursts (HERLOGA):**
   - AGNs as tracers for high-z FIR galaxy formation and evolution
   - ULIRG power source

   Coordinator: Luigi Spignolio, IFSI

7. **Follow-up of PLANCK sources**
   - Coordinator: Gianfranco de Zotti, Padua

Open Time Programmes

8. **Follow-up of Astro-F/SCUBA-2 sources**
   - Coordinator: Steve Serjeant, Kent
9. **FTS surveys of the high-z universe**
   - Coordinator: Dimitra Rigopoulou, Oxford
10. **Extended dust around nearby galaxies and intracluster dust**
    - Coordinator: Jon Davies, Cardiff
11. **Dust in ellipticals**
    - Coordinator: Manfred Stickel, MPIA
12. **HIFI programme on nearby galaxies**
    - Coordinator: Carsten Kramer, Cologne

The future?
Cosmic Vision 2015-2025
FIR missions proposals

- **European Instrument for SPICA**

  - Collaboration with ISAS/JAXAS
  - FIR Imaging spectrograph (35-200 μm)

  - Herschel: warm 3.5m telescope (70 K),

  - SPICA: colder (4 K) 3.5m telescope, better flux limits, spectroscopy of faint sources

- **FIRI (FAR Infrared Interferometer)**

  - High angular resolution in the FIR, formation flying interferometer