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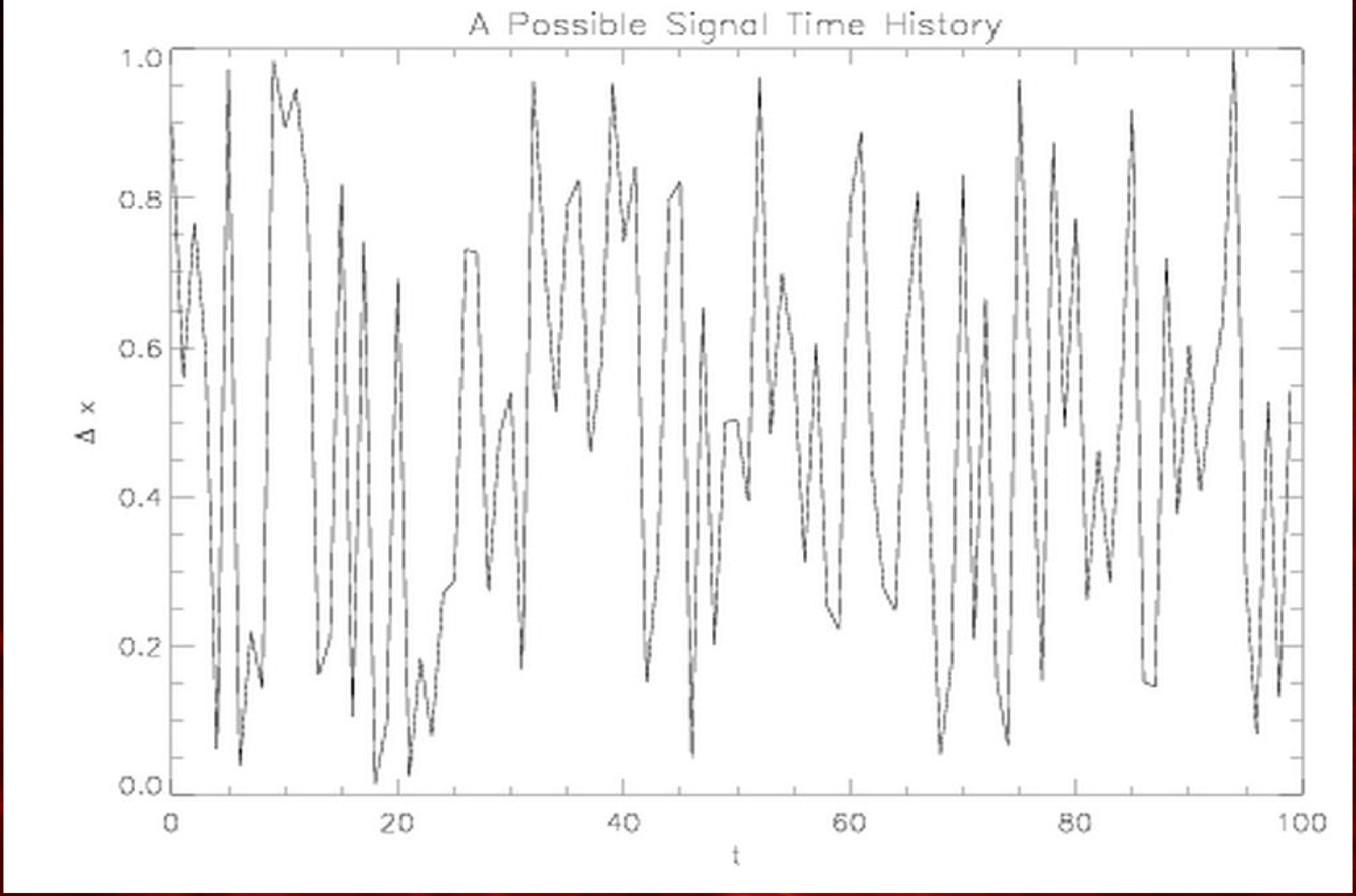
Signals: their Theory and Processing

By a loose "definition", any kind of "random" quantity (i.e. a quantity whose variations are "a priori" unpredictable in rate and amount) is a SIGNAL

SIGNAL THEORY is then concerned with clarifying the statistical properties of signal variations and how they depend on the surrounding "environment"

SIGNAL PROCESSING is the ensemble of analytical and numerical techniques developed with the purpose of interpreting, manipulating, reconstructing... signals

Signals: Examples



Time-Varying Signals: e.g. Vibrations and Sound-EM Waves

Space-Varying Signals: e.g. Images

Signal T&P: Related Disciplines

In studying signals, one thus basically deals with unpredictable quantities (formally, random variables) and phenomena (formally, random processes)

Therefore, Signal T&P are deeply connected with more fundamental theories such as probability and statistics

Besides, digital signals are presently ubiquitous in all technical areas as they arise from (ir)regular sampling of time/space-varying "phenomena", and related Digital Signal Processing thus greatly benefits from refined computing means and techniques

Basics: Probability and Statistics

Probability Density Function

$$Prob.(x \leq x(t_0) \leq x + dx) = p(x)\ dx$$

Statistical Expectation

$$E[x] = \int_{-\infty}^{\infty} x\ p(x)\ dx$$

Variance

$$\sigma^2 = E[x^2] - (E[x])^2$$

Probability Distribution Function

$$P(x) = \int_{-\infty}^{x} p(x)\ dx$$

$$\frac{dP}{dx} = p(x)$$

Stationary and Ergodic Random Processes

Random Variable ⇔ Random Process

Set of samples x ⇔ Set of sample functions x(t)

A random process is said to be STATIONARY if its statistical properties do not depend on absolute time

A random process is said to be ERGODIC if its statistical properties do not depend on chosen sample function

In practice, one always assumes that the random process of interest satisfies these requirements, at least over the time range of interest (statistically time-varying processes are better described by WAVELET ANALYSIS)

Correlation

Different definitions of CORRELATION formalize the intuitive concept that "to an increase of a variable X corresponds an increase/decrease of the variable Y"

Correlation Coefficient of two Random Processes

$$R_{xy}(\tau) = E[x(t)\ y(t+\tau)] \qquad R_{yx}(\tau) = E[y(t)\ x(t+\tau)]$$

$$R_{xy}(\tau) = \sigma_x\ \sigma_y\ \sigma_{xy}(\tau) + m_x\ m_y$$

Auto-Correlation of a Random Process

$$R_x(\tau) = E[x(t)\ x(t+\tau)]$$

Cross-Correlation of two Random Processes

$$R_{xy}(\tau) = E[x(t)\ y(t+\tau)] \qquad R_{yx}(\tau) = E[y(t)\ x(t+\tau)]$$

$$R_{xy}(\tau) = \sigma_x\ \sigma_y\ \sigma_{xy}(\tau) + m_x\ m_y$$

Fourier Analysis

An essential tool in almost every scientific field (e.g. Optics, Image Restoration, Quantum Physics...), Fourier Analysis relies on the possibility of decomposing any periodic function x(t) into a trigonometric series

$$x(t) = \sum_{k=0}^{k=\infty} X_k \, e^{i2\pi kt/T}$$

where

$$X_k = \frac{1}{T} \int_0^T x(t) \, e^{-i2\pi kt/T} \, dt$$

i.e. into a superposition of trigonometric functions whose periods and angular frequencies are

$$T_k = \frac{T}{k} \qquad \omega_k = \frac{2\pi k}{T} \qquad \Delta\omega = \frac{2\pi}{T}$$

Fourier Analysis

Generalizing this result to a generic function x(t) by heuristically calculating the limit of previous relations for

$$T \longrightarrow \infty \Rightarrow \Delta\omega \longrightarrow 0$$

one obtains that x(t) can be decomposed into the superposition of a continuous set of trigonometric functions, i.e. into a trigonometric integral

$$X(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} x(t)\ e^{-i\omega t}\ dt$$

$$x(t) = \int_{-\infty}^{\infty} X(\omega)\ e^{i\omega t}\ d\omega$$

so that one can work in the "time" or "frequency" domain, from time to time exploiting the properties of both

Spectral Analysis

Since the auto-correlation function contains information on the frequencies "making up" a signal, one can investigate the spectral properties of signals through the Fourier Transform of their auto-correlation functions, or

SPECTRAL DENSITY

$$S_x(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R_x(\tau)\, e^{-i\omega\tau}\, d\tau$$

"breaking down" the signal into its spectral components

$$R_x(\tau) = \int_{-\infty}^{\infty} S_x(\omega)\, e^{i\omega\tau}\, d\omega$$

and thus allowing the distinction of narrow-band, broad-band and white-noise processes

Spectral Density

Spectral density is related to the underlying signal by

$$E[x^2] = \int_{-\infty}^{\infty} S_x(\omega)\ d\omega$$

resembling the relation between the electric field associated with an electro-magnetic wave and its intensity

The spectral density of a derived random process dx/dt is

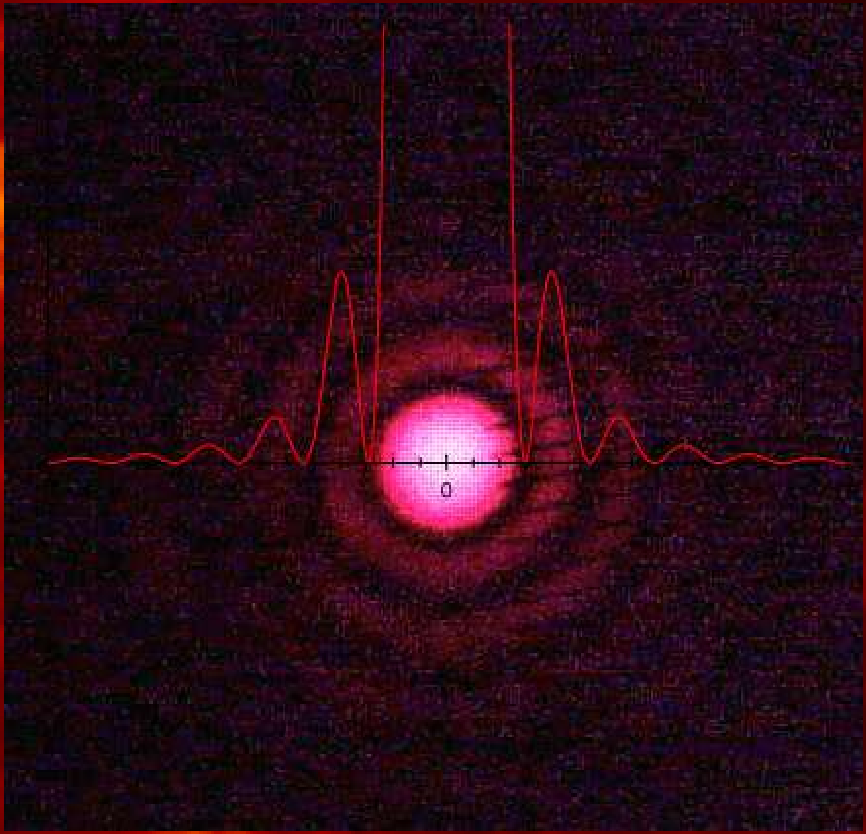
$$S_{\dot{x}}(\omega) = \omega^2\ S_x(\omega)$$

so that

$$E[\dot{x}^2] = \int_{-\infty}^{\infty} S_{\dot{x}}(\omega)\ d\omega = \int_{-\infty}^{\infty} \omega^2\ S_x(\omega)\ d\omega$$

Examples

The DIFFRACTION pattern produced by an aperture is given by its Fourier Transform in the space domain

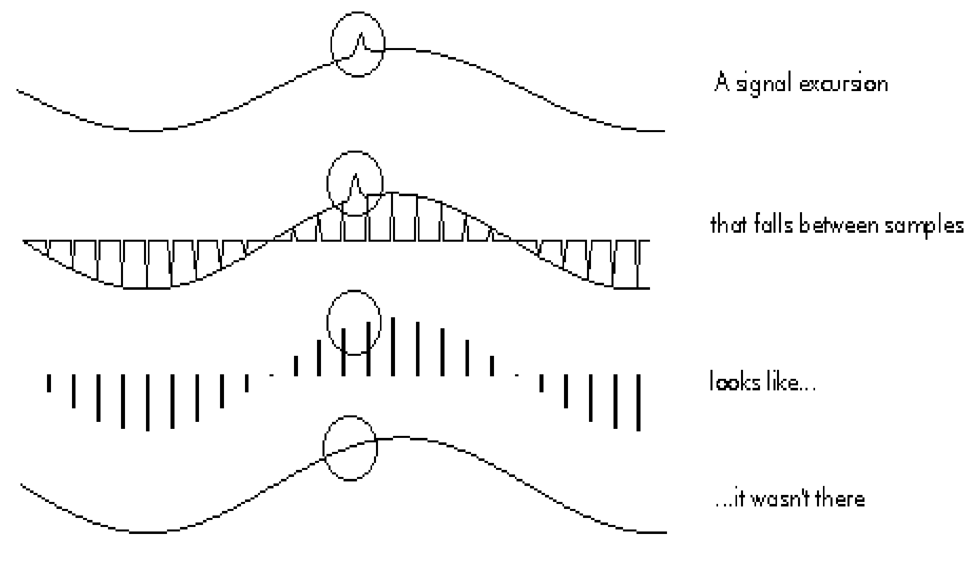


The VIBRATION pattern produced on a linear system can be described in frequency space

Digital Signal Processing (DSP)

Digital Signal Processing deals with the properties, analysis and treatment of digitized signals

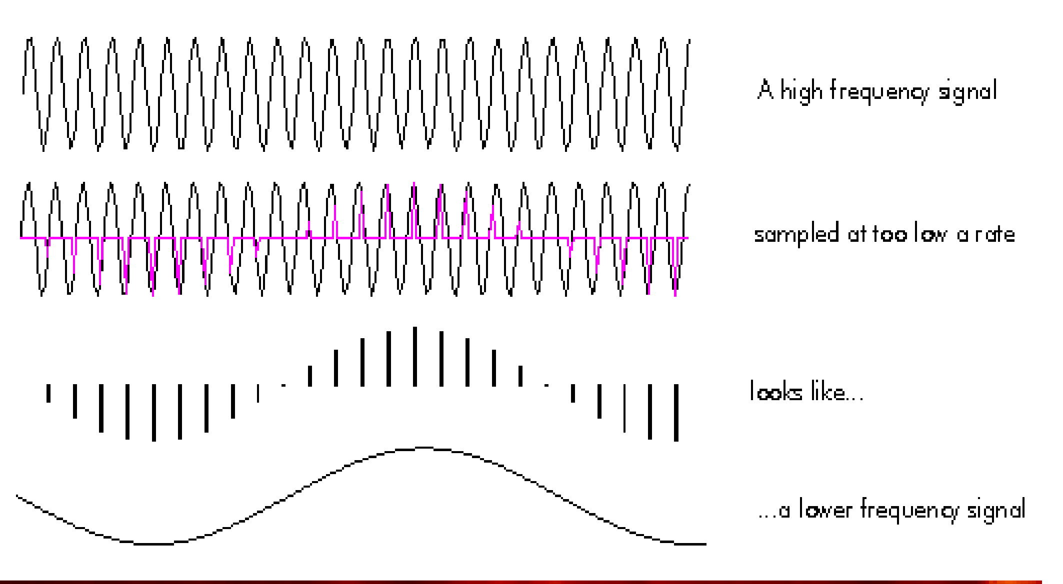
The most common practical need for DSP arises when trying to determine the spectral components and in reconstructing the "real" signal on the basis of a discrete sequence of measurements

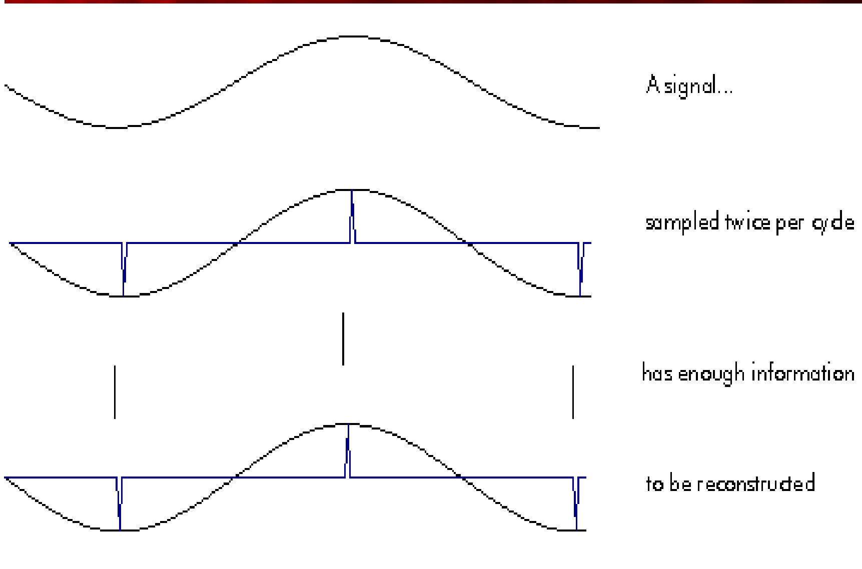


The Sampling Theorem

A band-limited signal can be perfectly reconstructed from samples taken uniformly at a rate > 2 max(supp(S(ω))).

Optimal sampling is of order of this latter upper limit!

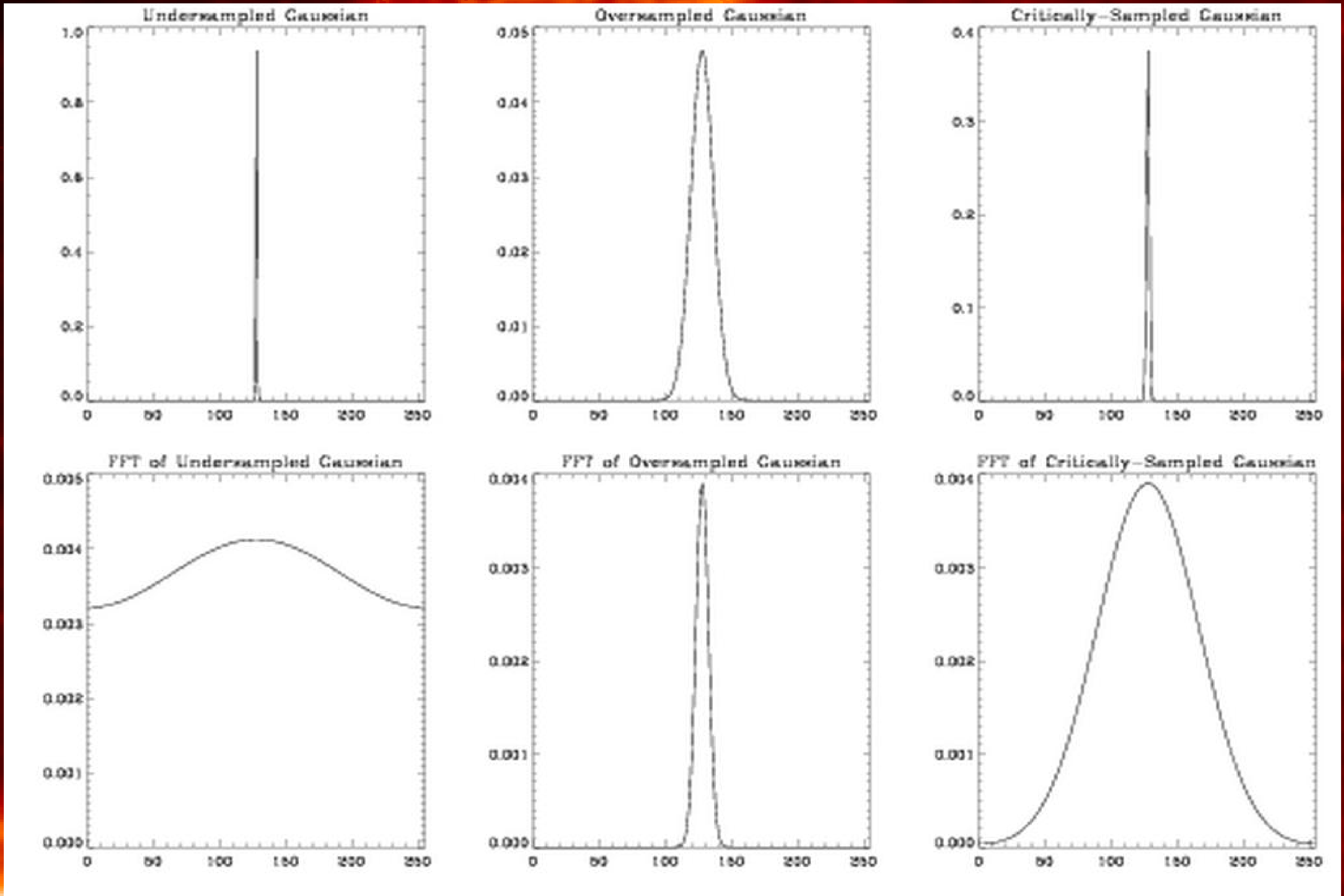




Sampling, Aliasing and Folding

Under-sampling generates spurious spectral components

Over-sampling generates a lot of useless information



Discrete Fourier Transform (DFT)

If one is to recover the spectral components of a discrete time series {x(r Δt)} with r=0,..., N-1 following the recipe

signal ⇨ auto-correlation function ⇨ spectral density

the integrals defining the Fourier coefficient can be "trapezoidally" approximated by

$$X_k = \frac{1}{N} \sum_{r=0}^{r=N-1} x_r \, e^{-i2\pi kr/N}$$

which are estimates of the spectral density for frequencies {r Δω} with Δω = 2 / so that the original discrete time series (but not its continuous "parent") is exactly given by

$$x_r = \sum_{k=0}^{k=N-1} X_k \, e^{i2\pi kr/N}$$

Fast Fourier Transform (FFT)

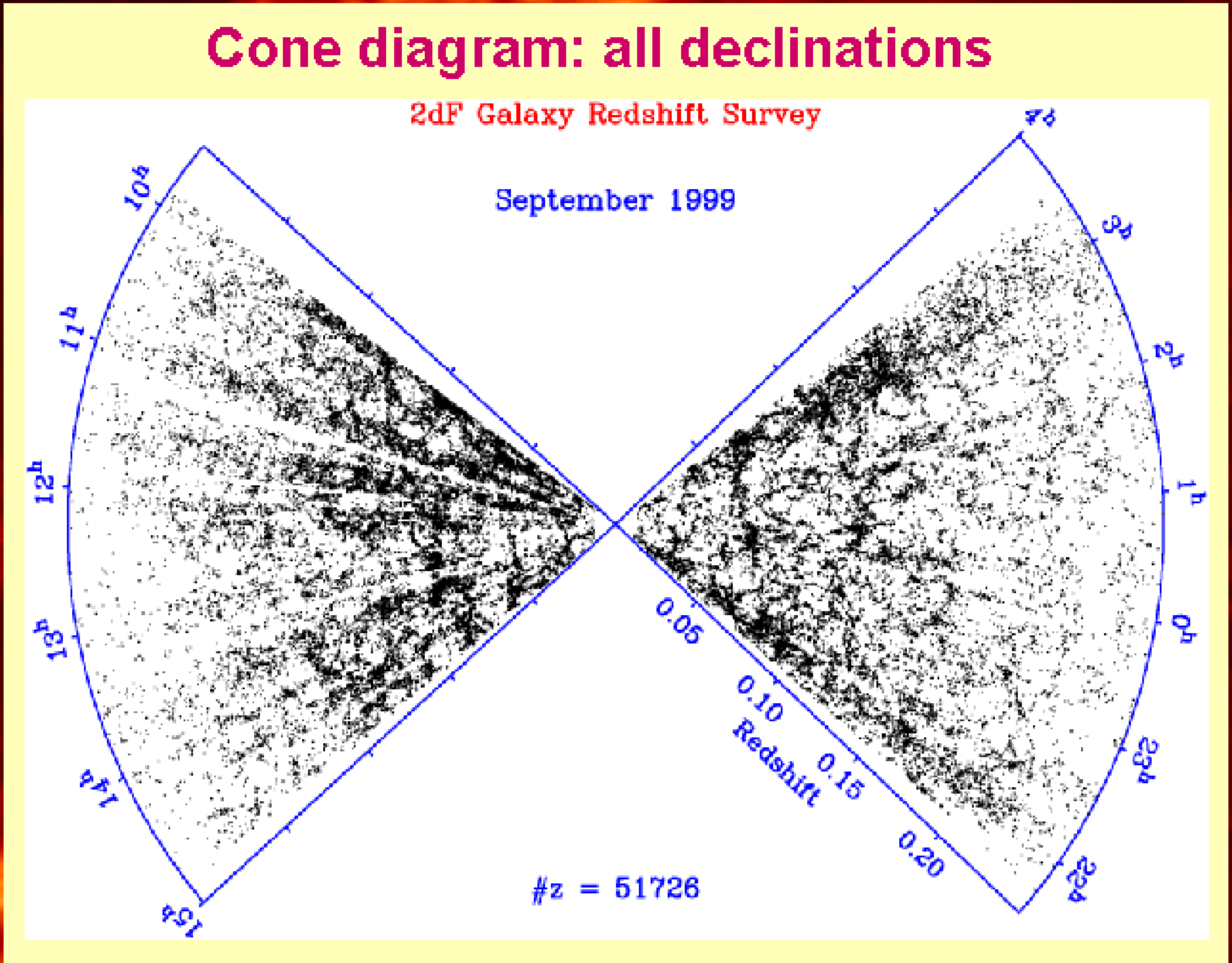
Direct calculation of DFTs requires ~ N^2 operations

FFT algorithms, starting from Cooley and Tukey's one (1965) reduces such value to ~ N log_2 N, i.e.

N	log_2 N	N^2 / (N log_2 N)
4	2	2
16	4	4
64	6	11
256	8	32
1024	10	102
4096	12	341
16384	14	1170
65536	16	4096
262144	18	14564

The Large Scale Structure of the Universe

Observations of the LSS of the Universe are mostly carried out by determining 2 or 3-D galaxy positions



Clustering

"Clustering" is usually quantified by the two-point angular/spatial correlation function defined by

$$dP \;=\; \rho_{ang}^2 \;\left[1 + w(\theta_{12})\right]\; d\Omega_1 \; d\Omega_2$$

$$dP \;=\; \rho_{sp}^2 \;\left[1 + \xi(r_{12})\right]\; dV_1 \; dV_2$$

and gives the excess probability of finding pairs of sources at a given distance with respect to a uniform distribution. However, the spectral density of galaxy distribution, or Fourier Transform of correlation function, gives an estimate of the spatial frequencies making up the galaxy distribution on the sky, and is extensively used whenever computational or noise-fighting related reasons make its use more effective

References

Printed Material

Newland D.E. 1993, An Introduction to Random Vibrations, Spectral and Wavelet Analysis, Third Edition, Longman

Papoulis A. And Pillai S.U. 2002, Probability, Random Variables and Stochastic Processes, McGraw-Hill

On-Line Material

On-Line Digital Signal Processing Class, Bores Signal Processing, http://www.bores.com/index_online.htm

An Introduction to Fourier Theory, Forrest Hoffman, http://aurora.phys.utk.edu/~forrest/papers/fourier/

MathWorld, Eric Weisstein's World of Mathematics, http://mathworld.wolfram.com/

The LARI Method

- The LARI method was developed to overcome the main difficulties affecting ISO-CAM/PHOT data:
  - Poor spatial coverage, sampling and redundancy
  - Transient behaviour after a flux change
  - Cosmic ray hits and "glitches"

- These severe problems call for the individual treatment of the "time history" of each pixel, in order to model the effects of transients and glitches and to determine the point-per-point flux excesses ascribable to potential sources and to project them onto the sky as a map

Mathematical Model for Charge Release

$$S = I - \frac{\mathrm{d}Q_{tot}}{\mathrm{d}t} = I - \frac{\mathrm{d}Q_b}{\mathrm{d}t} - \frac{\mathrm{d}Q_l}{\mathrm{d}t}$$

$$\frac{\mathrm{d}Q_i}{\mathrm{d}t} = e_i\, I - a_i\, Q_i^2 \qquad \text{where} \quad i = b, l$$

$$S = (1 - e_b - e_l)\, I + a_b\, Q_b^2 + a_l\, Q_l^2$$

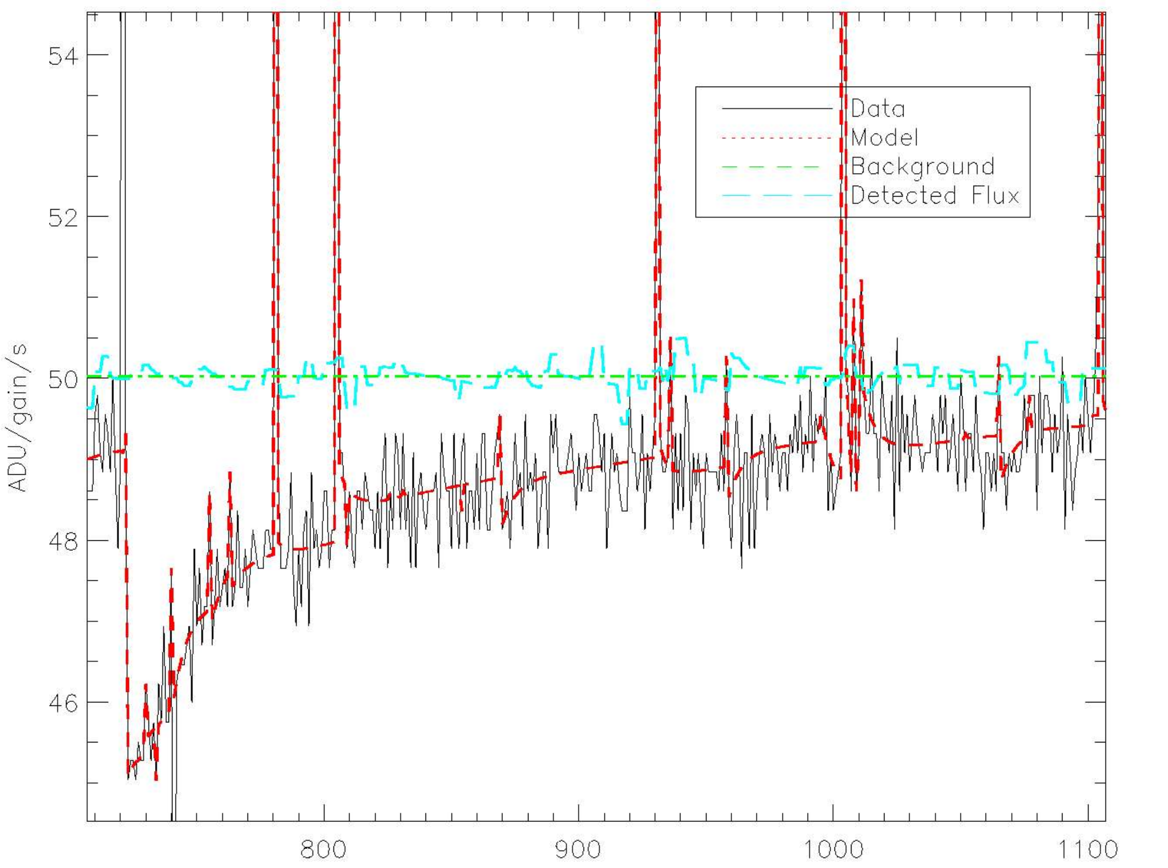
***S* = Signal *I* = Incident Flux *Q* = Accumulated Charge**

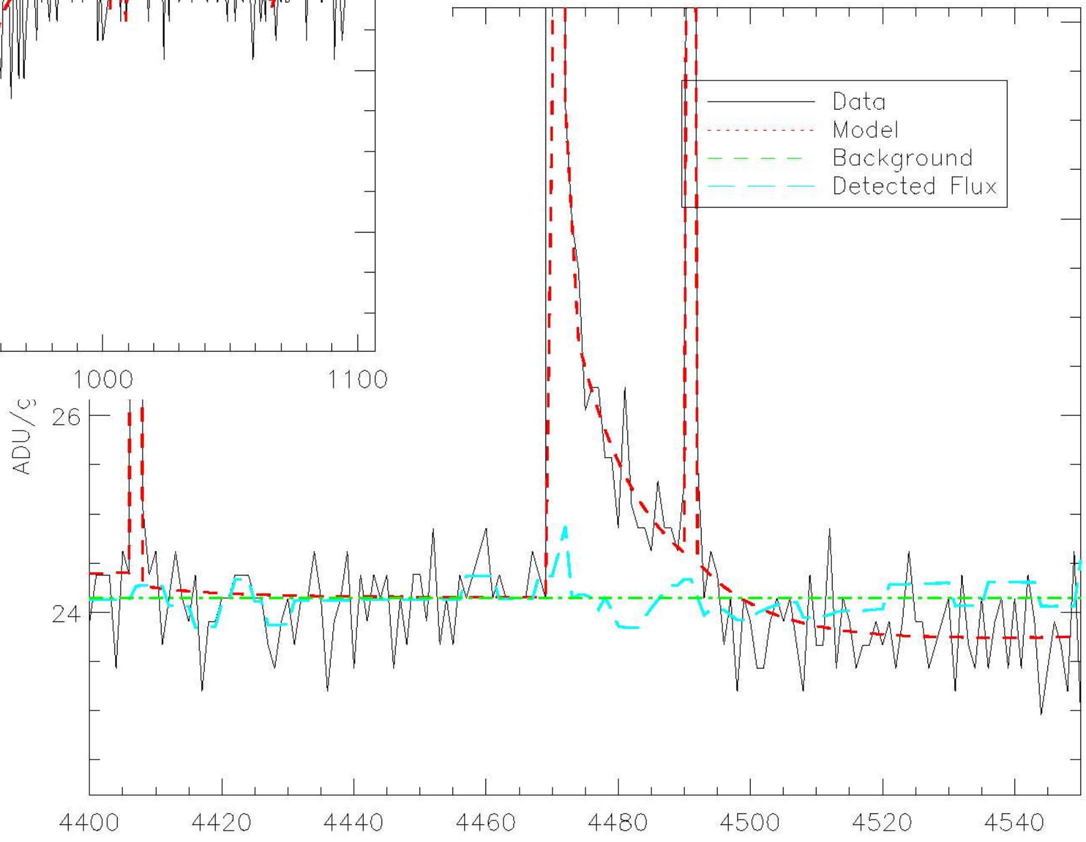
Completely conservative model

Charge is released with two different time scales

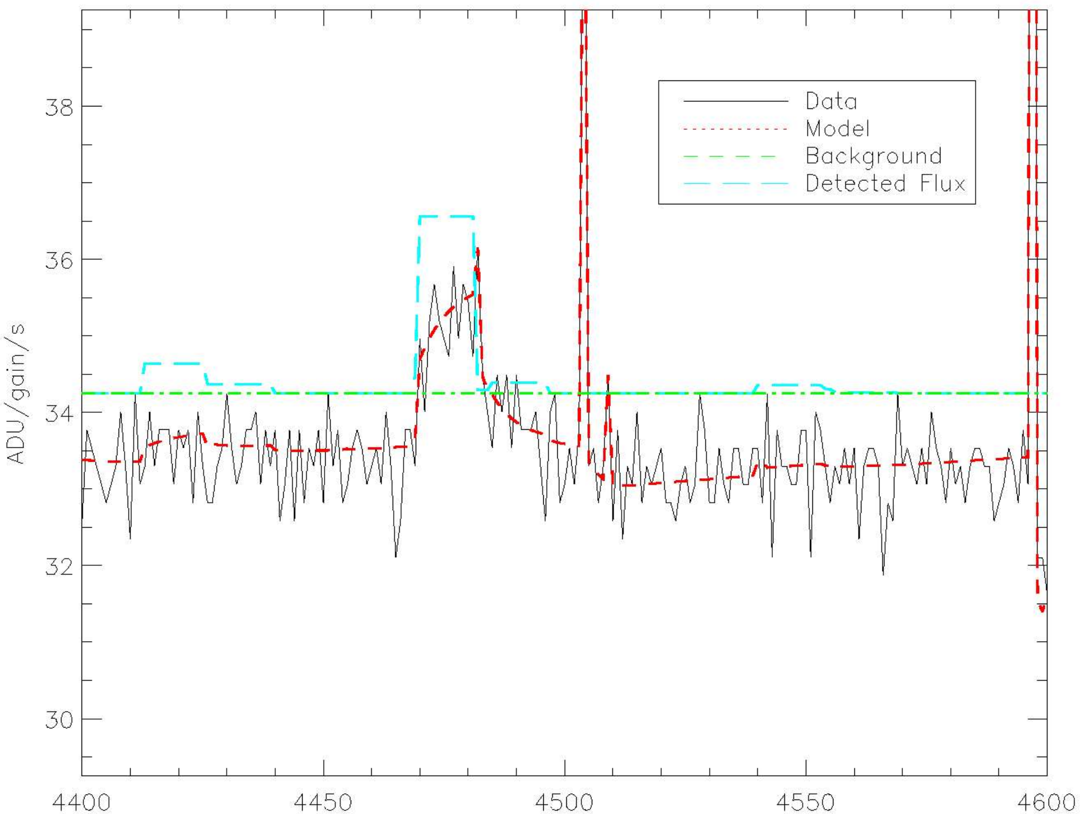
Glitches as discontinuities in charge release

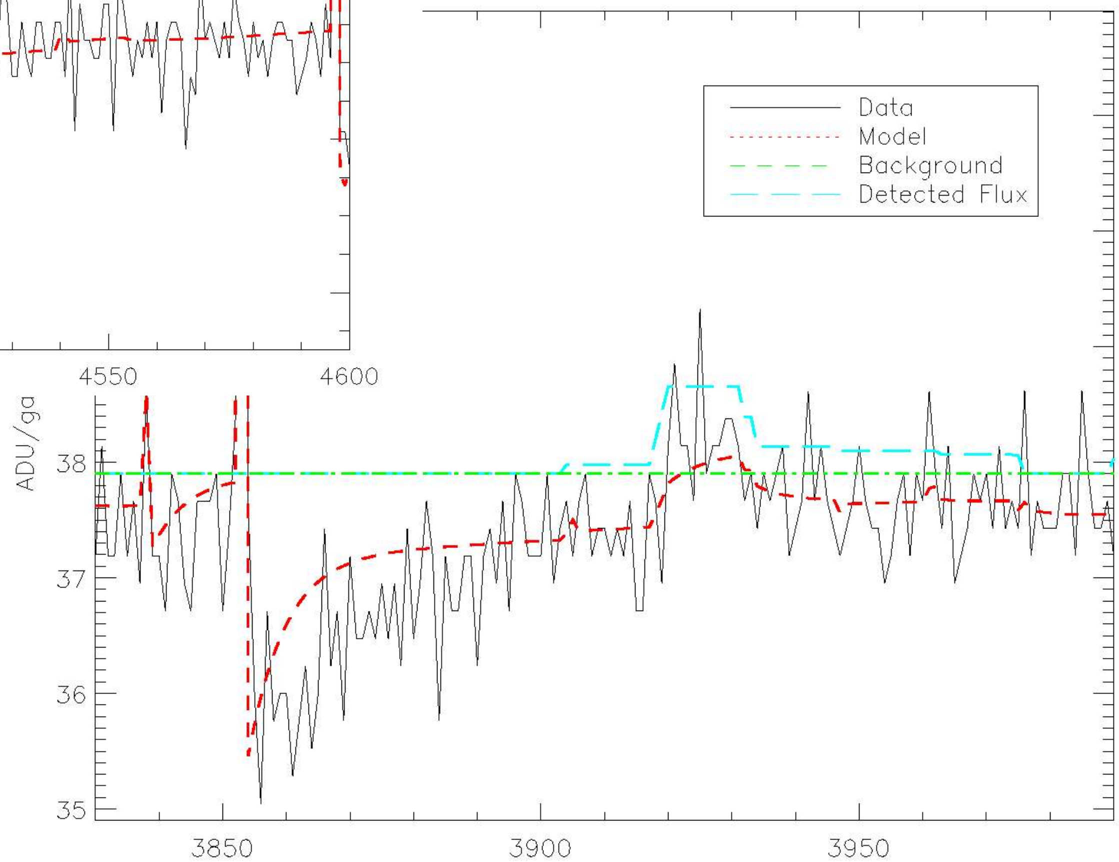
Pixel Time History Fitting: Glitches





Pixel Time History Fitting: Sources

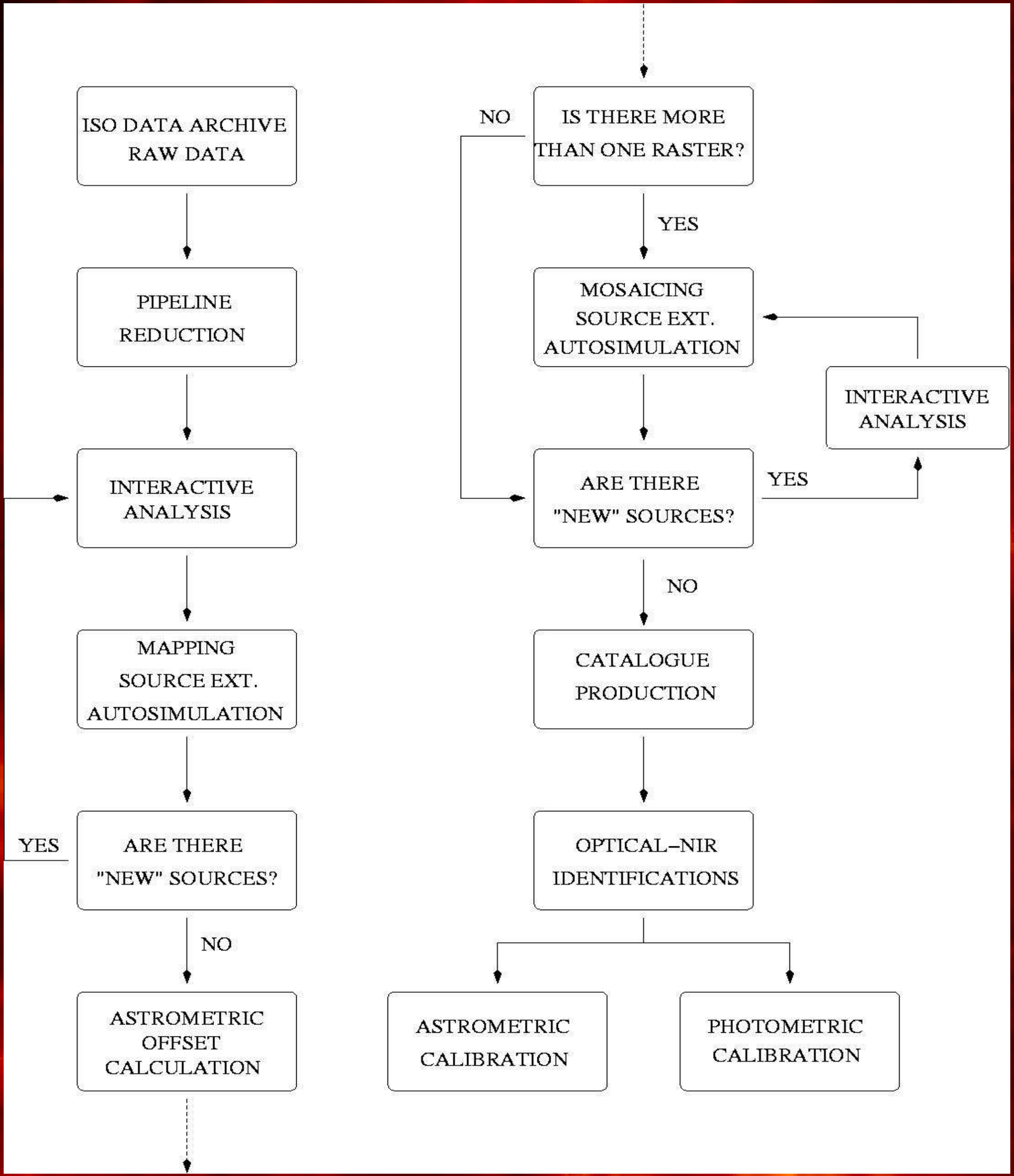




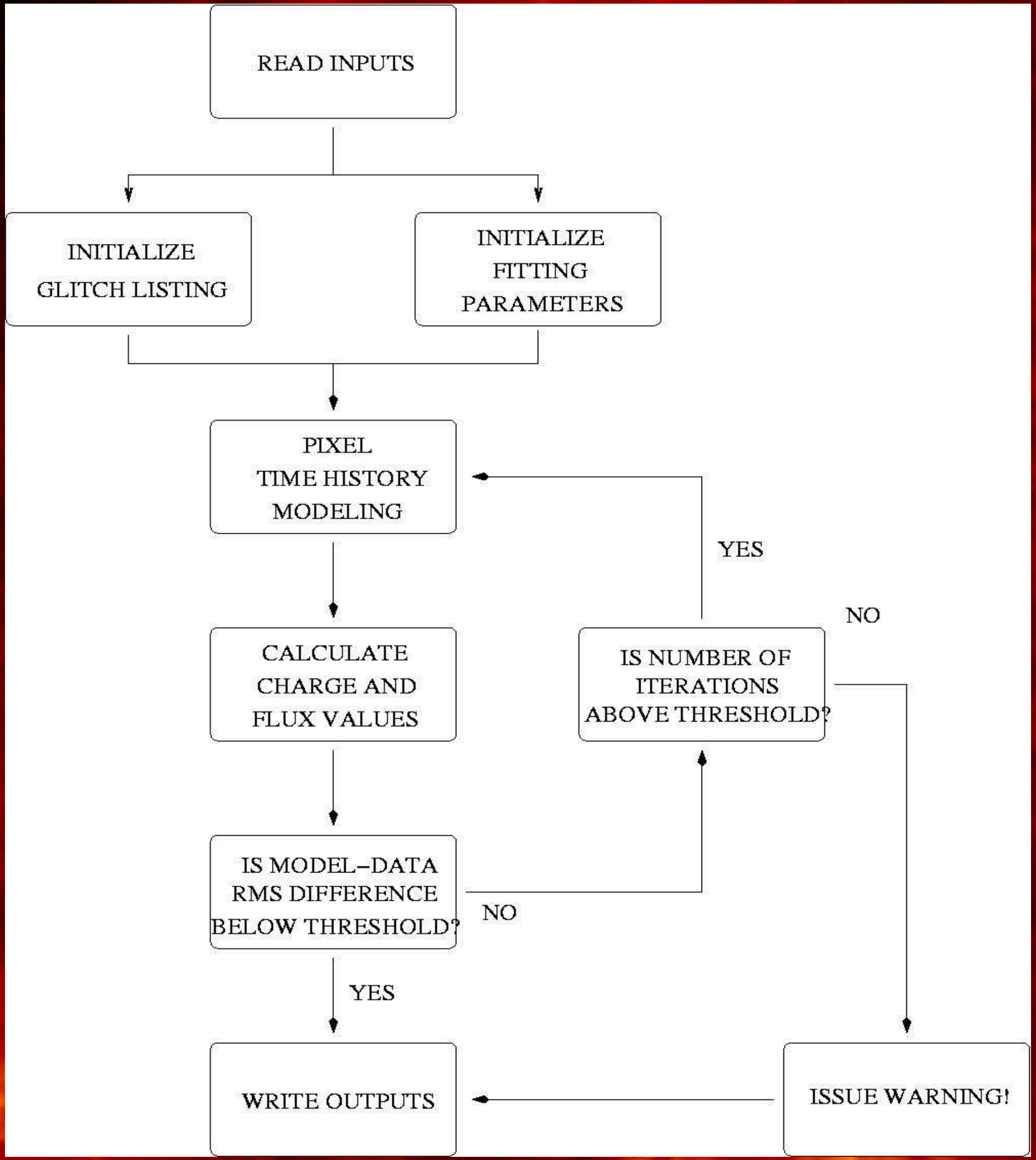
IDL Developed Programs

- Raw data export into IDL environment
- Pipeline reduction:
  - \- Stabilization background determination
  - \- Strong sources' and glitches' identification
  - \- Fitting parameters' "first guess"
- Pixel time history fitting
- Interactive analysis (graphical user interface)
- Mapping, mosaicing and source extraction
- Flux Estimation through Autosimulation
- Astrometric calibration (vs. stellar positions)
- Photometric calibration (vs. stellar fluxes)
- Data products formatting/release
- Simulations:
  - \- Astrometric and Photometric Accuracy
  - \- Reliability and Completeness

Data Reduction: An Overview



The Fitting Procedure



Widget Graphical User Interface

Break: Interactive Analysis Session...

Data Products

- Text Files
- ISO Source Lists
- Optical/NIR IDS
  - TYCHO2, USNO, GSC2
  - APM, SDSS
  - 2MASS
  - Multi-λ Follow-Up Catalogues
- Flags + Notes

- Images (FITS, EPS and PNG)
- Flux and S/N Sky Maps
- Flux and S/N Contour Maps
- Optical Finding Charts

Break: Browse Catalogues...

Documentation

- IDL-like documentation within source files for each program
- Overall HTML documentation hyperlinked to source files

- NAME
- PURPOSE
- CATEGORY
- INPUTS
- OPTIONAL INPUTS
- KEYED INPUTS
- OUTPUTS
- OPTIONAL OUTPUTS
- KEYED OUTPUTS
- WRITTEN FILES
- DEPENDENCIES
- COMMON BLOCKS
- EXAMPLES
- SIDE EFFECTS
- RESTRICTIONS
- SEE ALSO
- NOTES
- MODIFICATION HISTORY

Break: Browse Documentation...

Software Test Plan

- Pipeline Testing:
  -
  - - Run on different "kinds" of observational datasets
  - - Visual inspection and statistical tests
  - - Fine tuning of relevant parameters!
  -
- Overall Data Reduction Testing:
  -
  - - Generate a catalogue of additional sources
  - - Simulate their effects on "true" pixel time histories
  - - Reduce such simulated data as done with real data
  - - Compare "measured" and "injected" quantities
  - - Estimate Performance of Data Reduction Technique

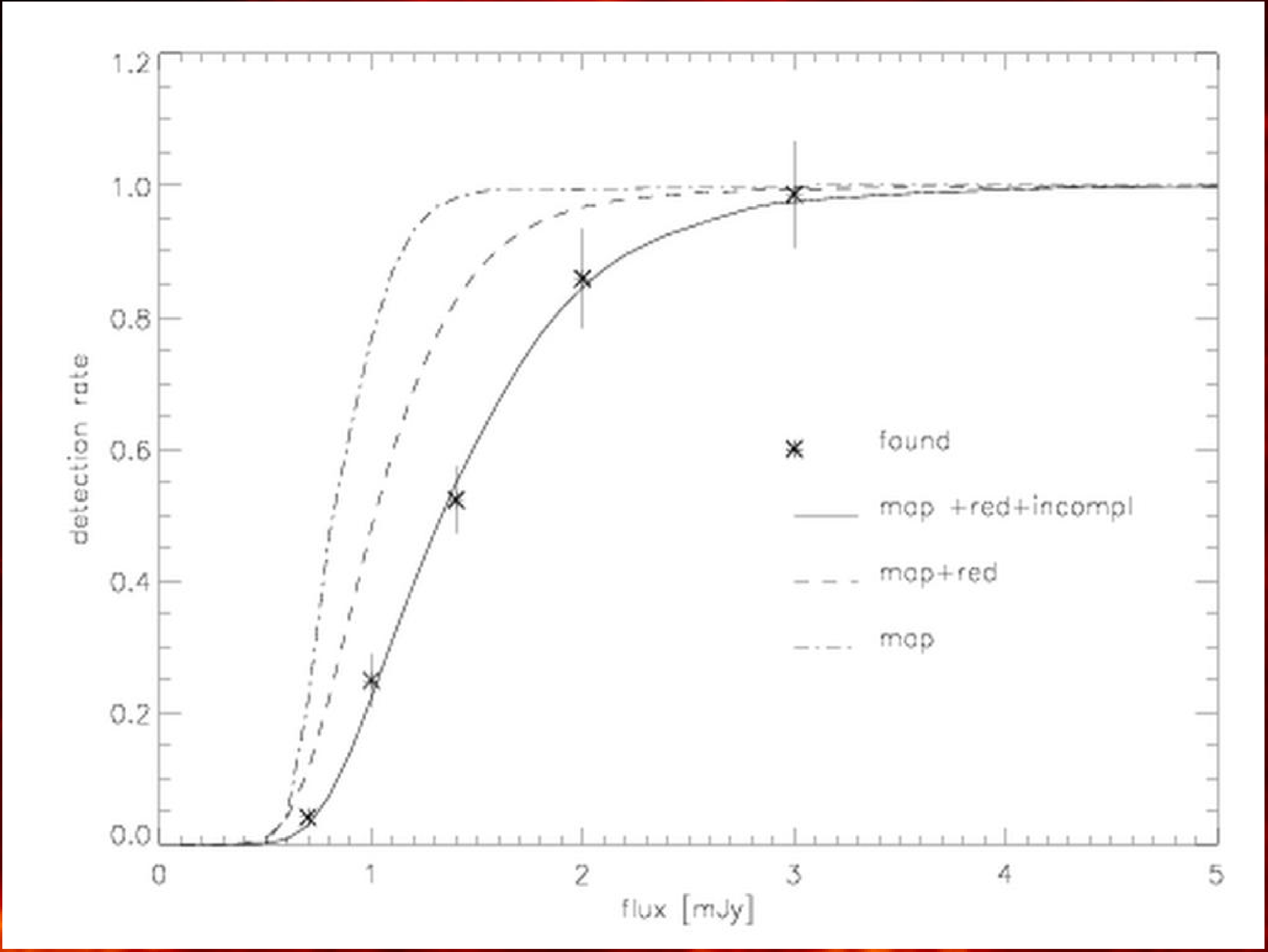
Pipeline Testing

Table 1: Datasets pre-reduced with LARI pipeline

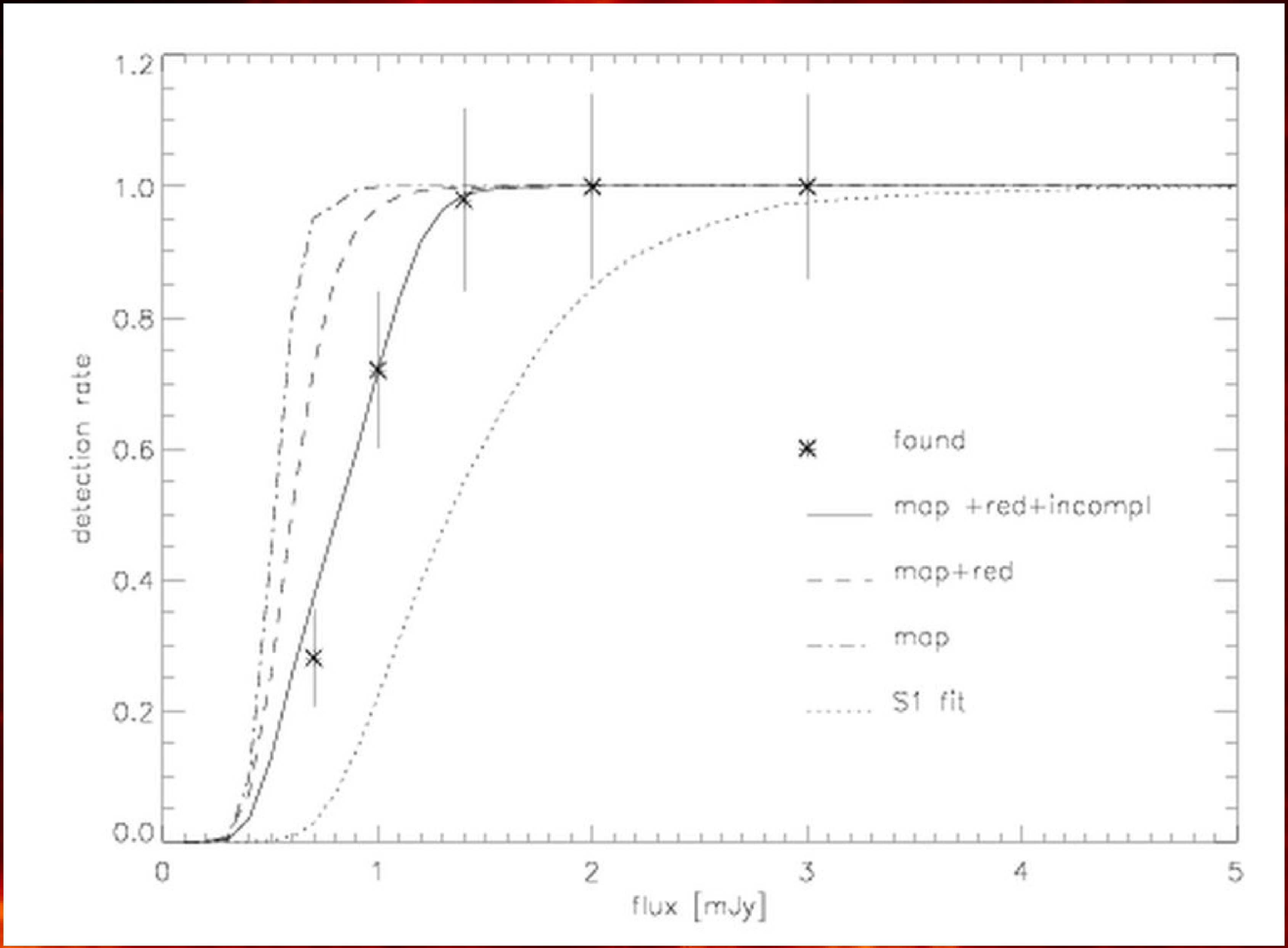
30200101	ELAIS_N1_1	LW3
30400103	ELAIS_N1_2_A	LW3
67200103	ELAIS_N1_2_B	LW3
30500105	ELAIS_N1_3	LW3
30600107	ELAIS_N1_4	LW3
31000109	ELAIS_N1_5	LW3
30900111	ELAIS_N1_6	LW3
50200119	ELAIS_N2_1	LW3
51100131	ELAIS_N2_2	LW3
50000723	ELAIS_N2_3	LW3
50200225	ELAIS_N2_4	LW3
50100727	ELAIS_N2_5	LW3
50200429	ELAIS_N2_6	LW3
11600721	ELAIS_N2_R_A	LW3
77900101	ELAIS_N2_R_B	LW3
42500237	ELAIS_N3_3	LW3
43800341	ELAIS_N3_5	LW3
23200251	ELAIS_S1_1	LW3
23200353	ELAIS_S1_2	LW3
41300955	ELAIS_S1_3	LW3
23300257	ELAIS_S1_4	LW3
23300459	ELAIS_S1_5_A	LW3
77500207	ELAIS_S1_5_B	LW3
78502406	ELAIS_S1_5_C	LW3
41001161	ELAIS_S1_6	LW3
40800663	ELAIS_S1_7	LW3
40800765	ELAIS_S1_8	LW3
41001867	ELAIS_S1_9	LW3
	ELAIS_X1-6	LW3
	HDFS_1-4	LW3
	HDFN_1-4	LW3
	LHS_1-8	LW3
	LHD_1-8	LW3
	HDFS_1-4	LW2
	HDFN_1	LW2
	ABELL_2390	LW2

- Observational Parameters:
  - - Filter
  - - Gain
  - - Pixel Field Of View
  - - Raster Step Size
  - - # of Pointings per Raster
  - - # of Readouts per Pointing
  - - Exposure Time per Readout

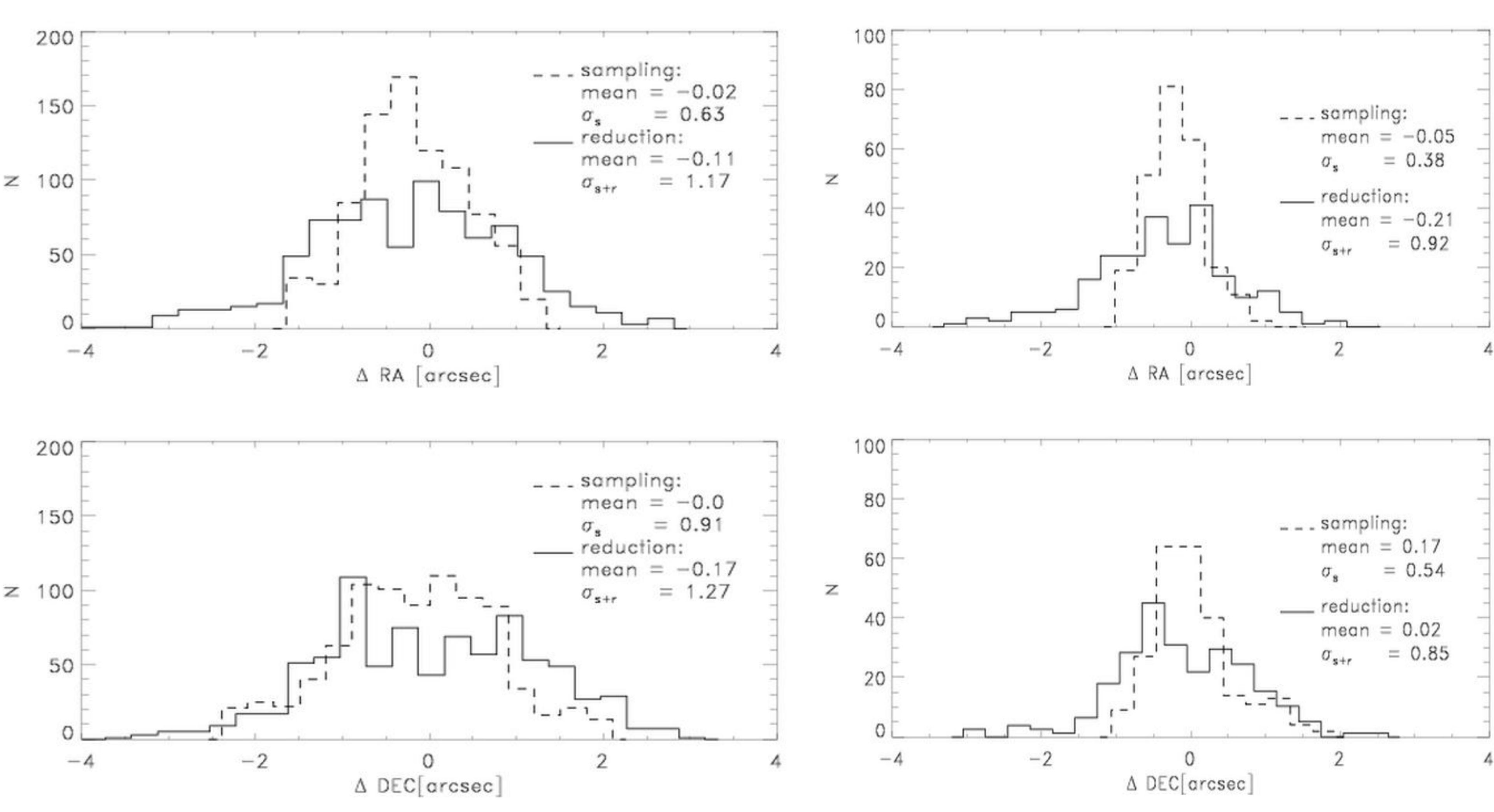
Completeness: Non-Repeated Regions



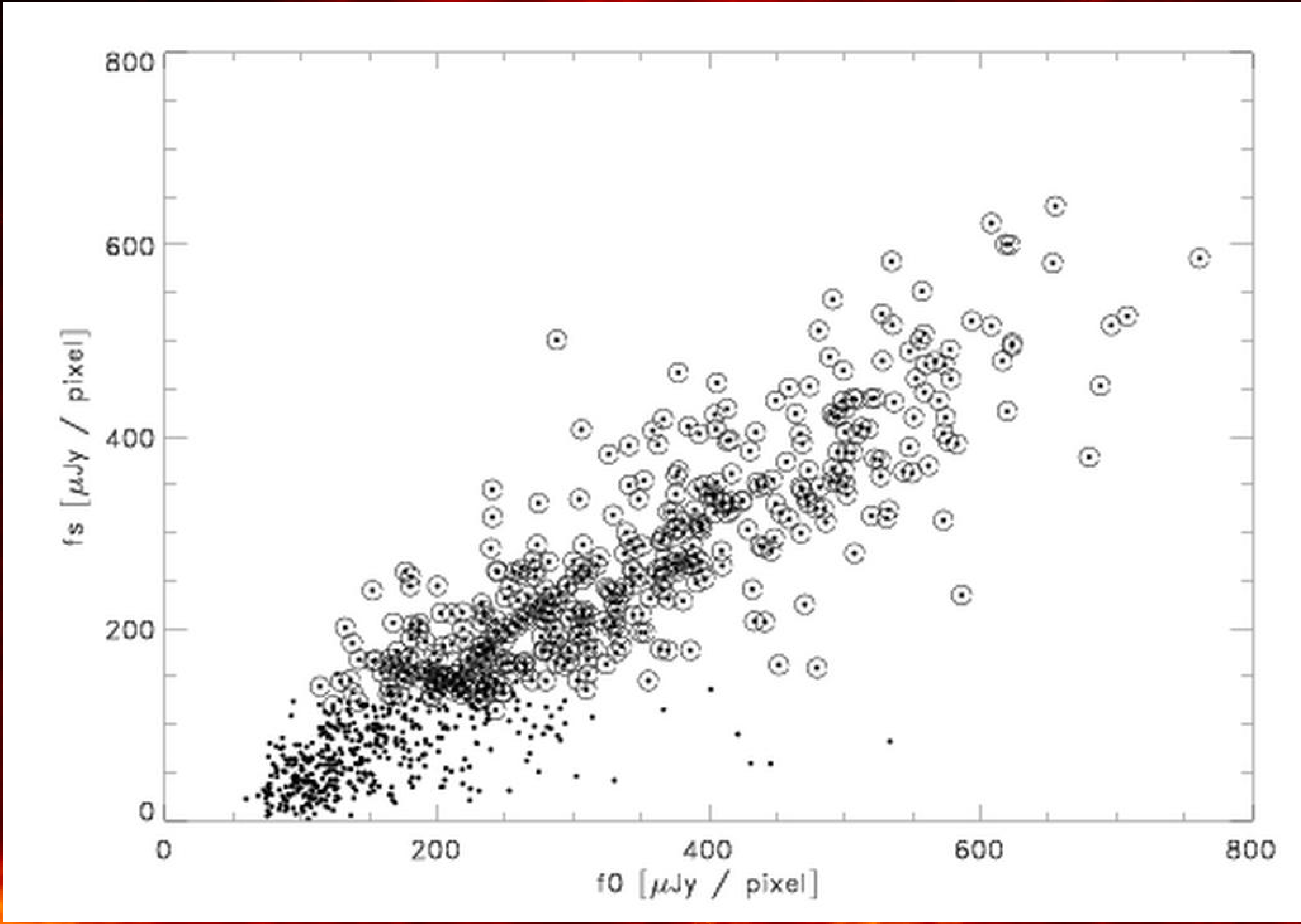
Completeness: Repeated Regions



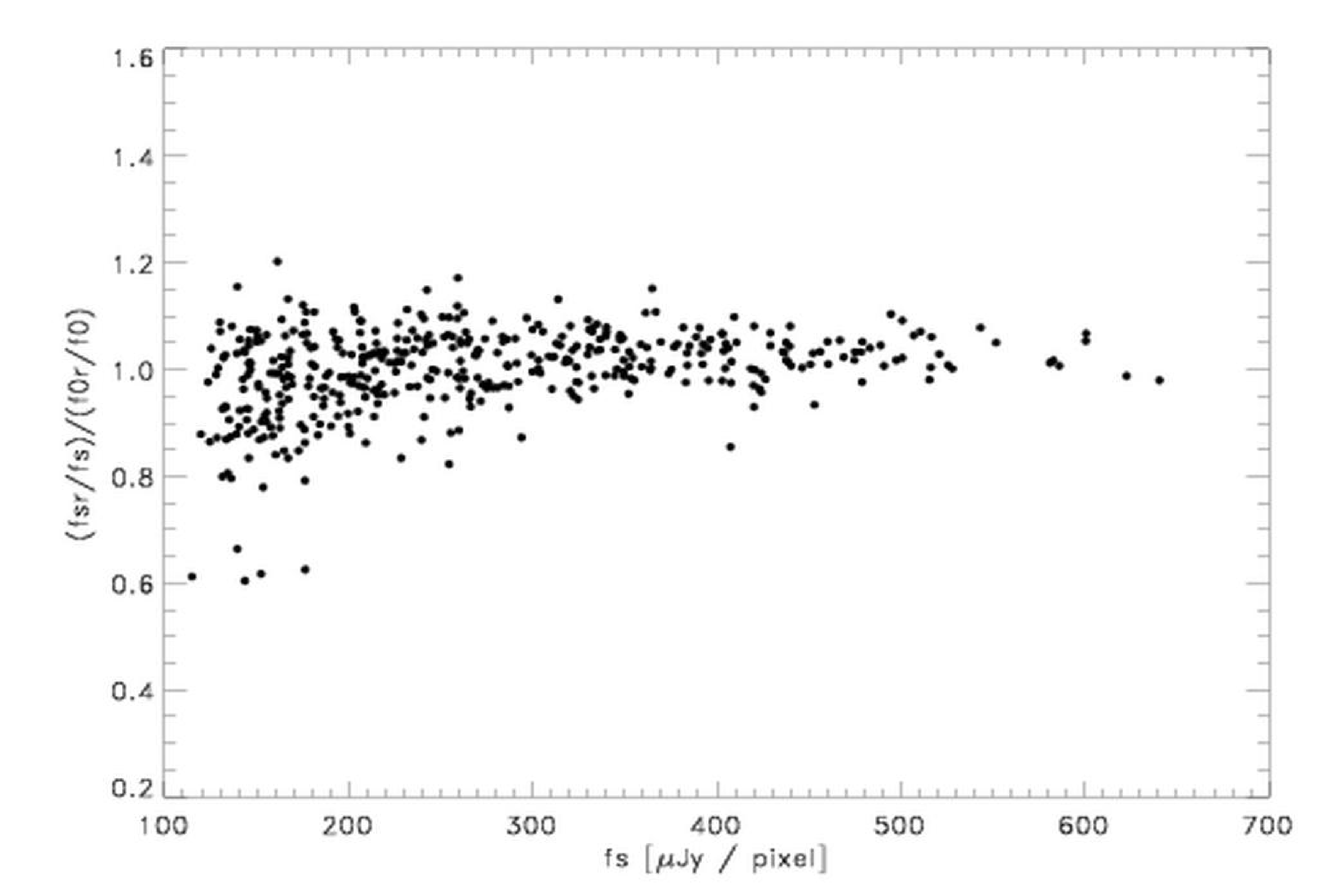
Astrometric Accuracy



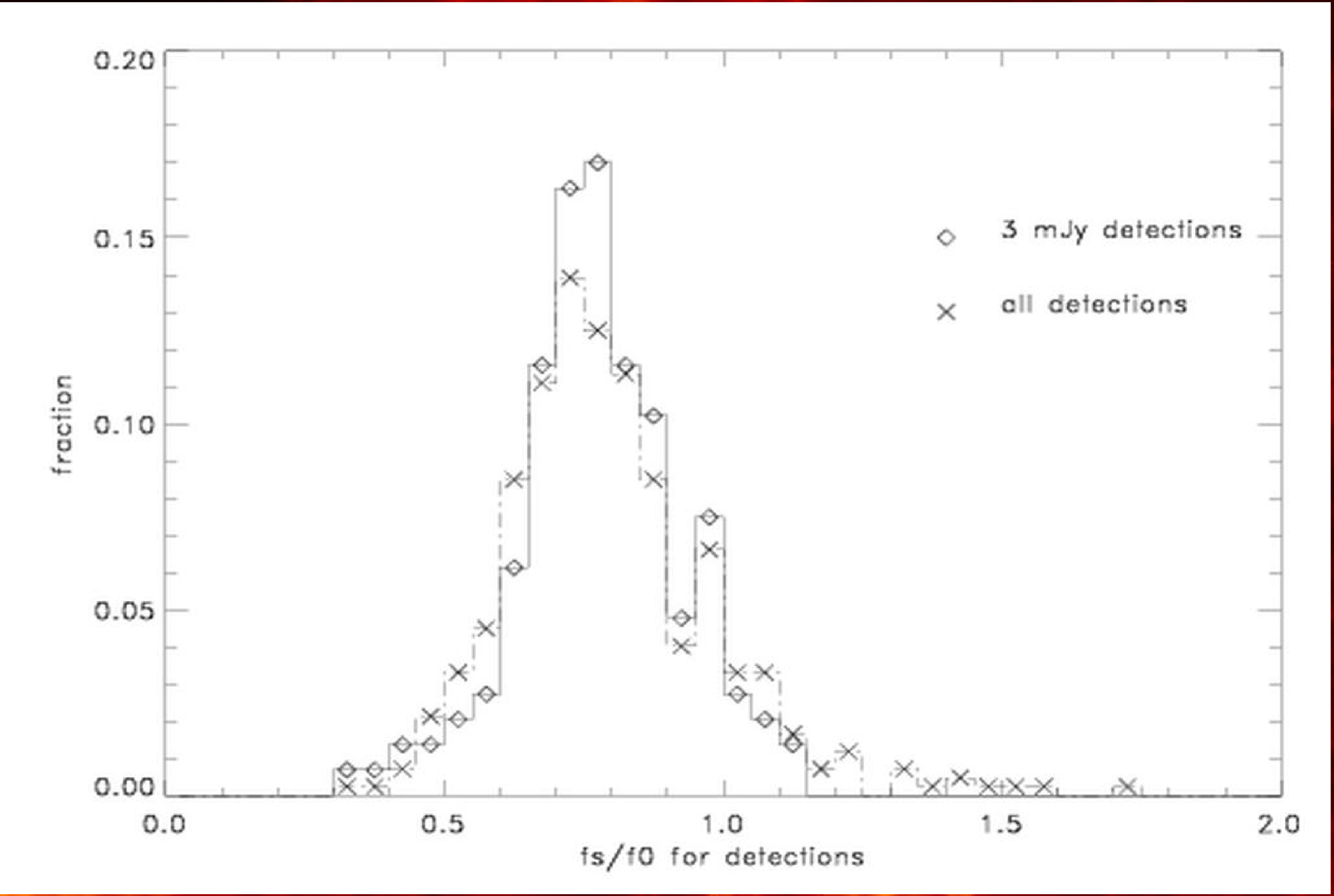
Photometric Accuracy: Linearity (1)



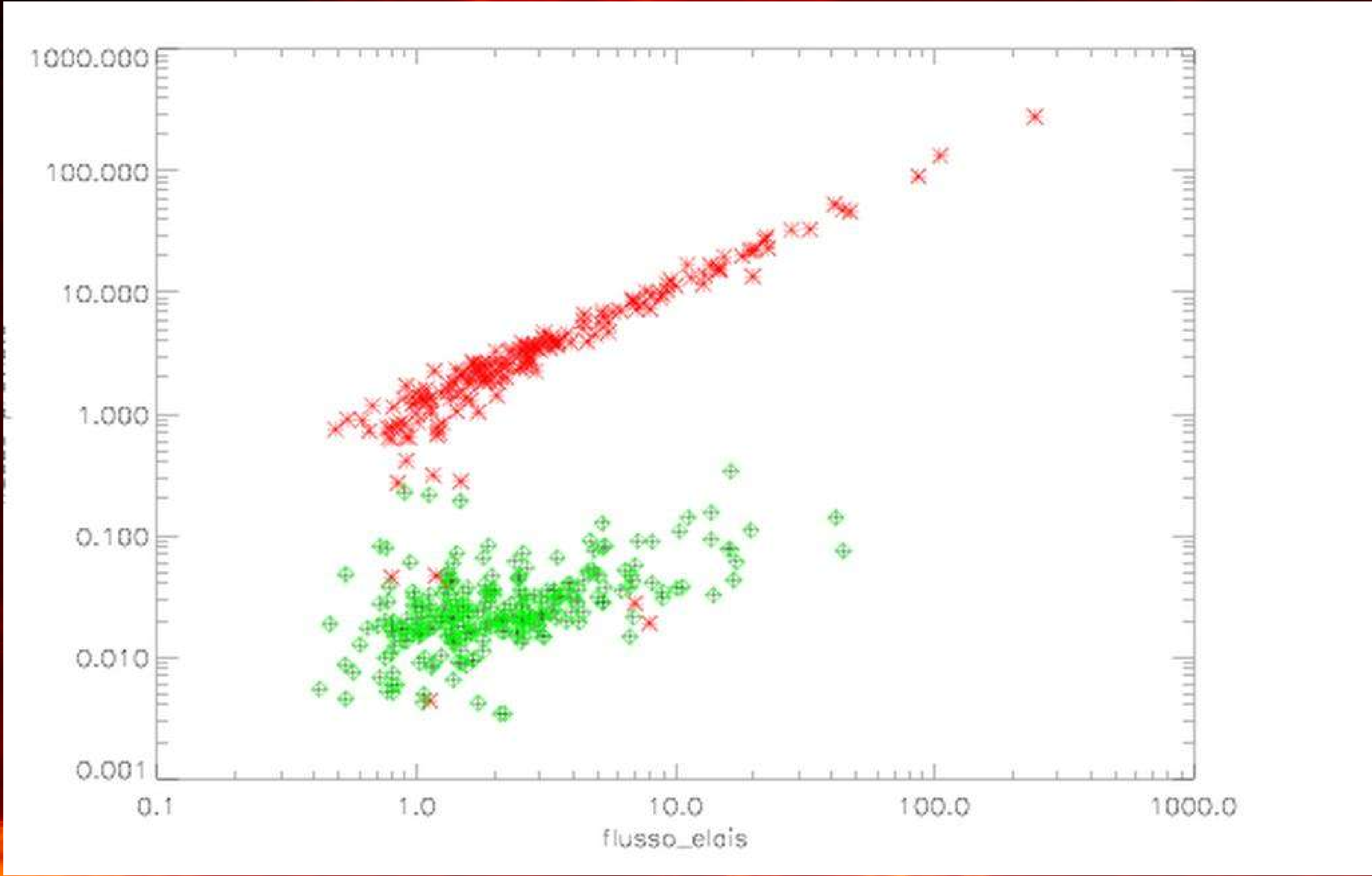
Photometric Accuracy: Linearity (2)



Photometry: Internal Calibration and Accuracy



Photometry: External Calibration and Accuracy



Conclusions

- Software Development:
  -
  - - Complete
  - - Some add-ons desirable
  -
- Software Documentation:
  -
  - - Essentially complete
  - - A "proper" User's Manual and "recipes" desirable
  -
- Software Testing:
  -
  - - Pipeline: extensive but superficial
  - - Overall Data Reduction: limited but thorough

Critical Steps

Raw data export into IDL environment

Pipeline reduction (first guess of fitting parameters)

Single pixels' time history fitting
Interactive analysis ⇒ graphical user interface

Mapping/Mosaicing and source extraction

Simulations:
Astrometric accuracy
Photometric accuracy
Completeness

External calibration with stars

Possible Applications/Contributions to PACS

Experience with ISO data suggests that:

- Pre-flight detectors' characterization is most desirable
- Mission success will critically depend on timely software development
- Effective observing and data exploitation can only be guaranteed through accurate knowledge of instrumental performance
- One must be ready to promptly face unexpected problems

Willingness to provide expertise during mission planning!

Things one would like to know about PACS

Are there (planned) realistic Num. Simulations and/or
Lab. Tests reproducing the satellite operational conditions?

and in particular

How do PACS Photoconductors and Bolometers
respond to Cosmic Ray Impacts???

Some work on available material is desirable for
LARI Method Testing / Dedicated Method Development

Application of the LARI Method

Instrument:

- **ISOCAM LW detector : matrix 32 x 32 (pixel size ~ 6'')**
  f.o.v ~ 3 ' x 3 '
- **ISOPHOT C100 detector : matrix 3 x 3 (pixel size ~ 45'')**
  f.o.v ~ 1.5 ' x 1.5 '

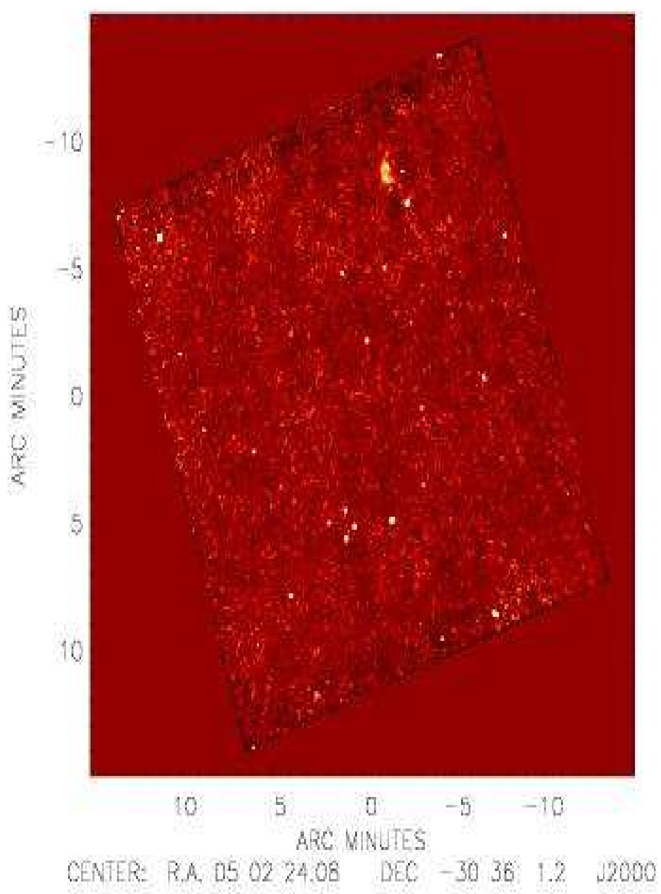
Projects being carried out:

- **ELAIS (~ 12 sq. deg.)**
  - **CAM-LW3 filter : λ=15 μm (S1: Lari et al. 2001; S2: Pozzi et al. 2003, sub.)**
    (N1, N2, N3: Vaccari et al. 2003, in prep.)
  - **PHOT-C90 filter : λ=90 μm (in progress)**
  - **CAM-LW3 Ultra-Deep 15 ' x 15 ' N1 Field (in progress)**

- **Lockman Hole (~ 40 ' x 40 ')**
  - **CAM-LW3 filter : λ=15 μm (Fadda et al. 2003, in prep.)**
  - **PHOT-C90 filter : λ=90 μm (Rodighiero et al. 2003, sub.)**
  - **Deeper LW3 integration on 20 ' x 20 ' central region (in progress)**

The ELAIS fields as seen by CAM (@ 15 μm)

S2 field (21' x 21')



ELAIS 15 μm Final Analysis

Catalogue : 2000 sources
Flux range : 0.4 - 150 mJy

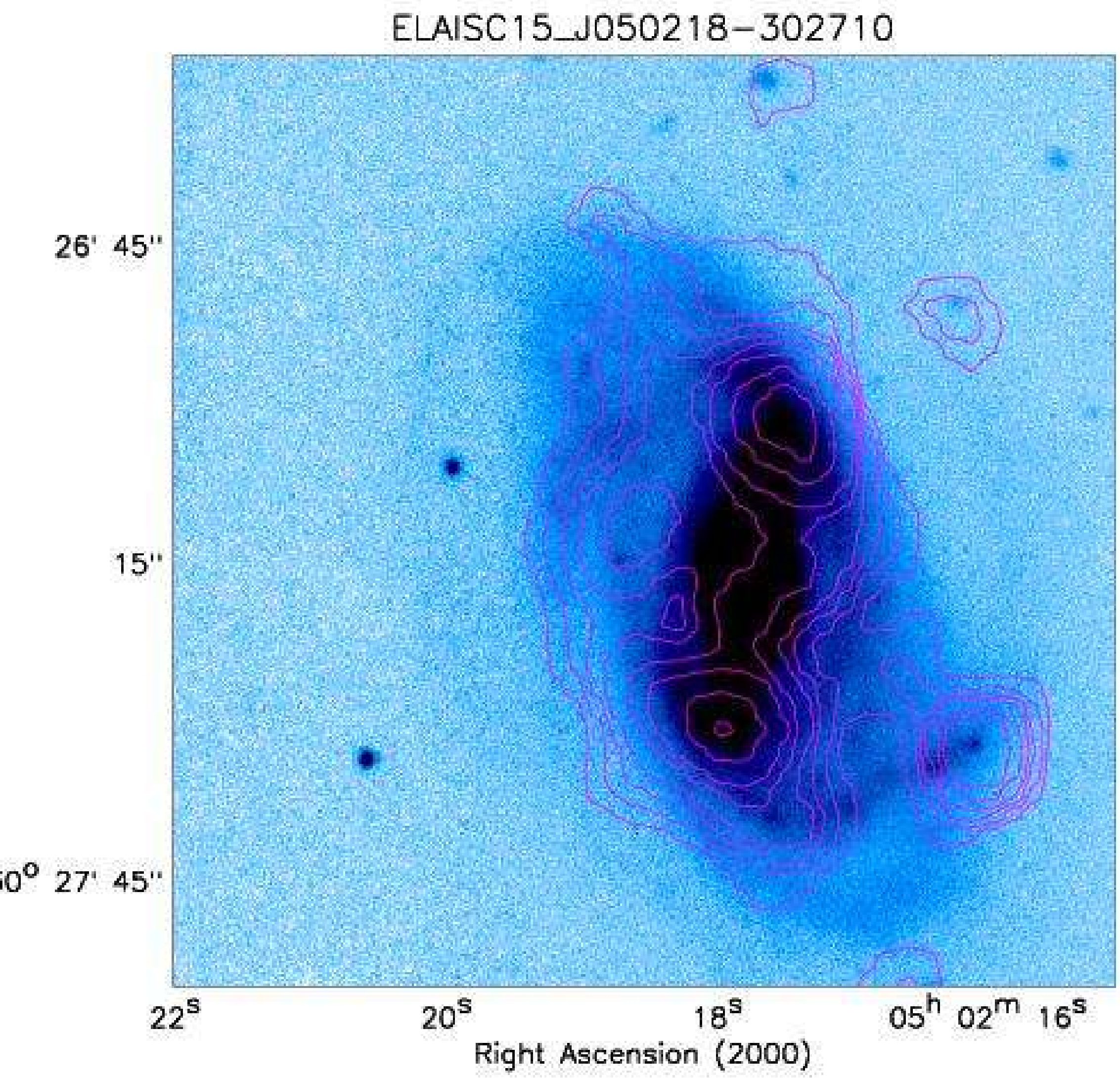
Simulations

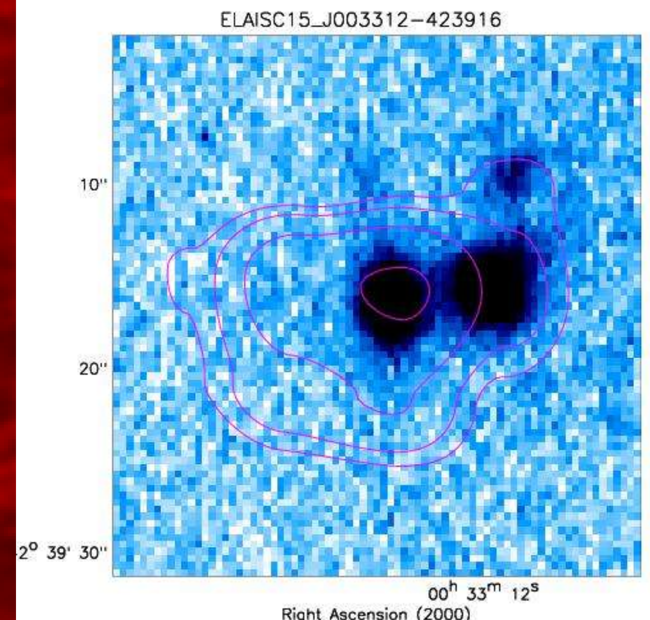
↓

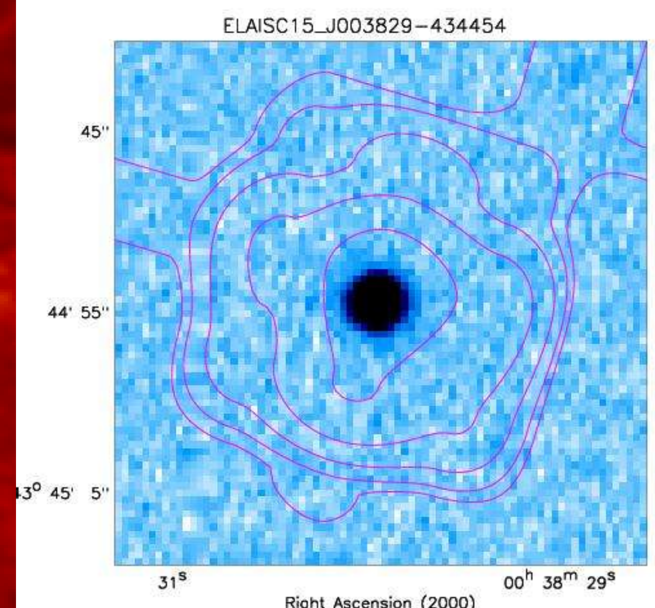
- **Completeness : <u>90% at 2mJy</u>**
- **Positional accuracy : <u>1-2''</u>**
- **Photometric accuracy : <u>10-20 %</u>**

Two interacting galaxies @ z=0.22, S=1.5 mJy

A spiral @ z=0.02, S=5.6 mJy

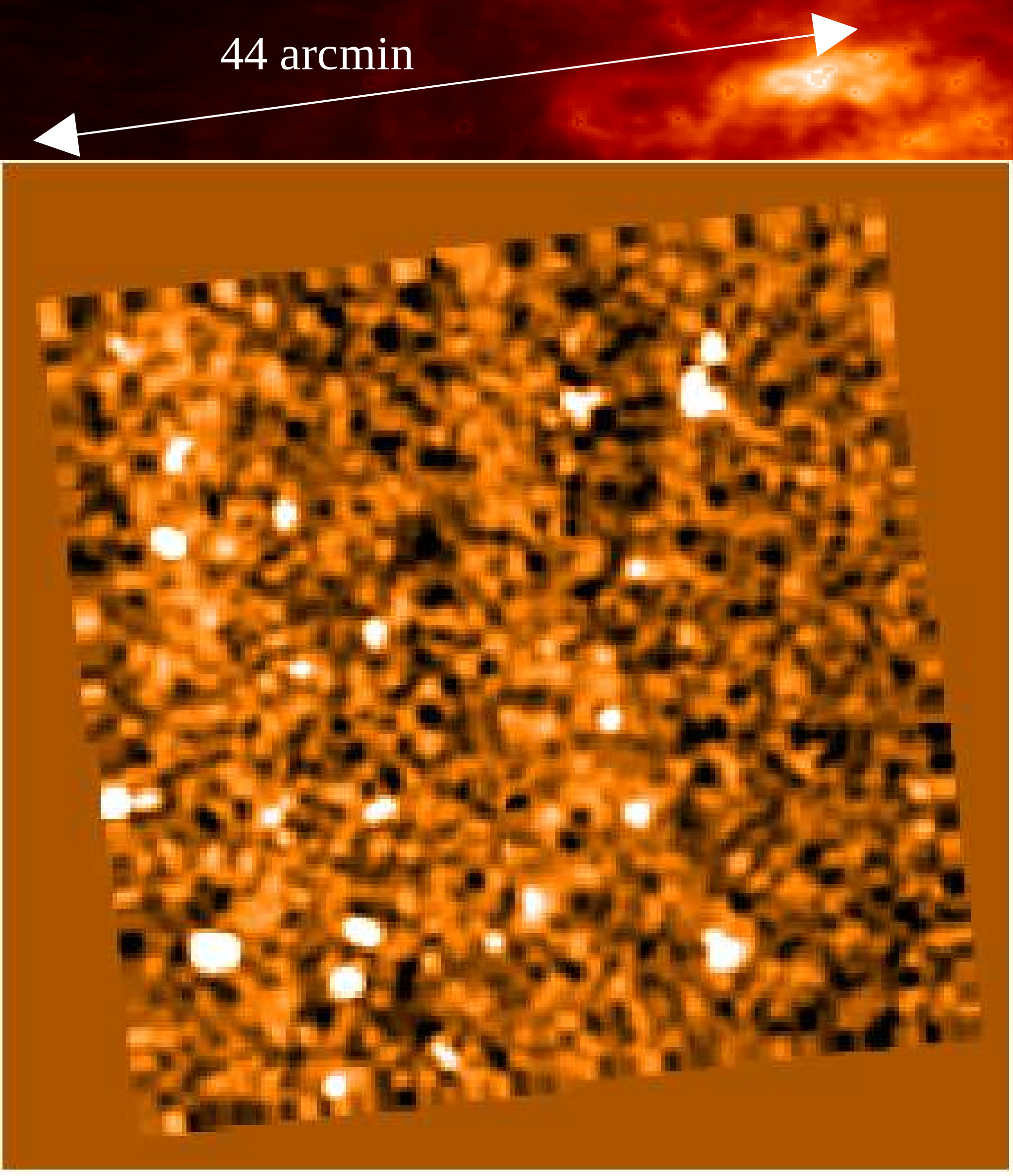






An AGN I @ z=1.56, S=6 mJy

The LOCKMAN HOLE as seen by PHOT (@ 90 μm)



LOCKMAN HOLE at 90 μm:

Catalogue : 36 sources

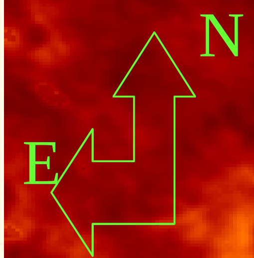
Flux range : 20 - 500 mJy

Simulations

- Completeness : 80 % at 100 mJy

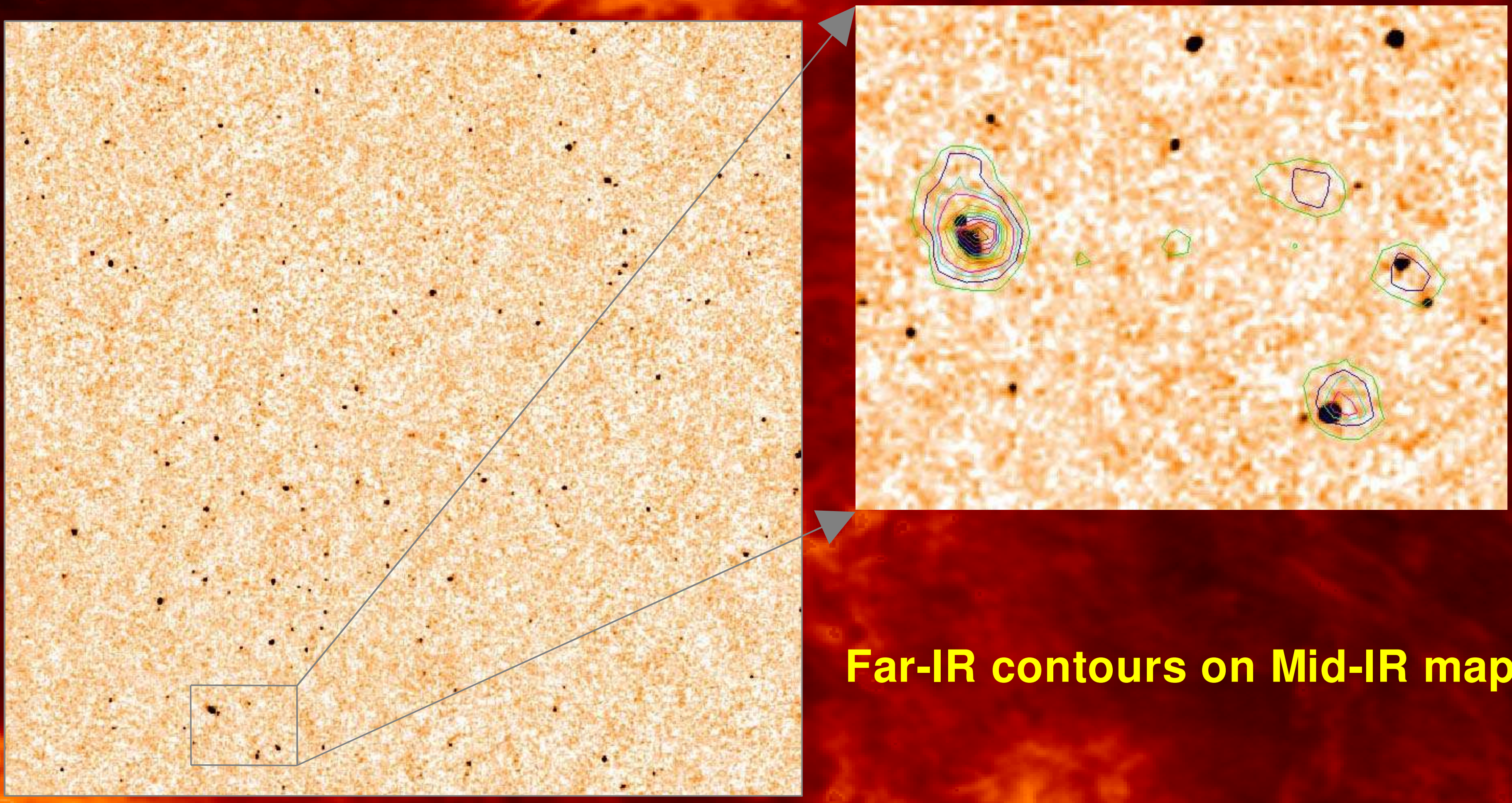
- Positional accuracy : 20 ''

- Photometric accuracy : 20 %



The LOCKMAN HOLE as seen by CAM (@ 15 μm)

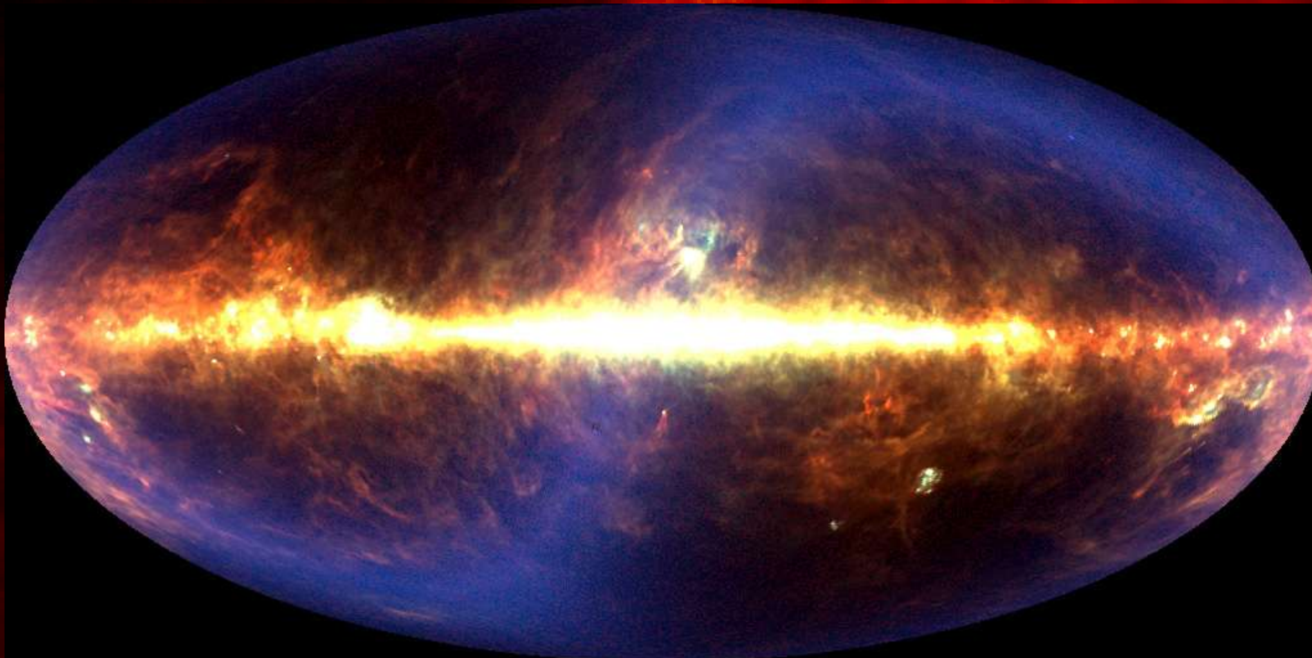
- Number of sources detected: ~ 350
- Minimum flux level: ~0.25 mJy

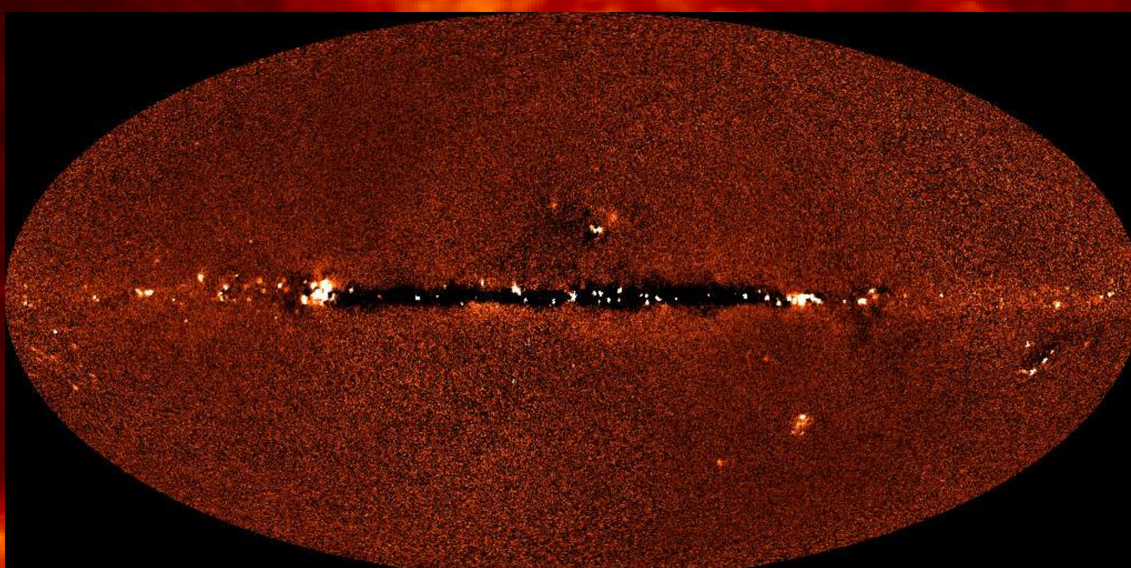


Far-IR contours on Mid-IR map

Herschel for cosmology

- A review of recent facts:
  - The Background Radiation: new discoveries
  - Observations with millimetric telescopes
  - IR observations with space observatories
- Main open problems to be addressed by Herschel cosmological surveys:
  - Formation of galaxies
  - Formation of quasars and AGNs
  - Relevance of long-λ observations: are they needed ?
- Herschel cosmological surveys in the context: what is *unique* compared to the variety of planned space and ground experiments



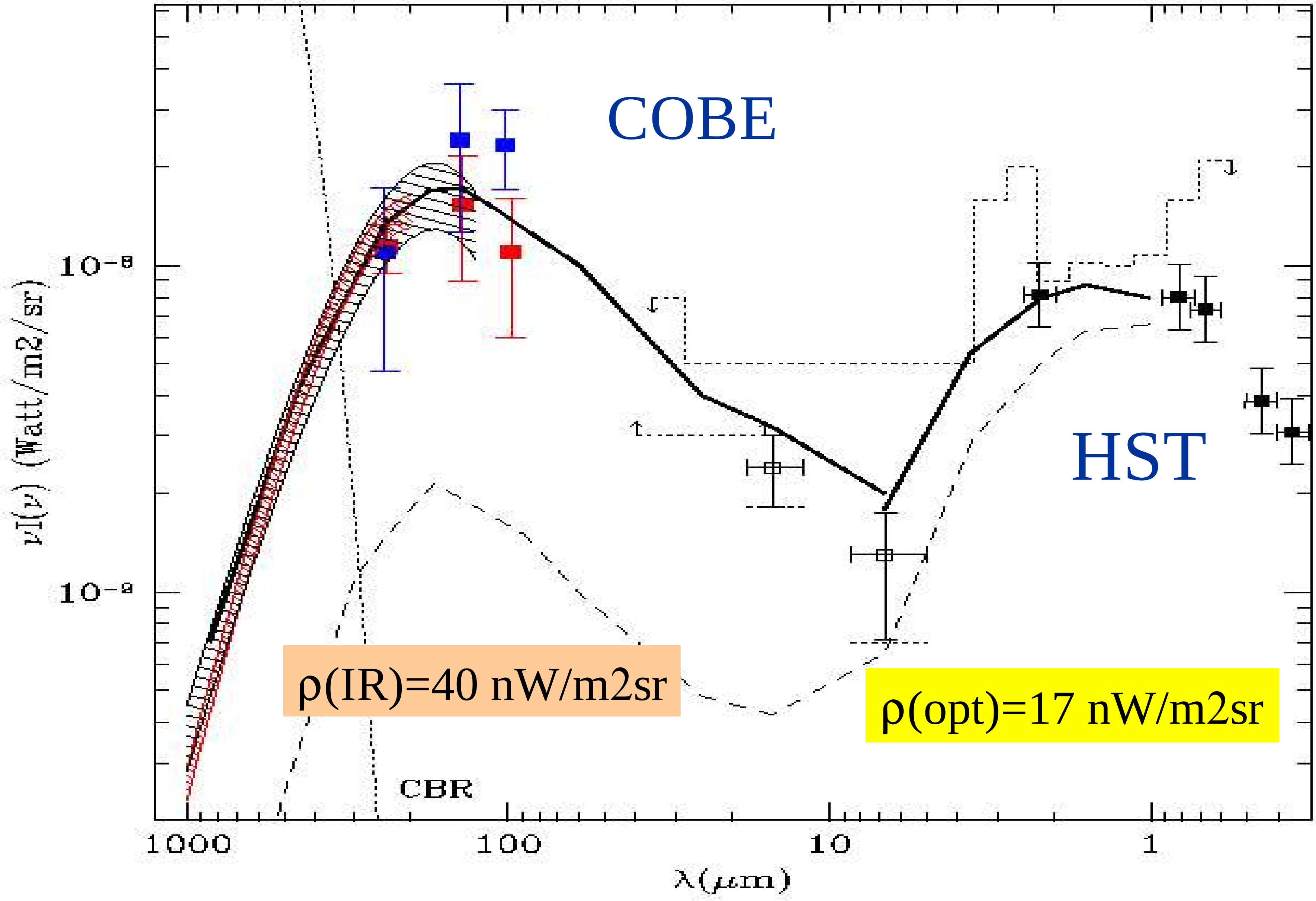


COBE

Discovery of the Cosmic Infrared Background (CIRB)

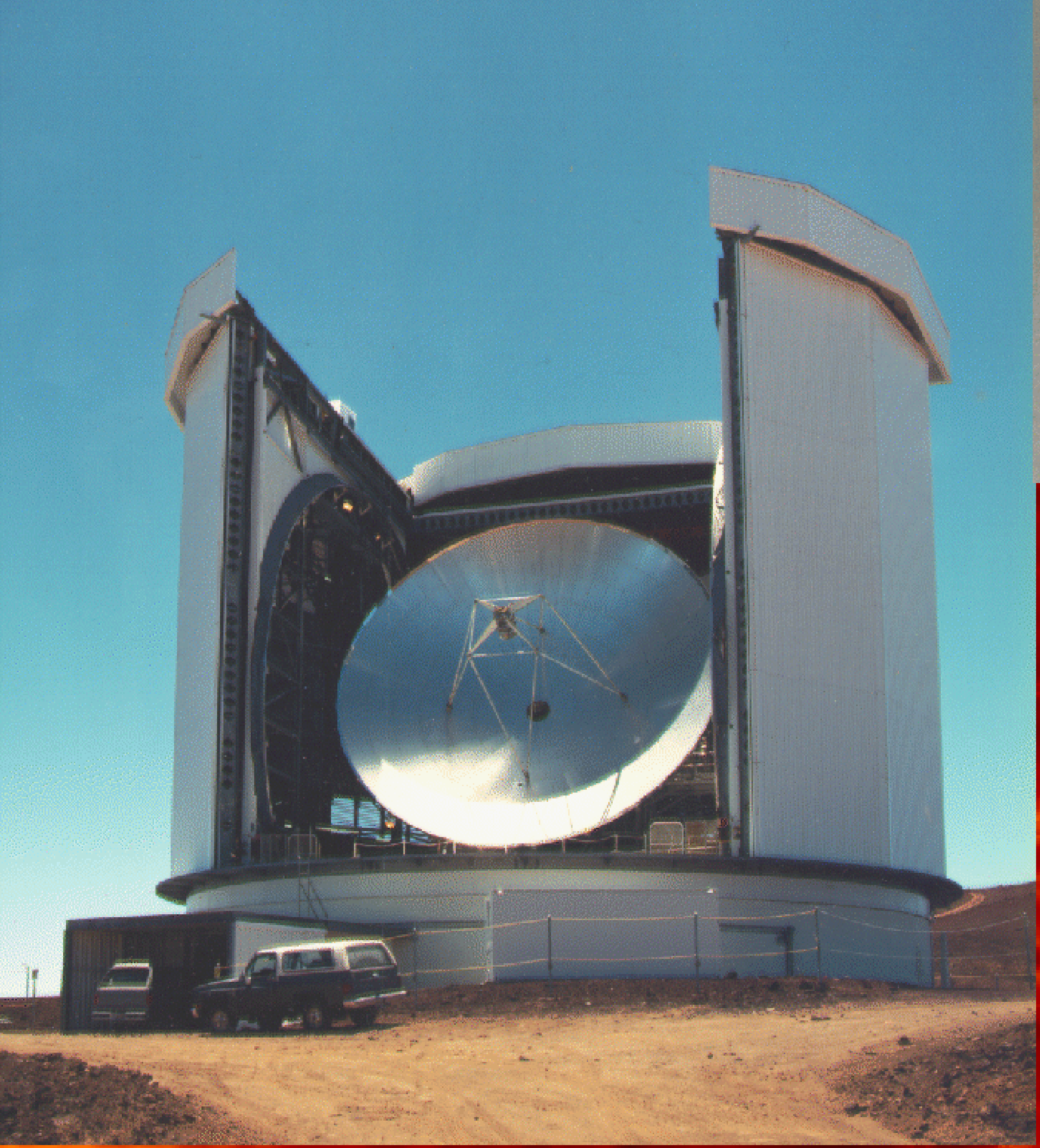
Puget et al. 1996
Hauser et al. 1998

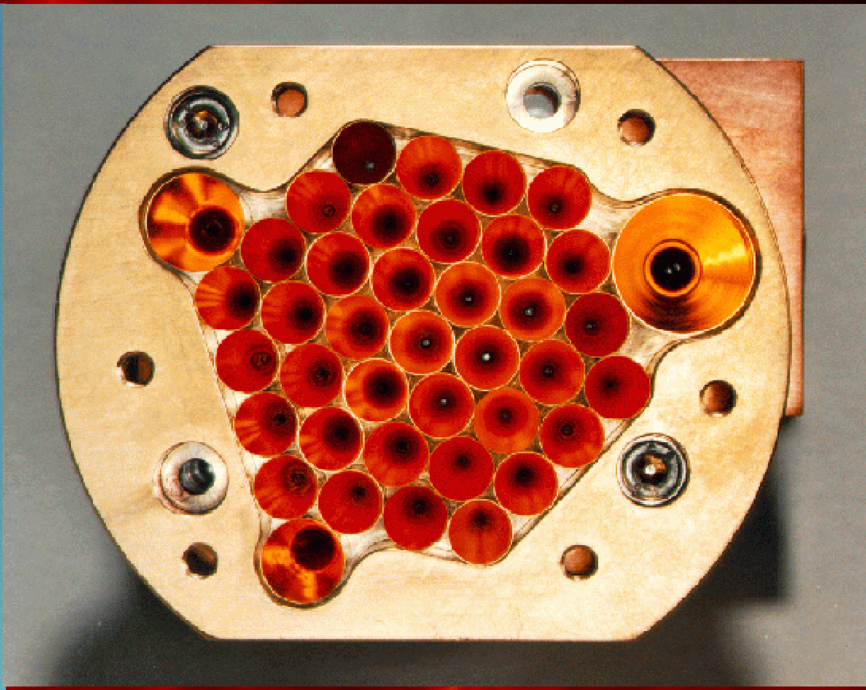
λ=100 μm



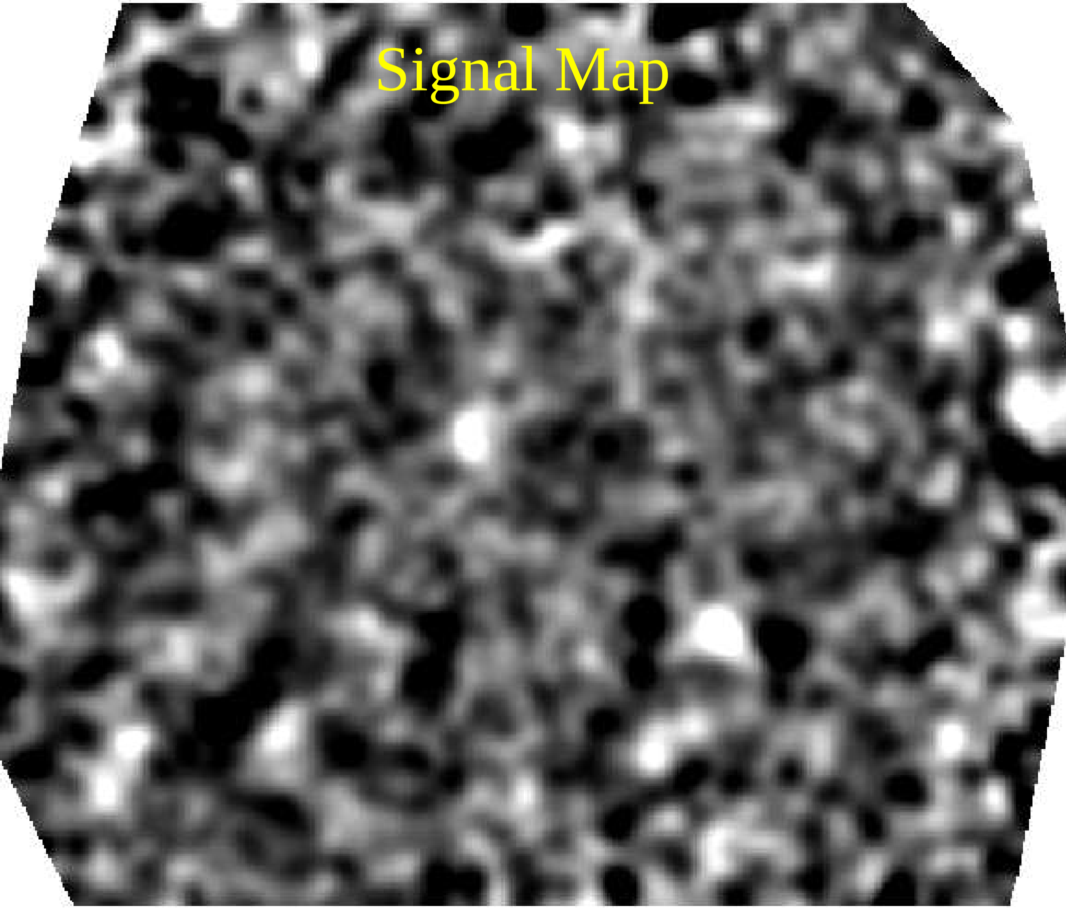
The Infrared and Optical Background Radiations

JCMT 15 m telescope

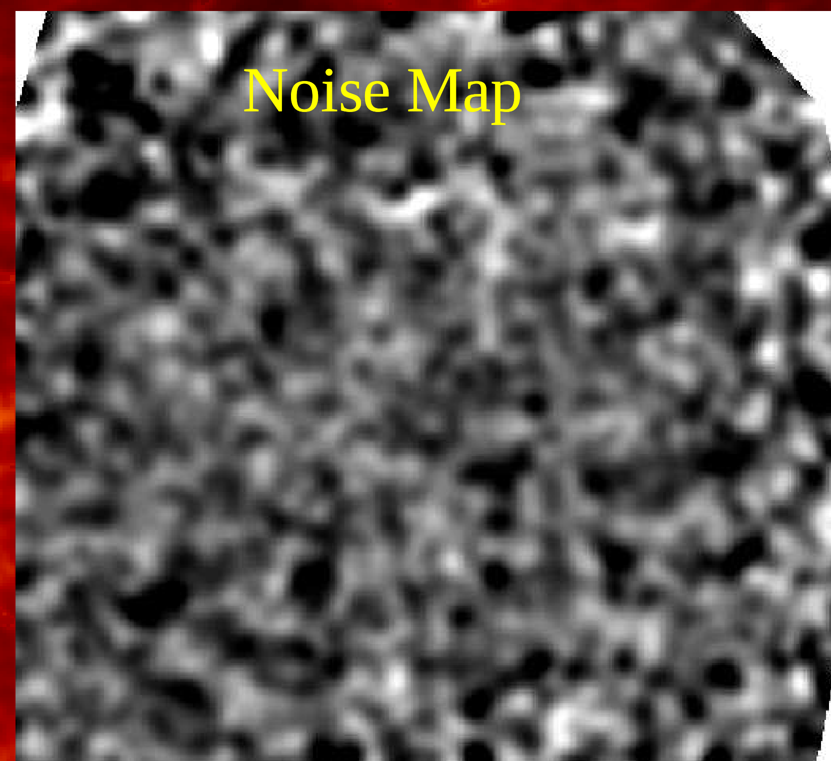




The SCUBA
37 element
bolometer array
operating
at λ=850 μm



6.9 x 6.4 arcmin
19 sources above 3.5 mJy



SCUBA 850 μm survey of CFRS 1415h field

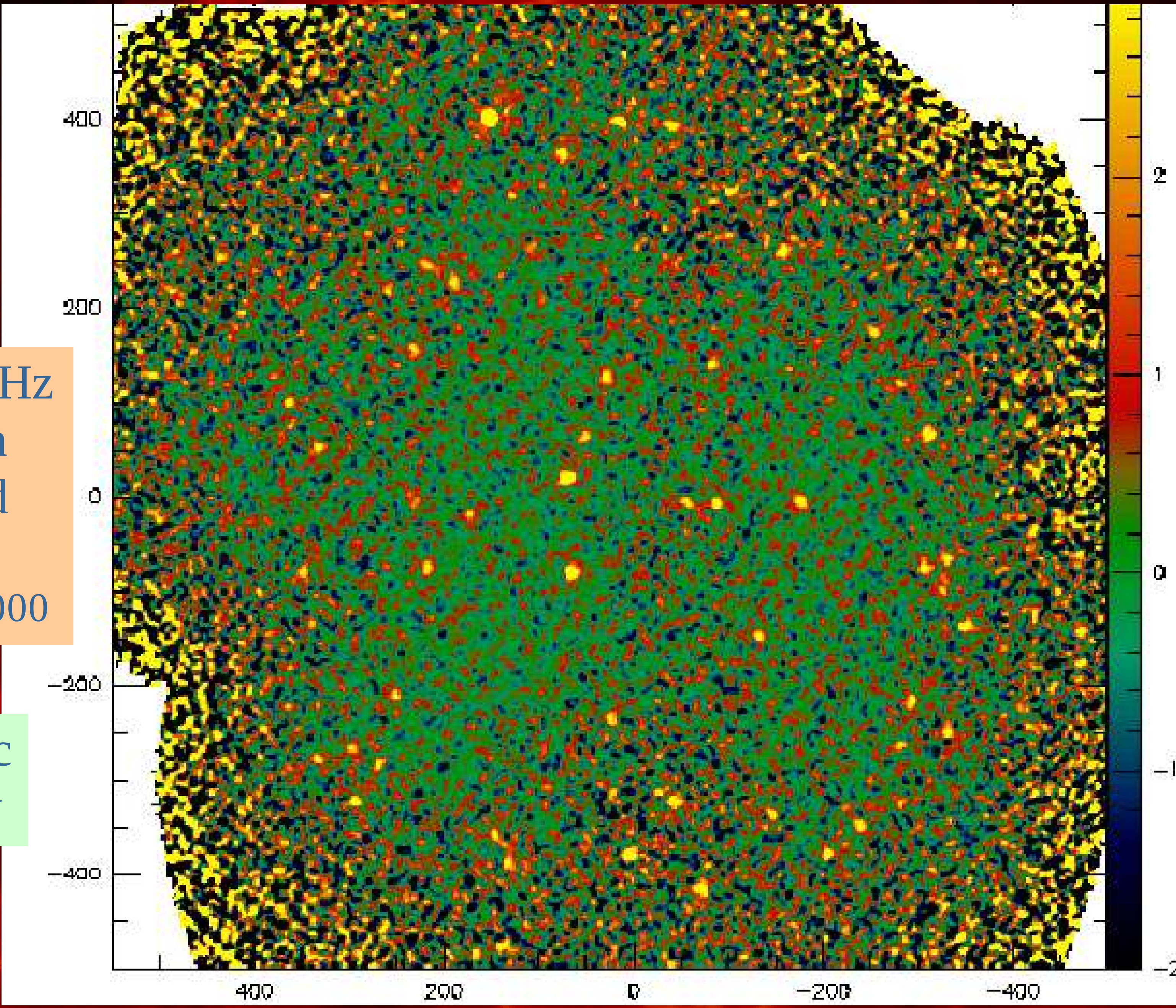
Eales et al. 2000

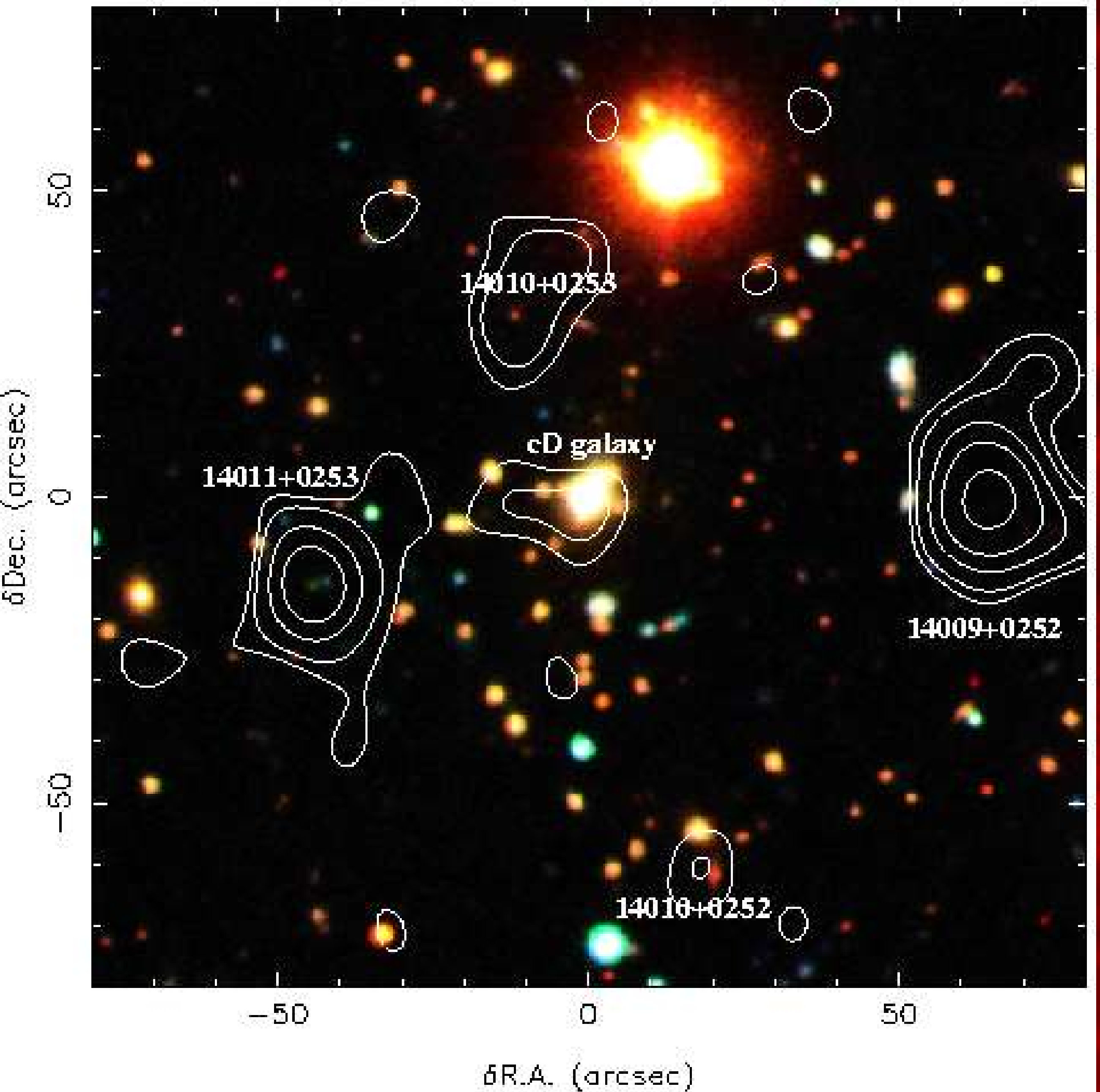
IRAM 30 m bolometer array

Map at 250 GHz (1.2 mm) in A2125 field

Bertoldi et al 2000

Scale in arcsec
rms = 0.5 mJy



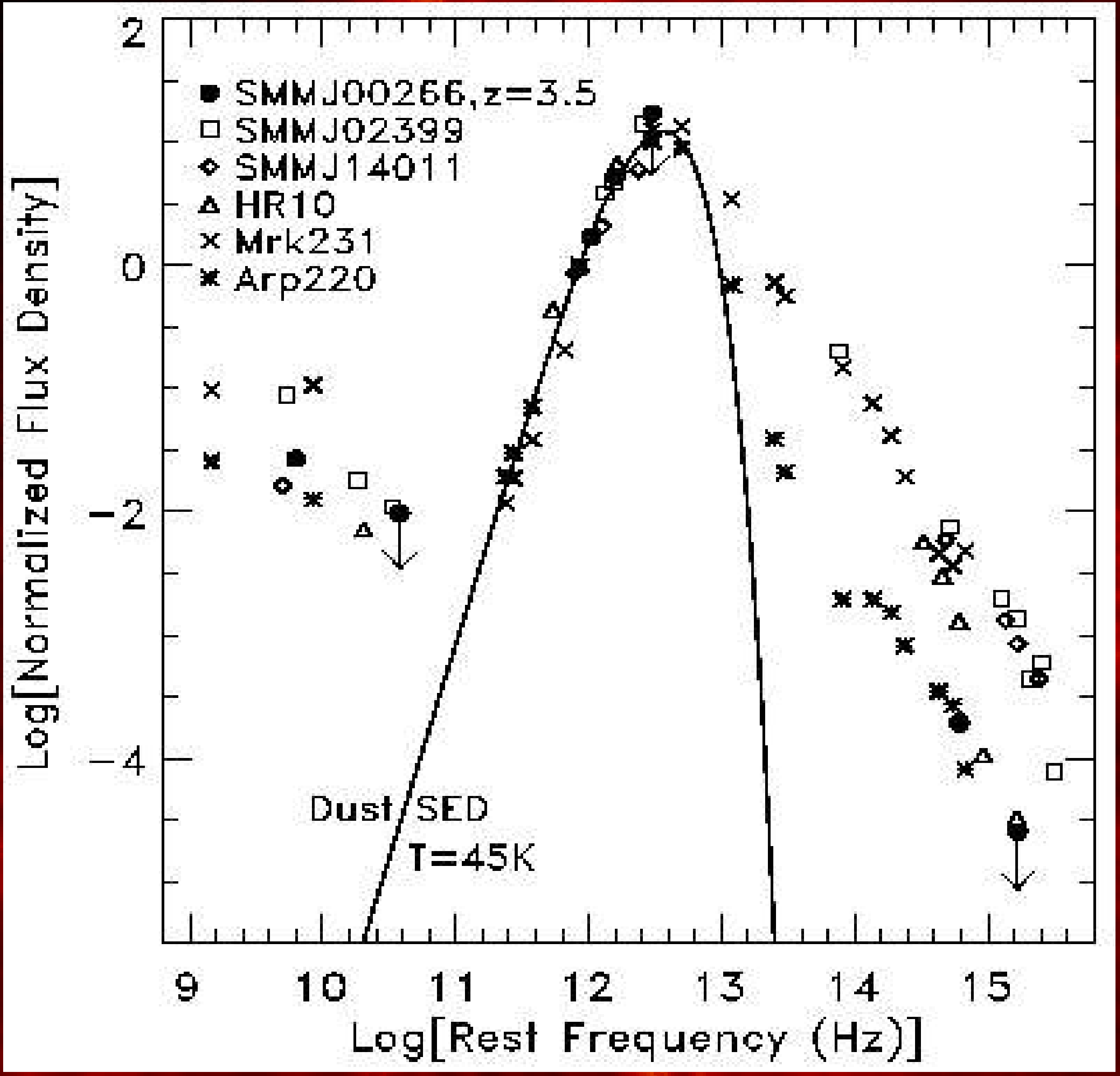


Optical Image:
Palomar 200 UBI

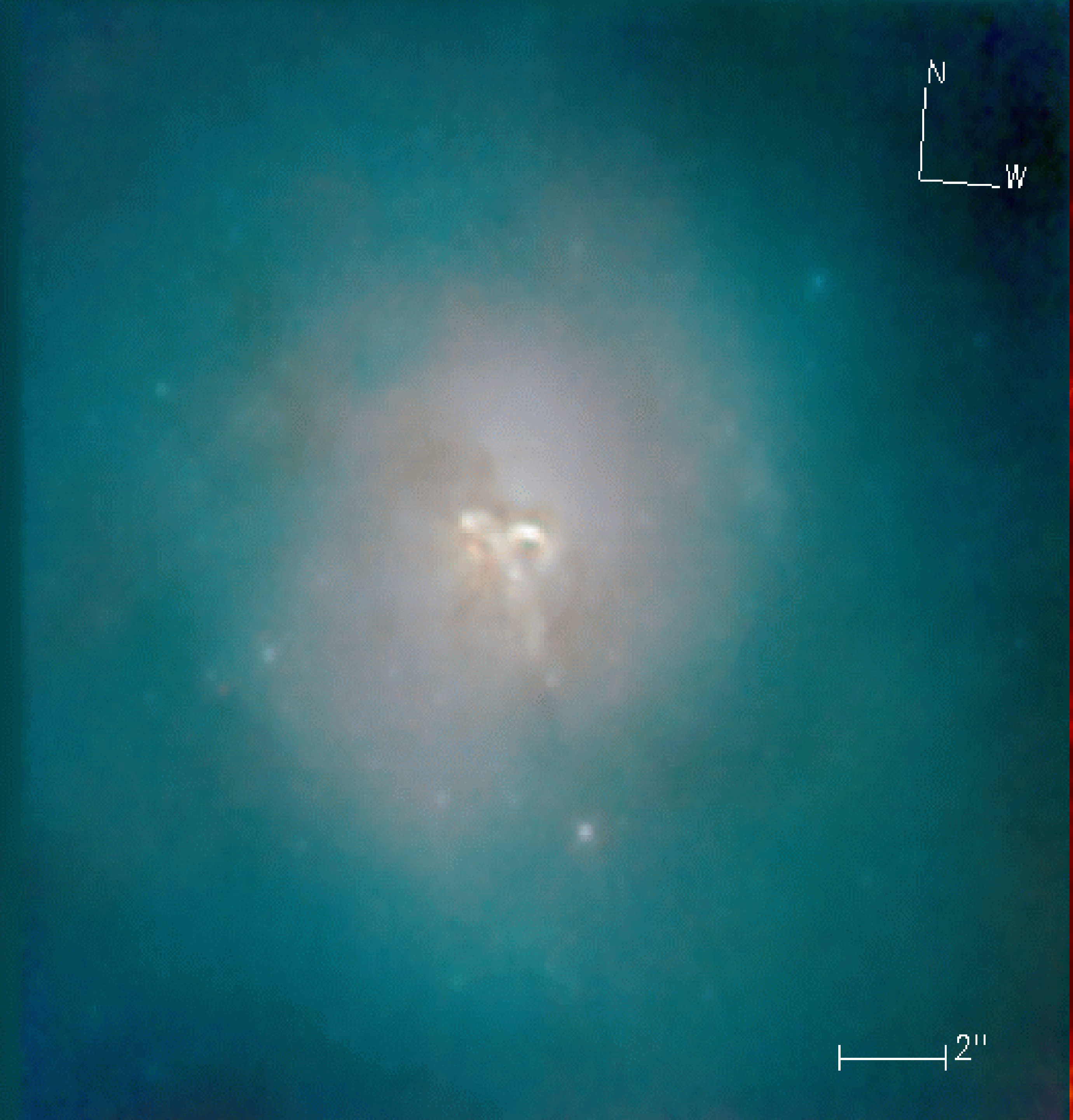
Sub-mm contours:
SCUBA smoothed to
20" resolution

Note: the brightest
SCUBA source has
no optical counterpart

SCUBA sources in A1835 field



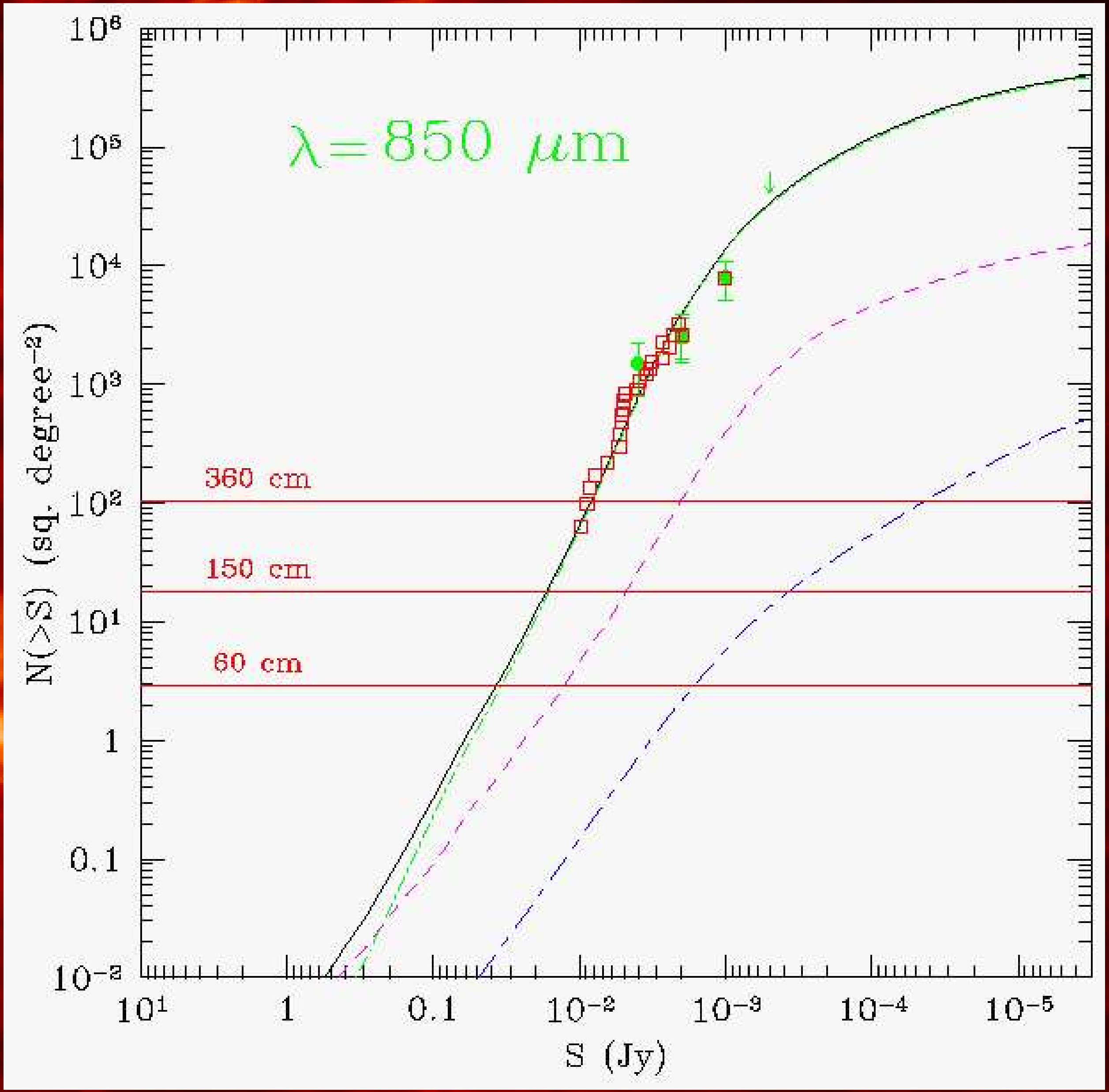
Spectral Energy Distributions of sub-mm selected sources are similar to those of local UltraLuminous IR Galaxies



Arp 220

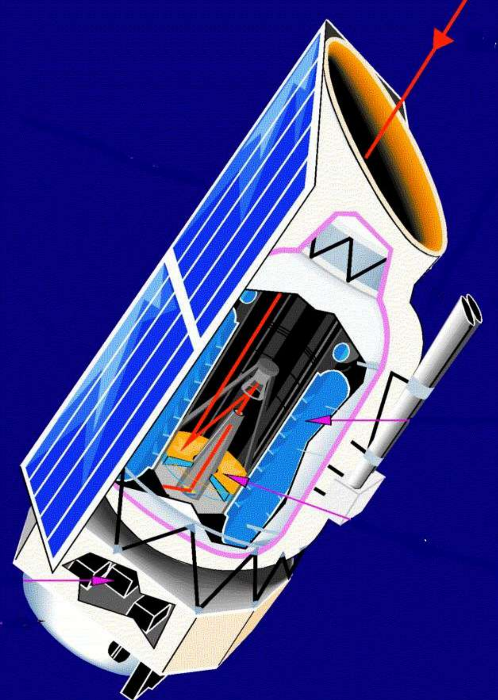
NICMOS false-color image (1.1-1.6-2.2 μm)

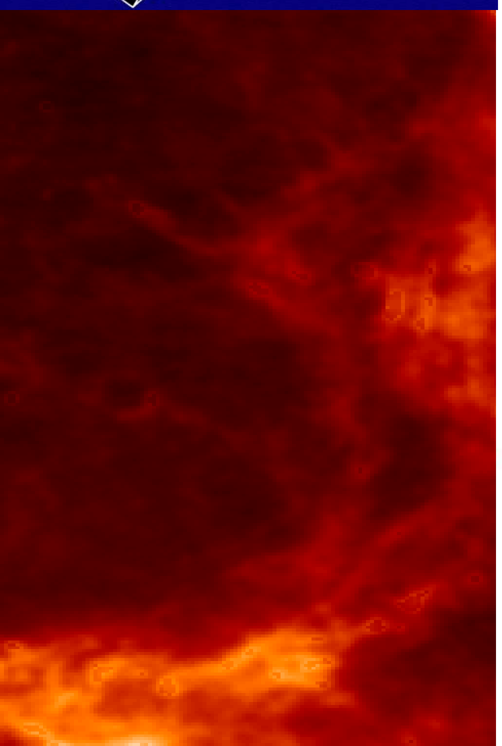
Integral counts at 850 μm

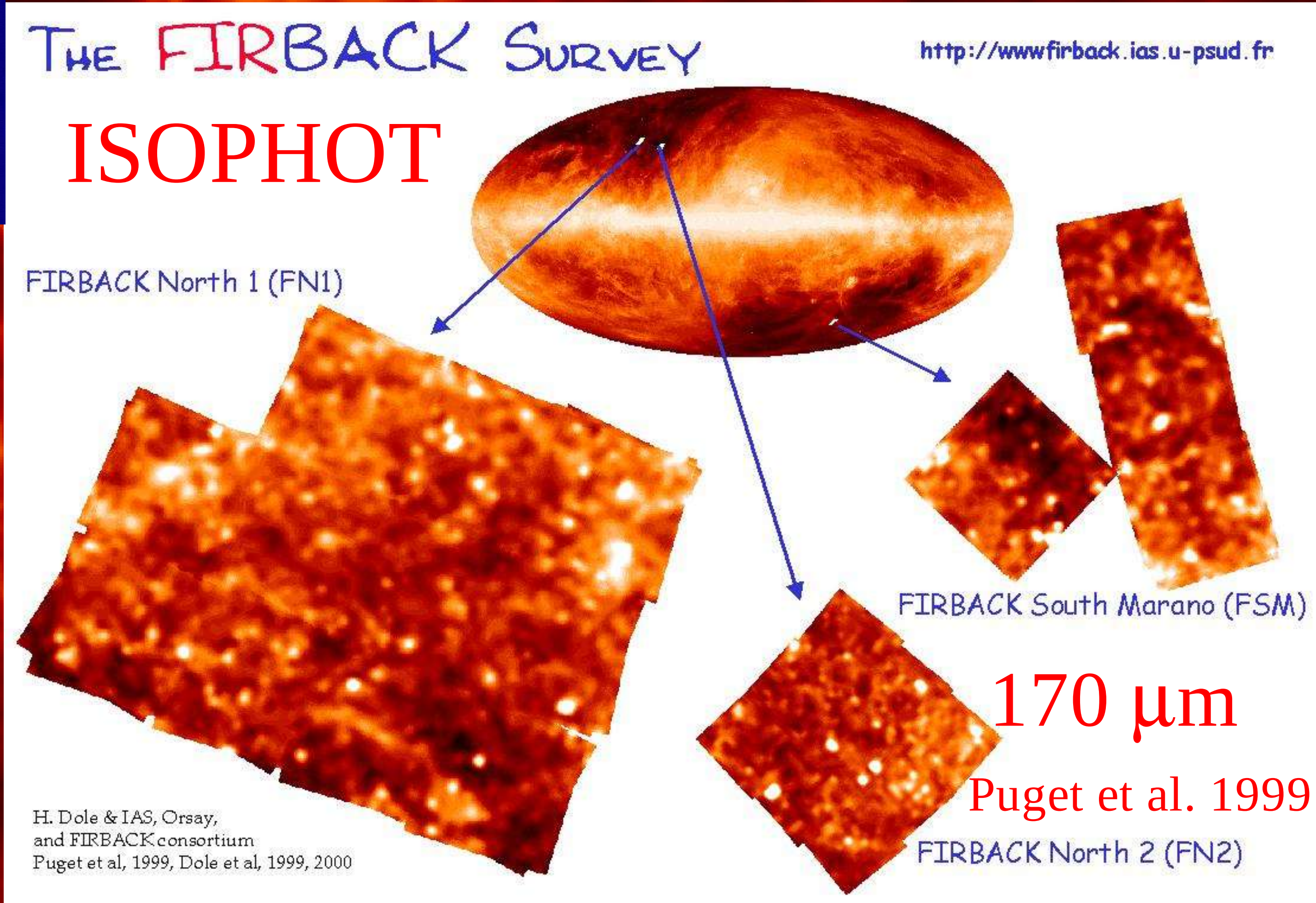


Franceschini et al. 2001

THE INFRARED SPACE OBSERVATORY





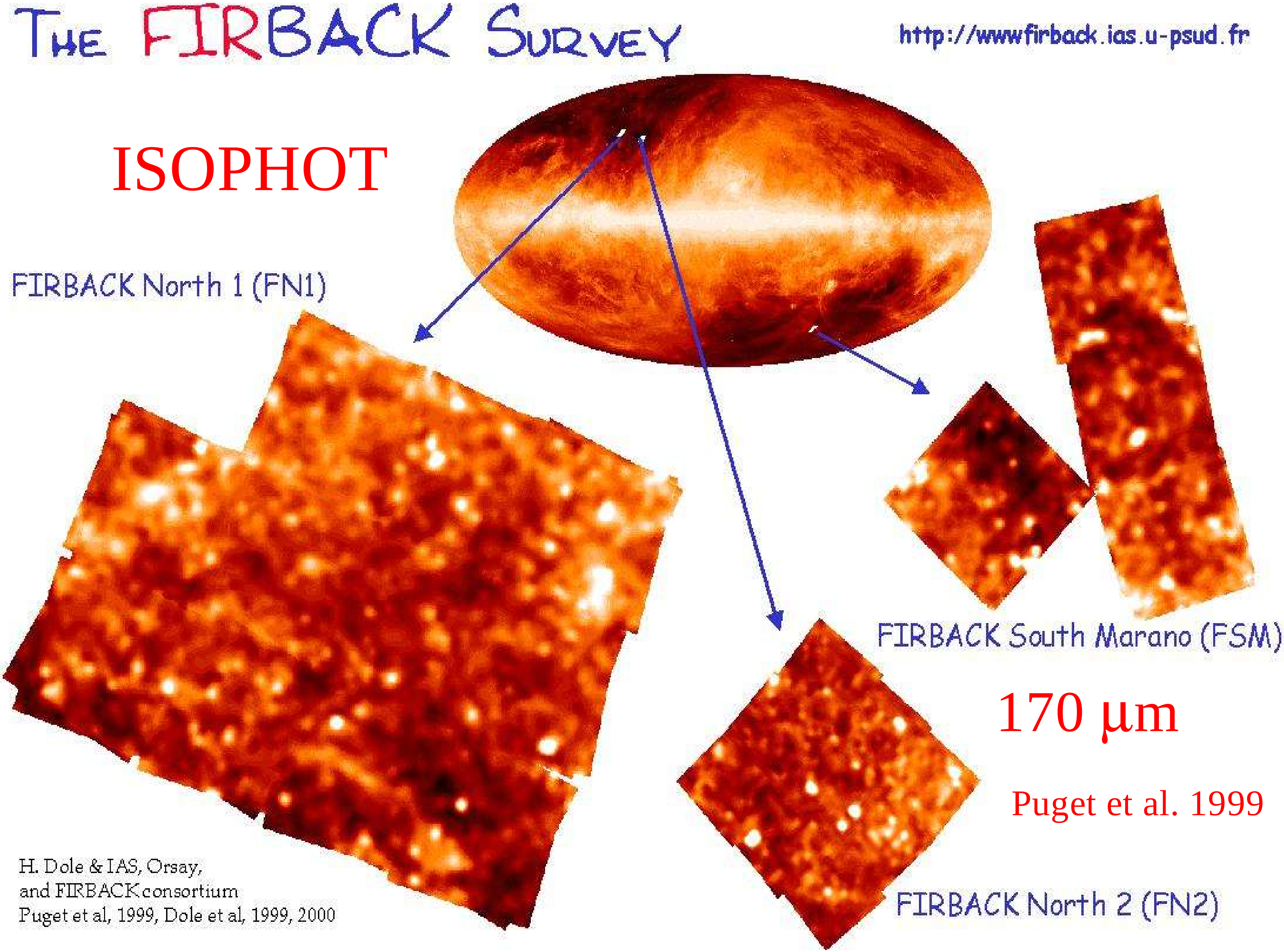


ISOPHOT

170 µm

Puget et al. 1999

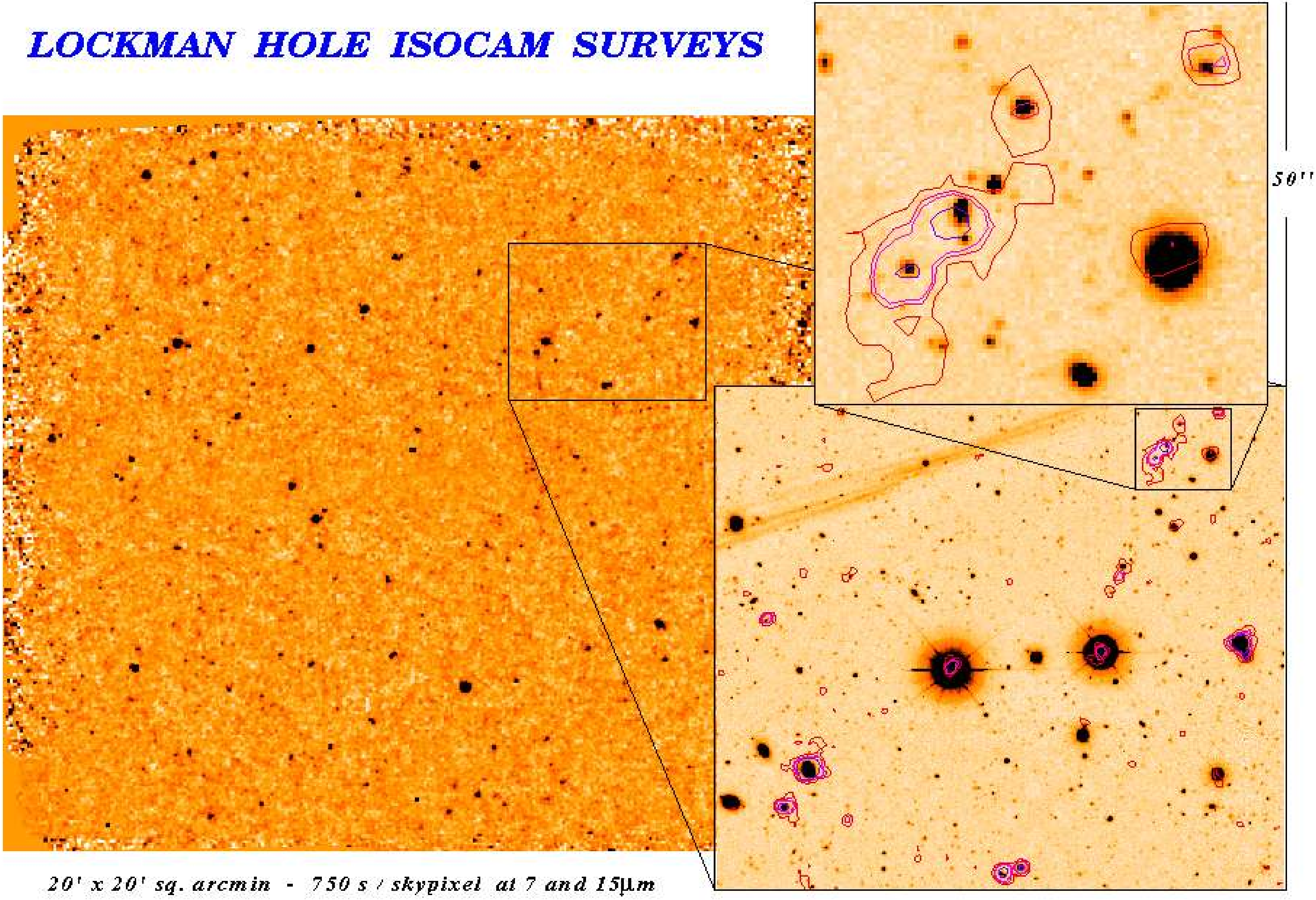
ISOPHOT



170 μm

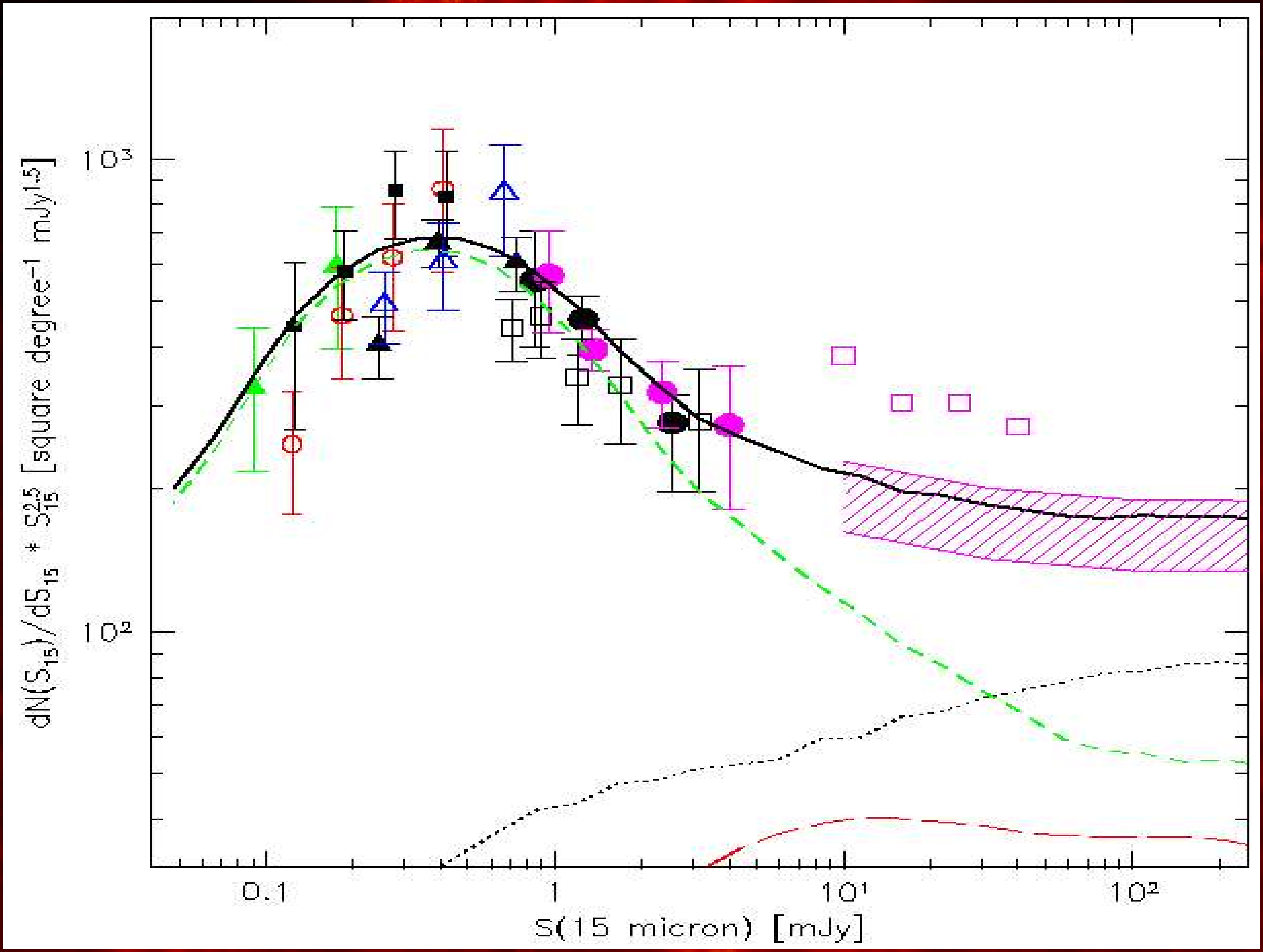
Puget et al. 1999

LOCKMAN HOLE ISOCAM SURVEYS

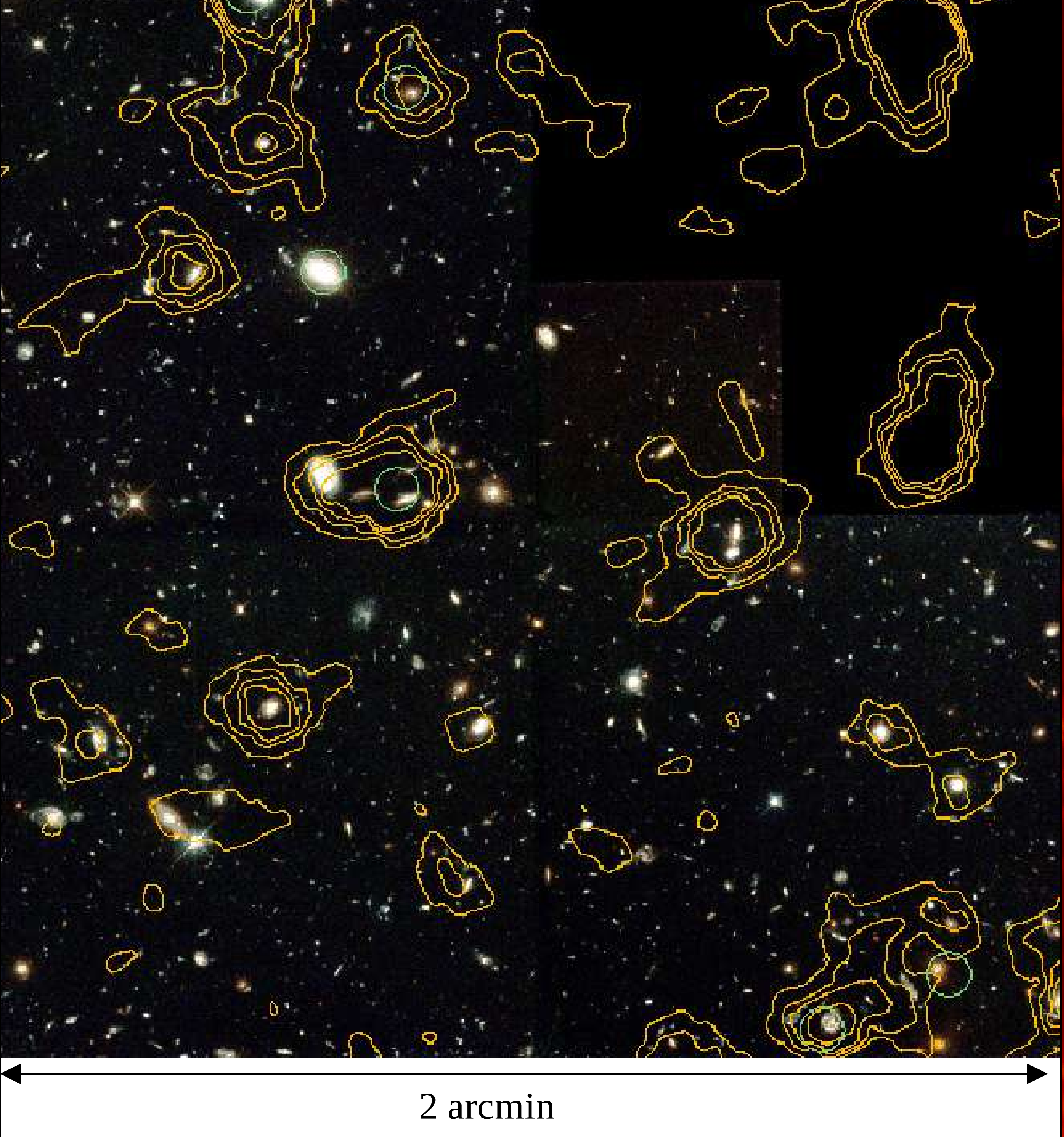


20' x 20' sq. arcmin - 750 s / skypixel at 7 and 15μm

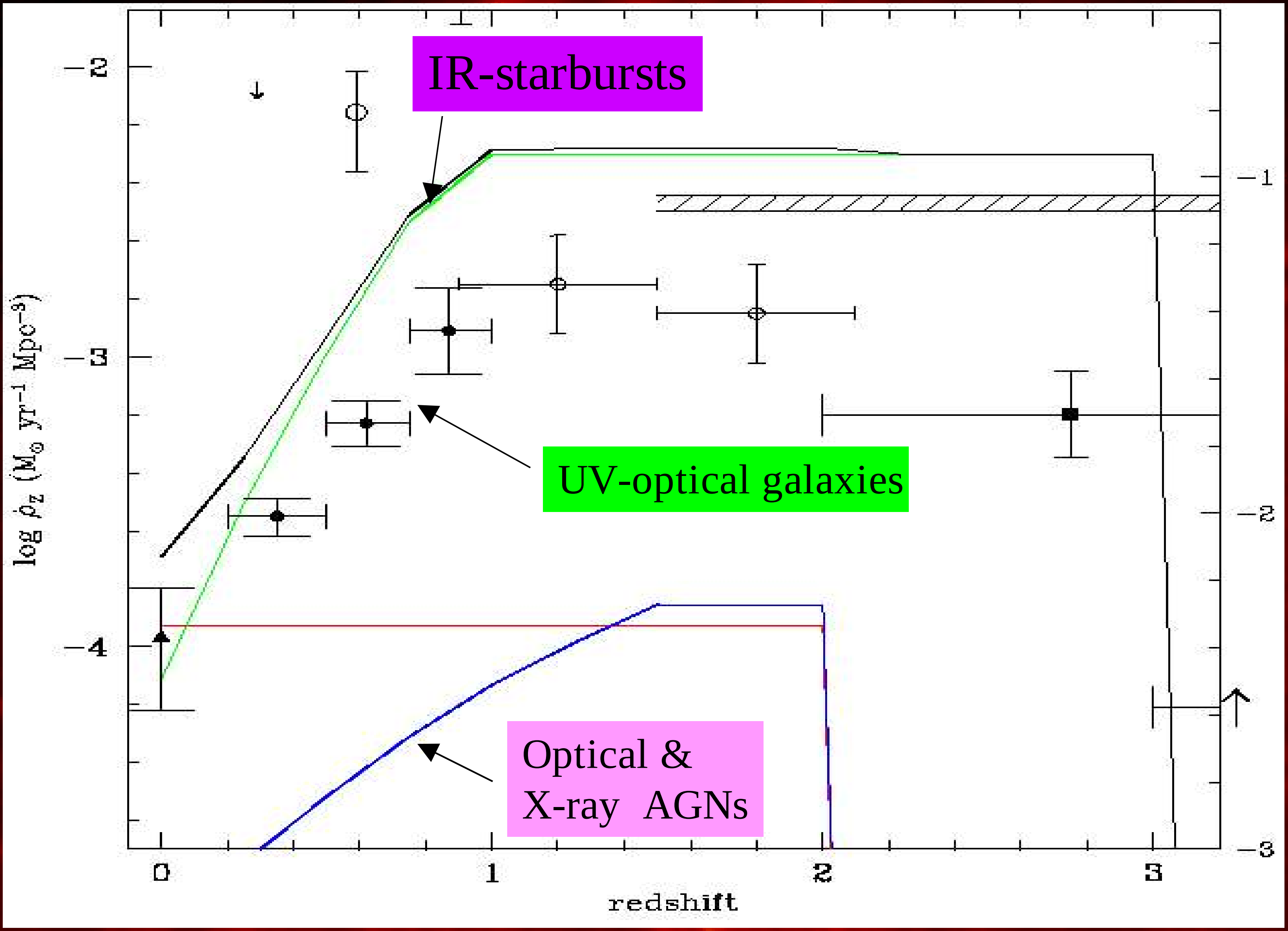
Fadda et al. 2002



ISOCAM 15 μm differential counts (Elbaz et al. 1999)



HDF-North image overlayed by the ISOCAM 15 μm contours by Aussel et al. 1999



Comoving star-formation rate density

Franceschini et al. 2001

The Formation of Stars

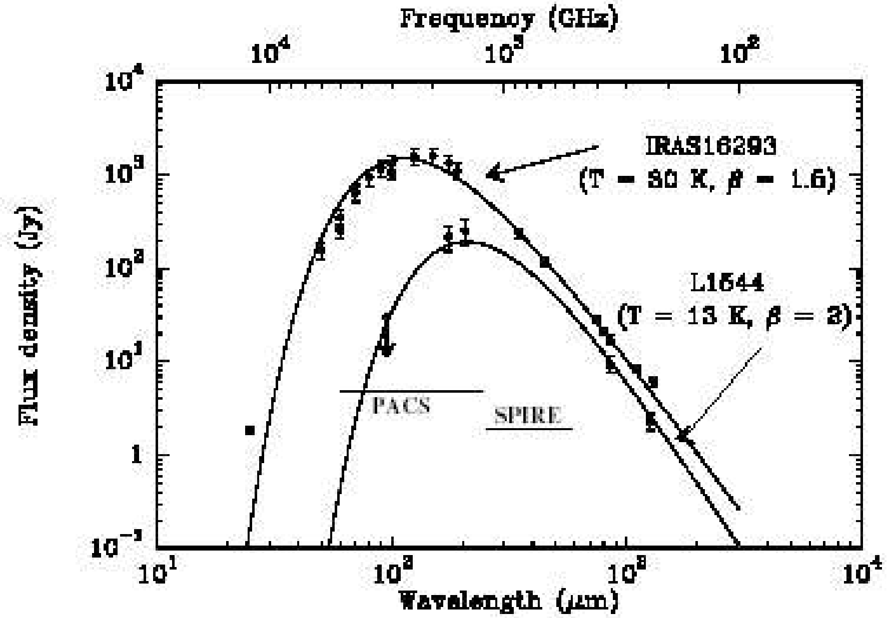
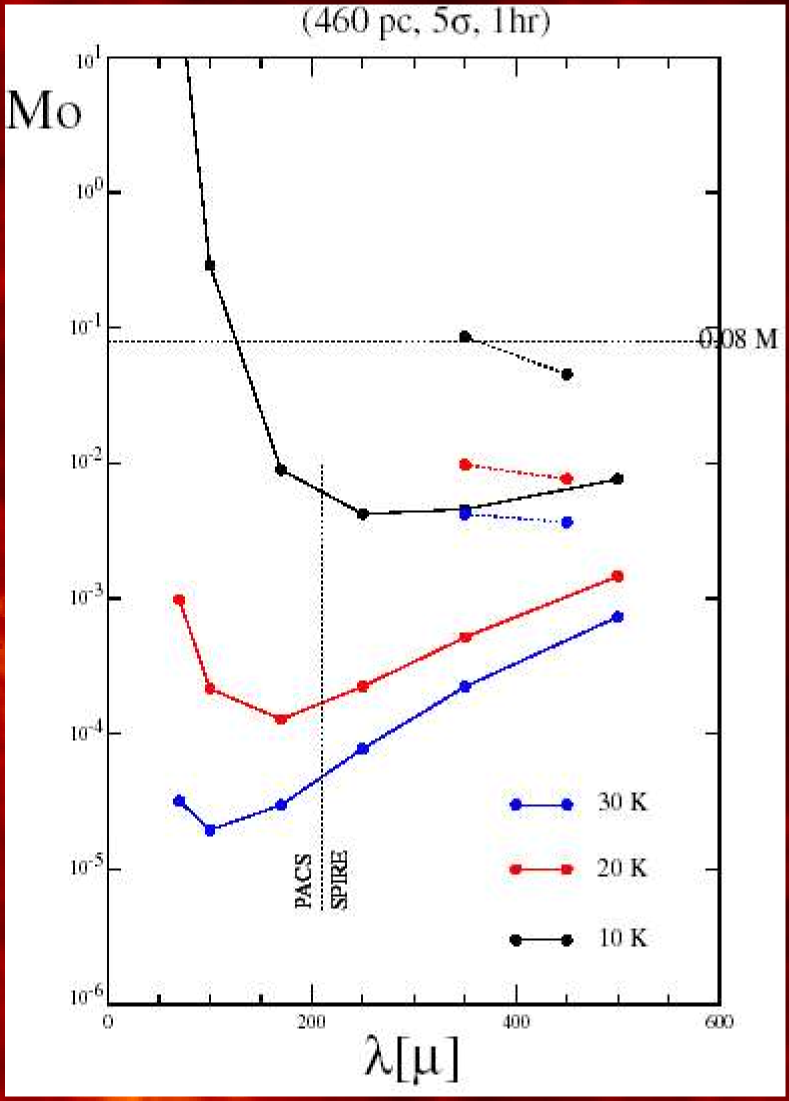
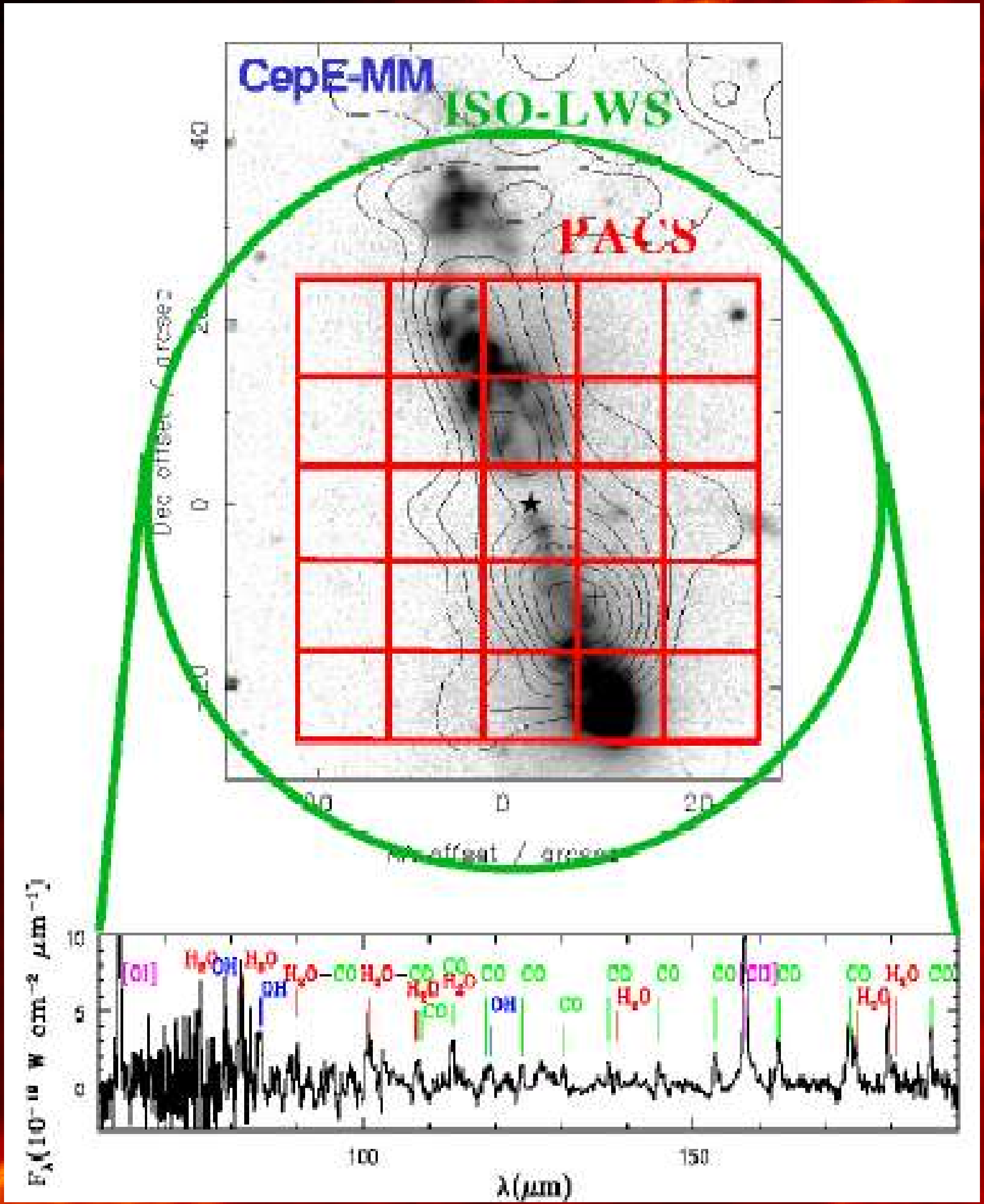


Figure 1. Spectral energy distribution of the pre-stellar core L1544 and the protostar IRAS 16293, together with simple gray body fits. PACS and SPIRE spectral windows are reported (adapted from André et al. 2000).

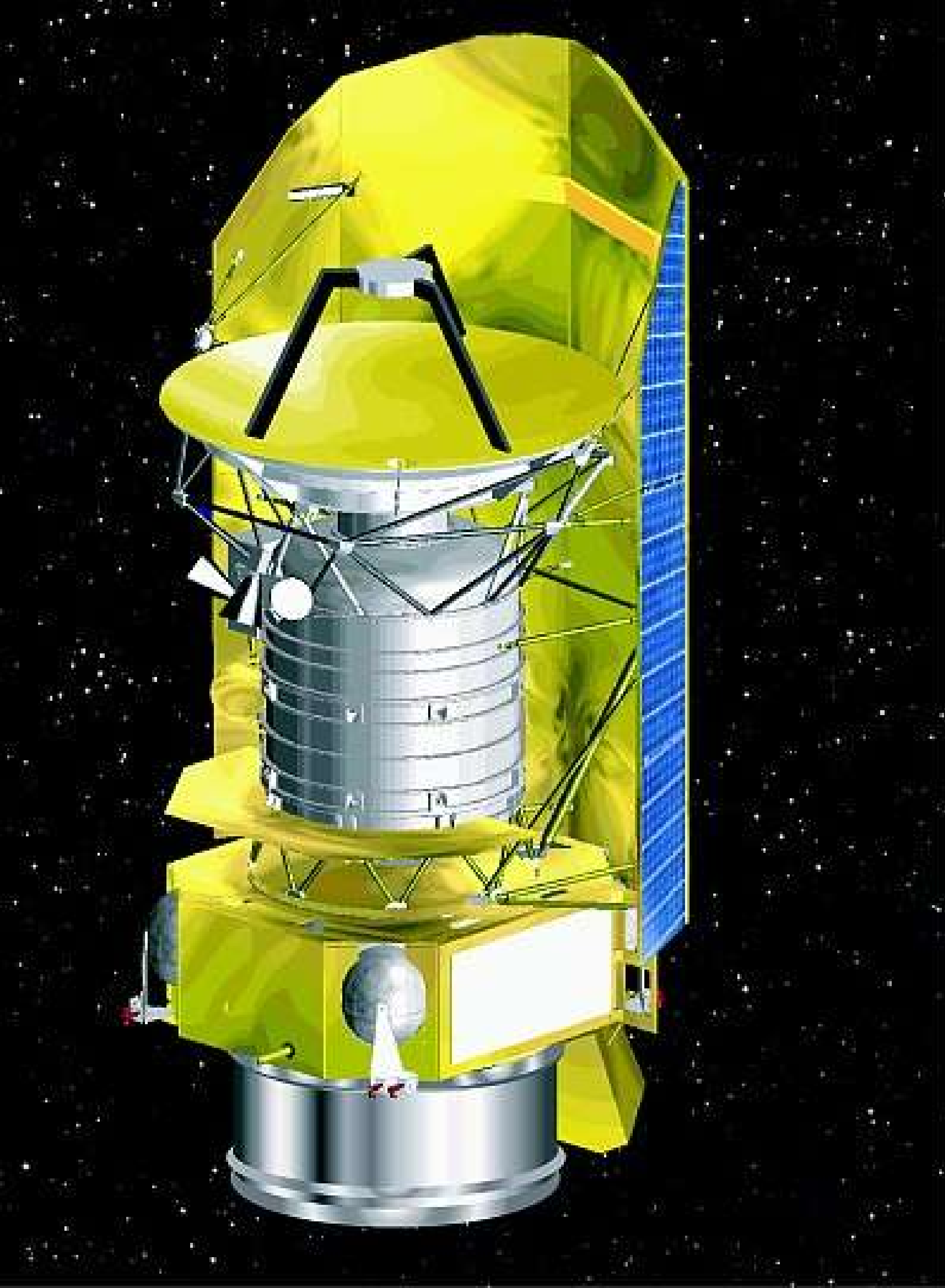


Minimum detectable mass for dust-enshrouded protostars



Rich information available from observations at long λ only

All these pioneering results indicate that a new important branch of astrophysics, with especially relevant implications to understanding key issues about the formation of galaxies and QSOs, and the complex physics ruling the generation of stars, has been born



Herschel

The Herschel Space Observatory (formerly known as FIRST) is the fourth cornerstone mission in ESA's Horizon 2000 programme, scheduled for launch in 2007. A 3.5 m diameter telescope, passively cooled to around 70 K, will feed a suite of three cold focal plane instruments providing high-throughput photometry and spectroscopy in the 60 - 670 μm range. The instruments will be contained in a liquid helium cryostat with an operational lifetime of at least three years.

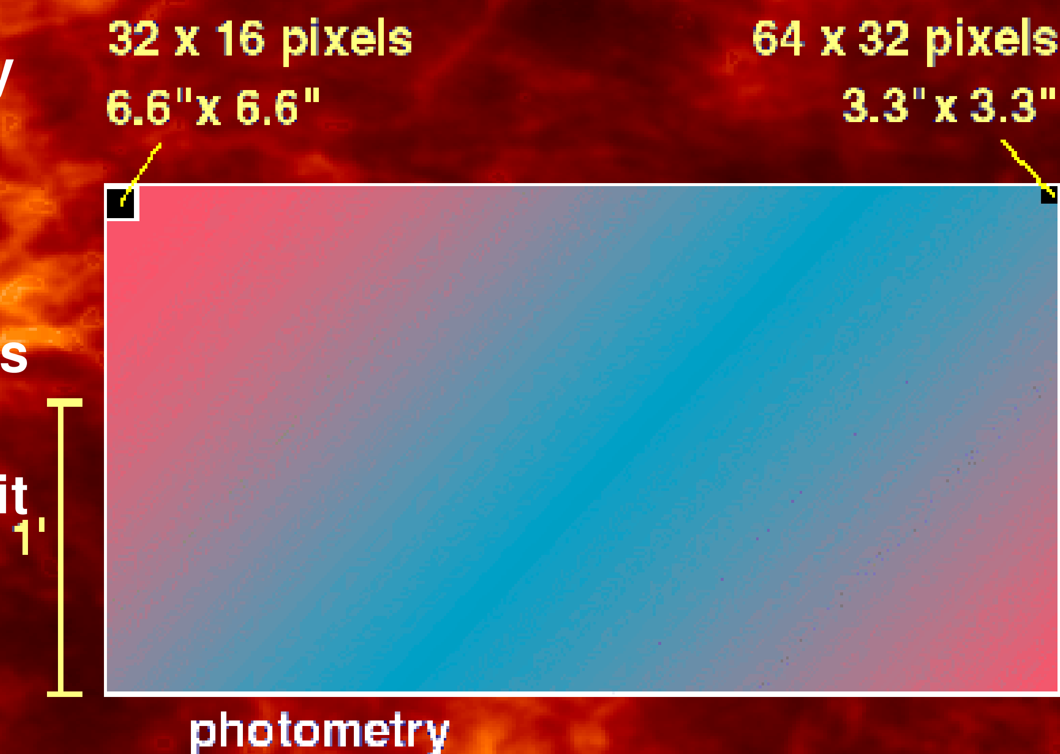
PHOTODETECTOR ARRAY CAMERA AND SPECTROMETER (PACS)

Imaging Photometry

- two bands simultaneously (60-90 µm or 90-130 µm and 130-210 µm) with dichroic beam splitter
- two filled bolometer arrays (32x16 and 64x32 pixels)

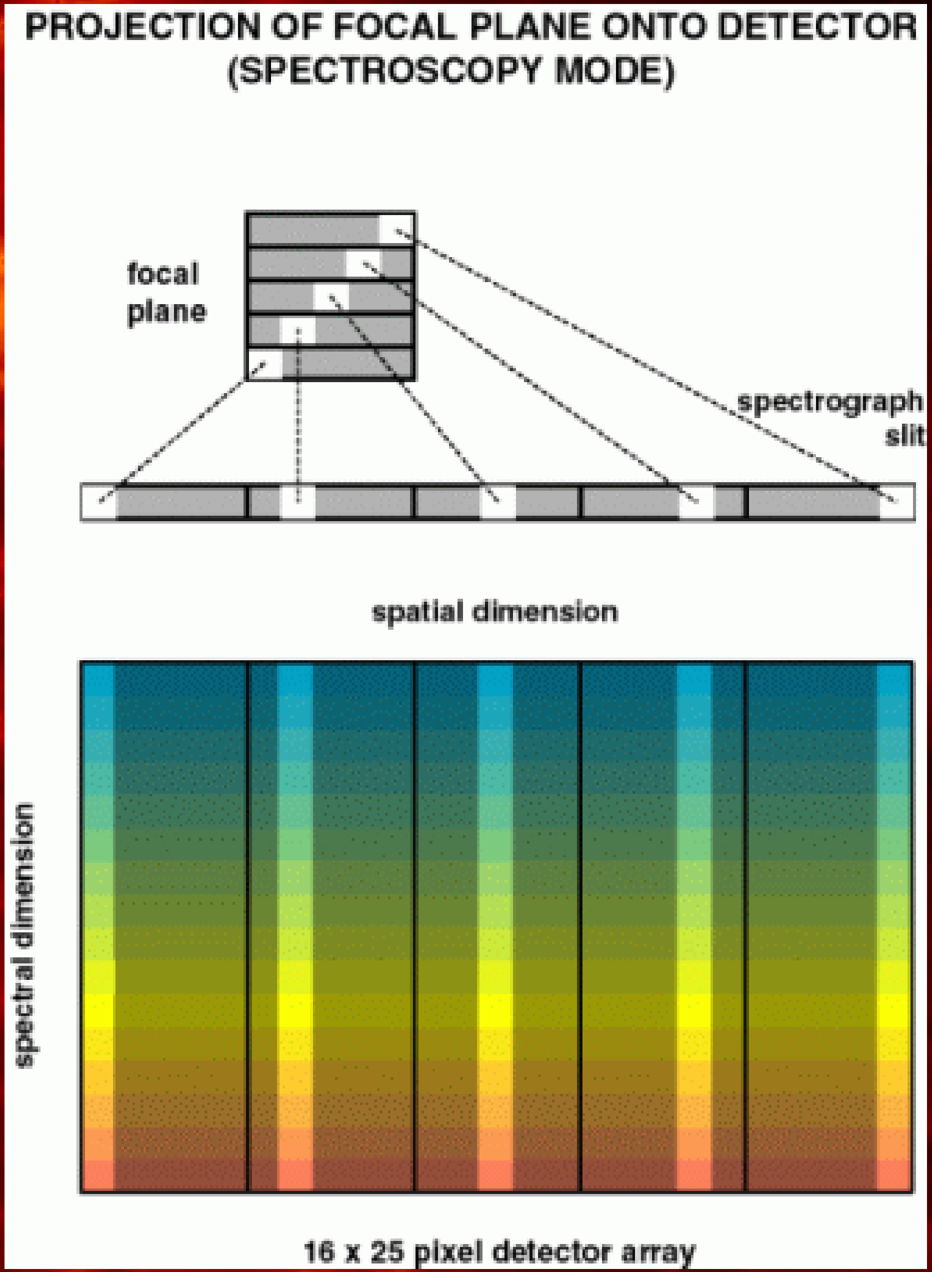
point source detection limit ~ 3 mJy (5 sigma, 1h)

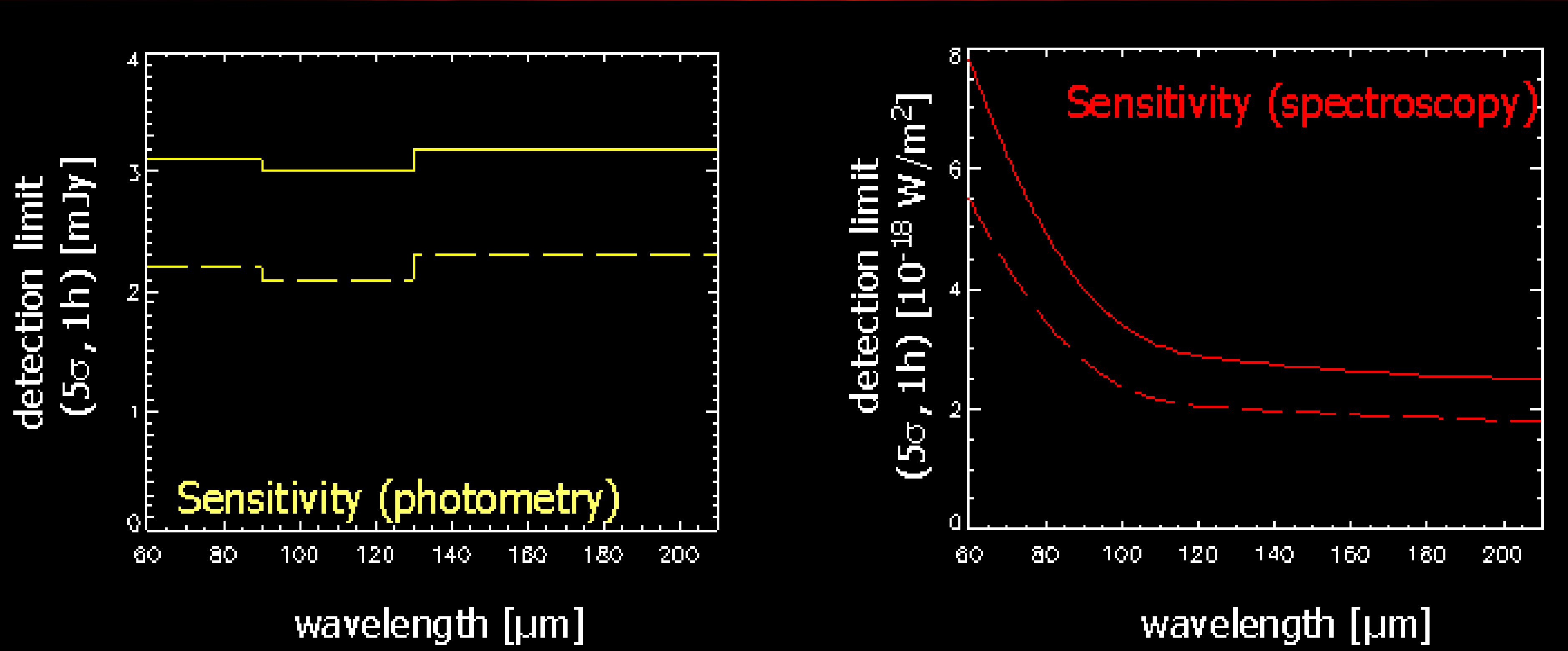
Focal Plane Footprint



Integral Field Line Spectroscopy

• wavelength range : 57-210 µm
• optical image slicer rearranges 2-D field of view (5x5 pixels) along 1-D slit (1x25 pixels)
• long-slit grating spectrograph (R ~ 1500) disperses light
• dispersed slit image is projected on 16x25 pixel Ge:Ga Photoconductor arrays (stressed/unstressed)
• 16 spectral channels recorded simultaneously for each spatial element
• point source detection limit is 2.5 - 8 x 10^{-18} W/m^2 (5 sigma, 1h)





PACS sensitivity (5 σ in 1h) in photometry and spectroscopy modes with (dashed lines) and without (solid lines) on-array chopping

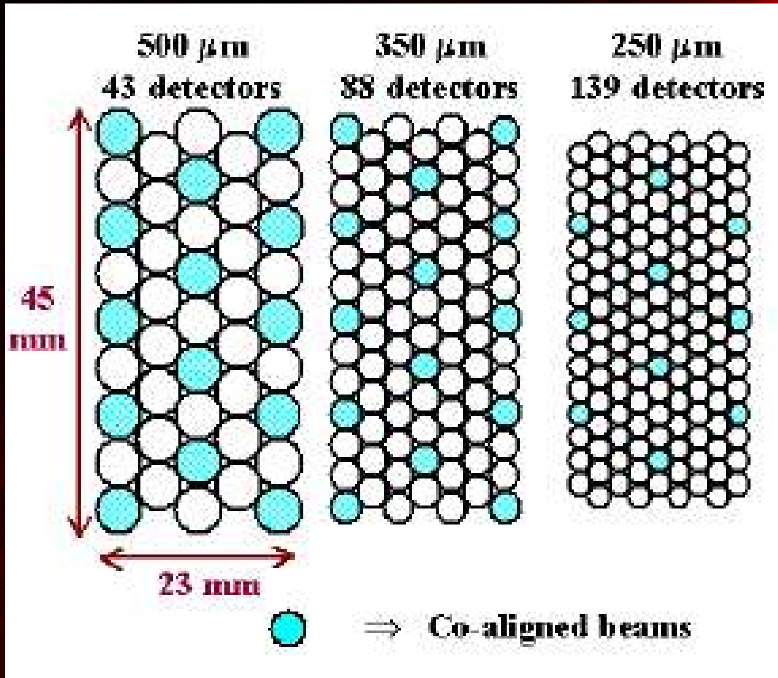
Spectral and Photometric Imaging Receiver (SPIRE)

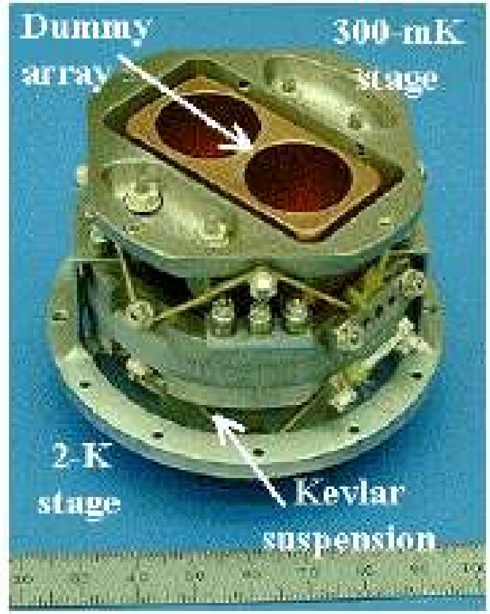
SPIRE Instrument Features

- **3-band Imaging Photometer**
  - Wavelengths (μm): 250, 350, 500
  - **S**imultaneous observation in 3 bands
  - Beam FWHM (arcsec): 17, 24, 35
  - Field of view (arcmin): 4 x 8

- **Imaging Fourier Transform Spectrometer (FTS)**
  - Wavelength Range (μm): 200-400 (req.) 200-670 (goal)
  - Simultaneous imaging of the whole spectral band
  - Field of view (arcmin): 2.0 (req.) 2.6 (goal)
  - Max. spectral resolution: $\lambda/\Delta\lambda$=100 (req.) 1000 (goal)
  - Min. spectral resolution: $\lambda/\Delta\lambda$=20

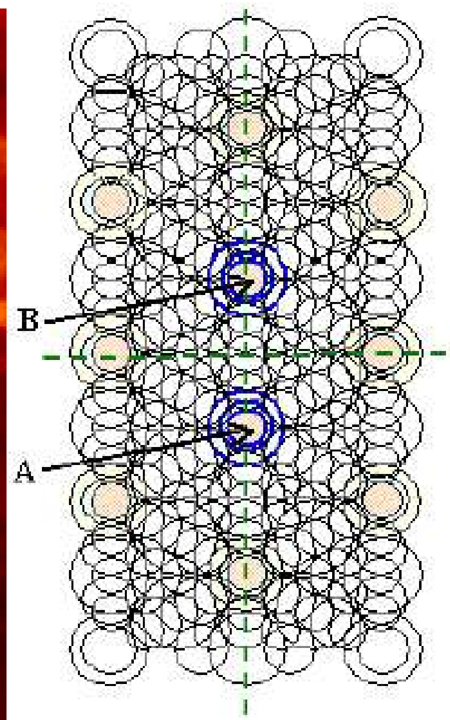
SPIRE Imager





The bolometer arrays (spider-web bol. with Ge-microthermometers)

Photometer observing modes



Point source observation

- ± 63" chop between A and B
- No jiggle (reliable pointing)
- 7-point jiggle (unreliable pointing)

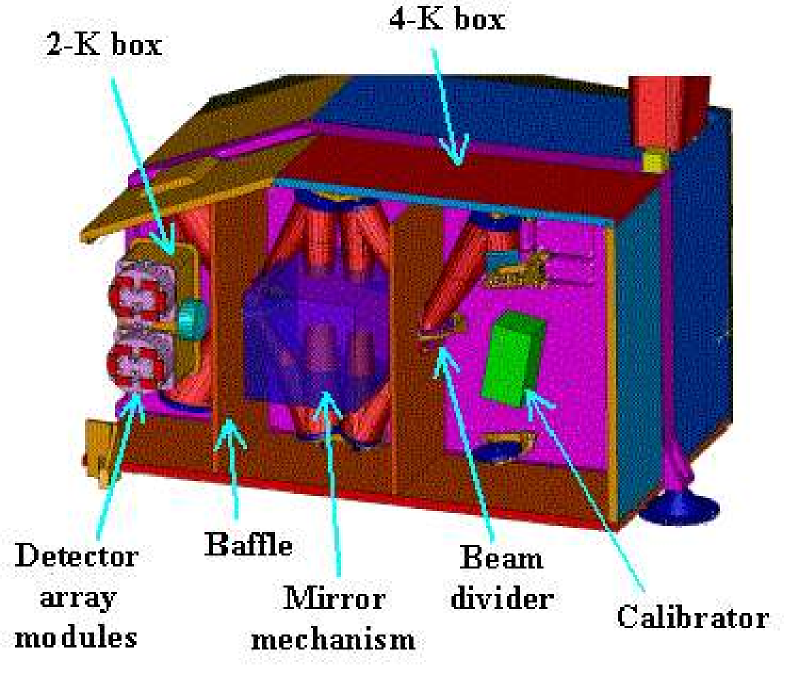
Field map (4 x 4 arcmin.)

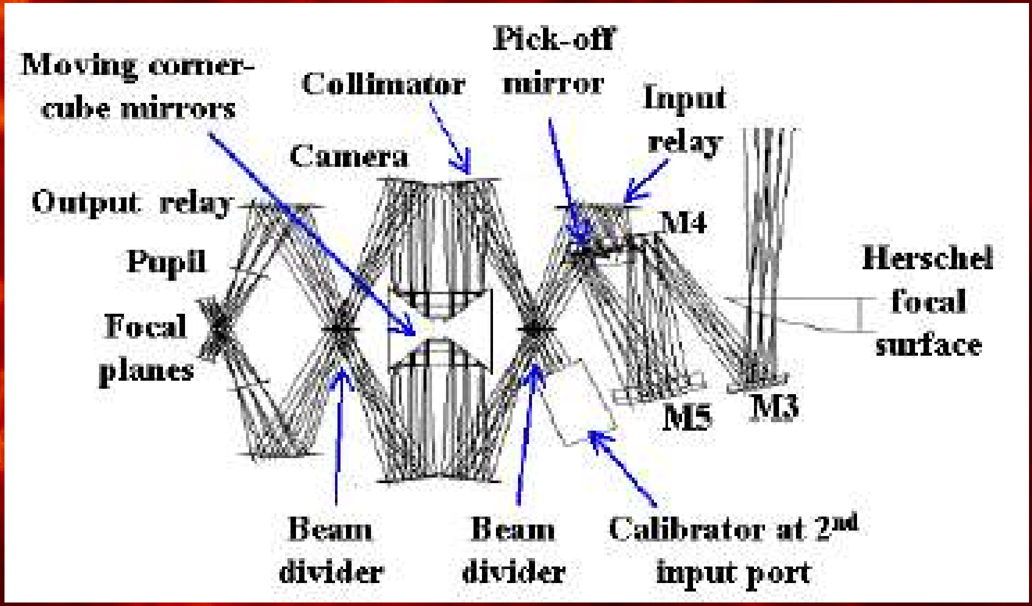
- ± 120" chop
- 64-point jiggle

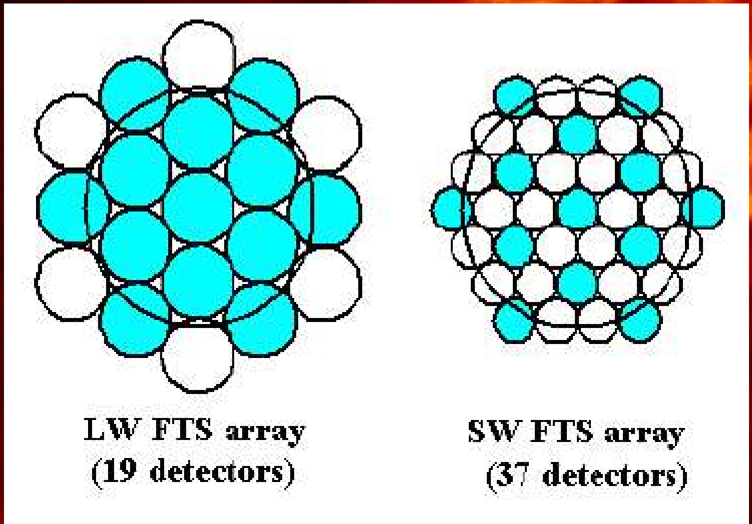
Scan map

- 4 x 8 arcmin. fov
- No chop or jiggle
- Telescope scanned at 14.5° wrt either of the array axes

SPIRE Imaging Spectrometer (highly-optimized 2-band FTS)







300-670 μm 200-300 μm

SPIRE Performance

Item	Assumption
Telescope temperature (K)	80
Telescope used diameter (m)	3.29
Telescope emissivity	0.04
Photometer	
Throughput	λ^2
Bands (μm)	250, 350 and 500
Numbers of detectors	139, 88 and 43
Beam FWHM (arcsec.)	17.4, 24.4 and 34.6
Bolometer DQE	0.6, 0.7 and 0.7
Feed-horn/cavity efficiency	0.70
Field of view (arcmin.)	4 x 8
Overall instrument transmission	0.3
Filter widths ($\lambda/\Delta\lambda$)	3.3
Observing efficiency	0.9
FTS spectrometer	
Nominal bands (μm)	200-300 and 300-670
Numbers of detectors	37, 19
Bolometer DQE	0.65
Feed-horn/cavity efficiency	0.70
Field of view (arcmin.)	2.6
Max. spectral resolution (cm^{-1})	0.04
Overall instrument transmission	0.15
Signal modulation efficiency	0.5
Observing efficiency	0.8
Electrical filter efficiency	0.8

Photometer (mJy, 5σ, 1h)

Band (μm)	250	350	500
Point source	2.5	2.6	2.9
4' x 4' jiggle map	8.8	8.7	9.1
4' x 8' scan map	7.0	6.9	7.2

Spectrometer (5σ, 1h)

Line spectroscopy ($\Delta\sigma = 0.04\ cm^{-1}$)			
Wavelength (μm)	200	400	670
Point source: ($Wm^{-2} \times 10^{-17}$)	3.4	3.9	7.8
Map: ΔS ($Wm^{-2} \times 10^{-17}$)	9.0	10	21
Spectrophotometry ($\Delta\sigma = 1\ cm^{-1}$)			
Wavelength (μm)	200	400	670
Point source (mJy)	110	130	260
Map (mJy)	300	350	700

FIRST - Technical Overview

The FIRST satellite is approximately 7 m high and 4.3 m wide, with a launch mass of around 3.25 tons

- The superfluid liquid helium cryostat is based on ISO technology, providing temperatures down to 1.7 K for the payload.
- The 3.5 m diameter Ritchey-Chrétien telescope will passively cool to around 80 K; it will be provided by NASA.
- Three focal plane science instruments (HIFI, PACS, and SPIRE) inside the cryostat.
- Launch (together with Planck) by Ariane 5 into a transfer trajectory towards the operational orbit around the L2 point, which is located 1.5 million km antisunwards away from the Earth.
- Operation in a pre-programmed mode with only a few hours groundstation contact per day.
- Operational lifetime of minimum 3 years. FIRST potentially offers about 7000 hours of science time per year, it is a multi-user observatory with guaranteed (about 1/3) and open time.

FIRST - Science Instruments

The FIRST payload complement consists of three instruments which will be provided by Principal Investigator (PI) consortia:

HIFI - the Heterodyne Instrument for FIRST (PI: Th. de Graauw, SRON, Groningen, The Netherlands)

- very high resolution heterodyne spectroscopy spanning 480-1250, 1410-1910 and 2400-2700 GHz
- wide-and-narrow-band spectrometers operating in parallel

PACS - the Photoconductor Array Camera and Spectrometer (PI: A. Poglitsch, MPE, Garching, Germany)

- broadband imaging photometry or medium resolution spectroscopy with two 25x16 'bulk' Ge:Ga photoconductor arrays covering 80-130 and 130-210 µm simultaneously, velocity resolution 100-250 km/s and instantaneous 1300-3000 km/s coverage
- point source detection limit ~ 5mJy (5 sigma, 1 hour)

SPIRE - the Spectral and Photometric Imaging REceiver (PI: M.Griffin, QMW, London)

- broadband imaging photometry in 250, 350 and 500 µm bands simultaneously with 32^2, 24^2, and 16^2 pixel arrays covering the same 4'x4' FOV, or low-to-medium spectroscopy with 16^2 (200-300 µm) and 12^2 (300-670 µm) pixel arrays covering a 2'x2' FOV
- bolometer detectors operating at 300mK (dedicated ^{3}He fridge), point source detection limit ~ 3 mJy (5 sigma, 1 hour)

FIRST - Distinctive Features

FIRST is the only space facility covering the far infrared to submillimetre (80 - 670 µm) range.

- Low emissivity (few %), passively cooled to around 80K, large (3.5 m) telescope
- No atmospheric absorbtion - full access to entire spectral range
- No atmospheric emission - low and stable background across whole range
- Deep, wideband photometry and full spectral coverage

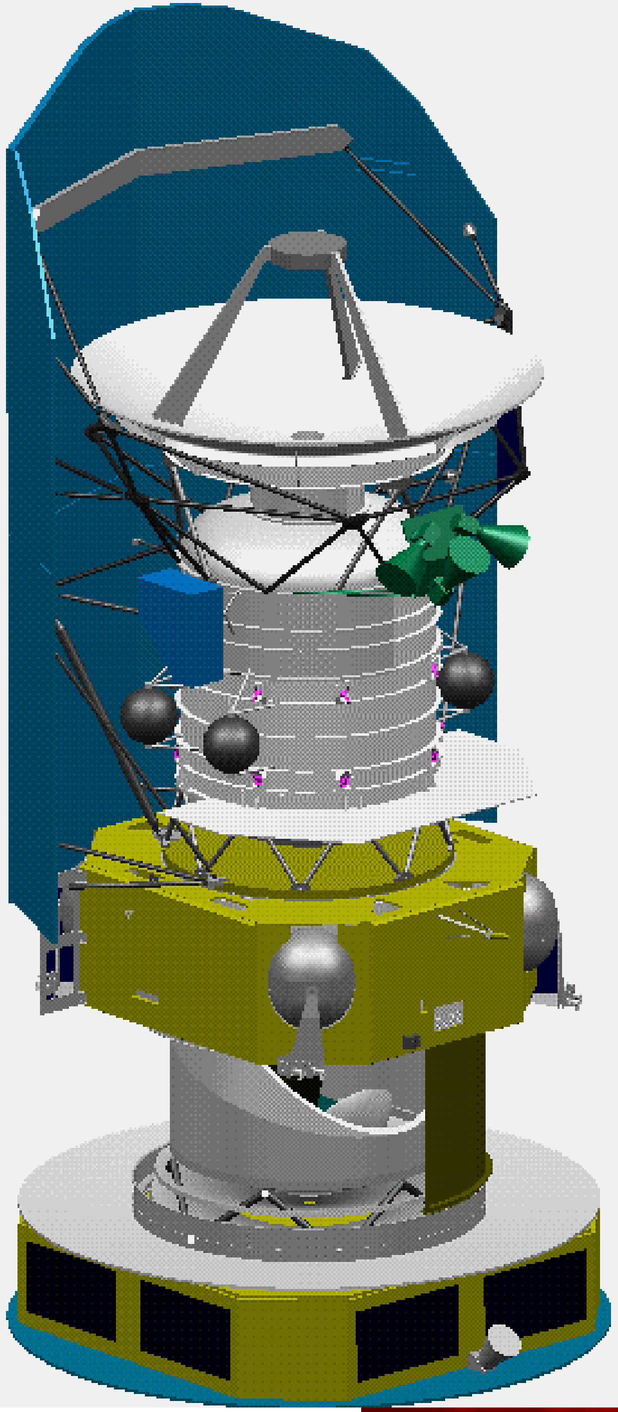
A complementary airborne facility, SOFIA, has a warmer, smaller telescope and must operate in Earth's atmosphere. FIRST will offer observing time equivalent to ~ 1000 SOFIA flights during every year in operation.

FIRST - Mission Status

FIRST will be implemented in parallel with Planck by a common project team.

After studying different concepts, the so-called "carrier" scenario was chosen: FIRST is "carried" by Planck during the launch phase, when the last stage is in a transfer trajectory towards L2 the two spacecraft separate from the each other and the rocket and are operated independently.

FIRST and Planck will be launched in 2007 by an Ariane launcher. The transit time towards L2 will be approximately 4 months; it is expected that commissioning and performance verification will be accomplished en route. Routine science operations for at least 3 years will then follow.



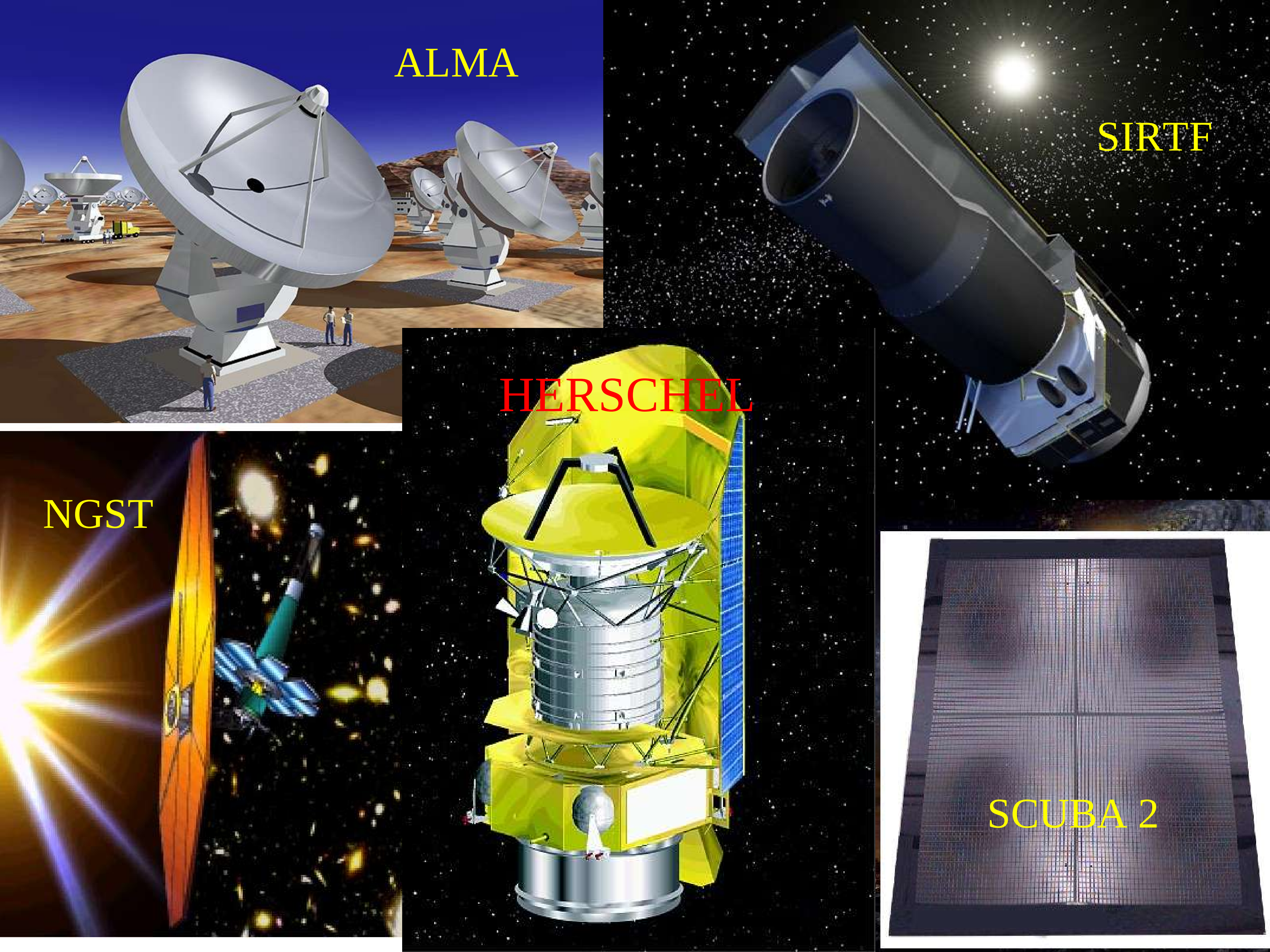
esa ASTROPHYSICS

Herschel Extragalactic Surveys

- General motivation for Herschel was identified long ago in the framework of the worldwide systematic effort undertaken to ***Search for the Origins***, involving most major future space and ground projects (see NASA dedicated program + next-generation observatories such as ALMA, OWL, SKA)

ORIGINS OF →

Large Scale Structure
Galaxies & Quasars
Stellar Populations
Planetary Systems (Life!)


ALMA
SIRTF
HERSCHEL
NGST
SCUBA 2

Herschel as a critical element of this effort

Can select cosmic sources from their bolometric emission over an extremely wide redshift interval

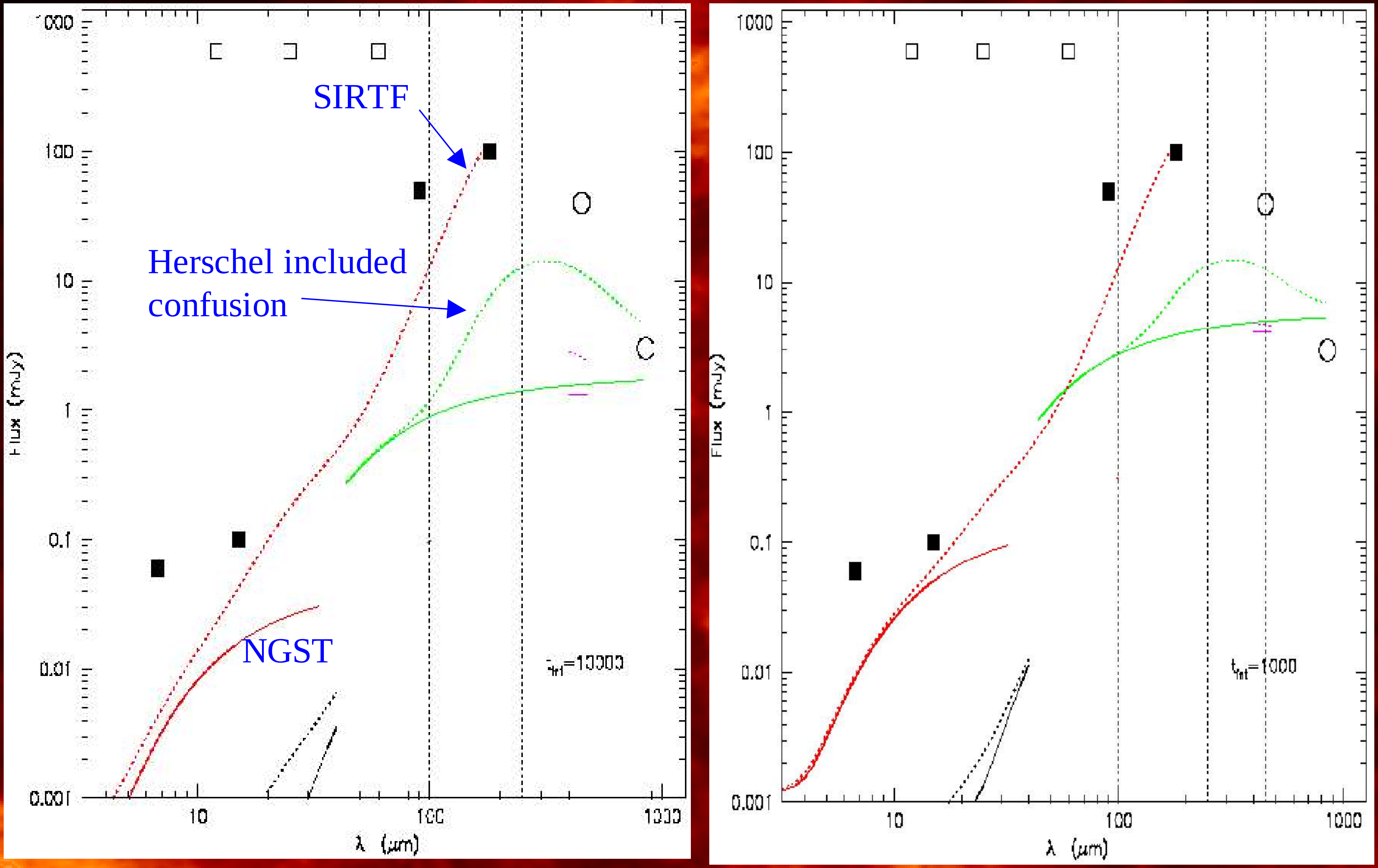
(overcoming the limitations of optical cosmological surveys such as K-correction and limited spectral coverage, sampling the ISM)

The most efficient and unbiased way to select the **active phases in galaxy evolution** : surveys at 100 - 300 μm (PACS + SPIRE)

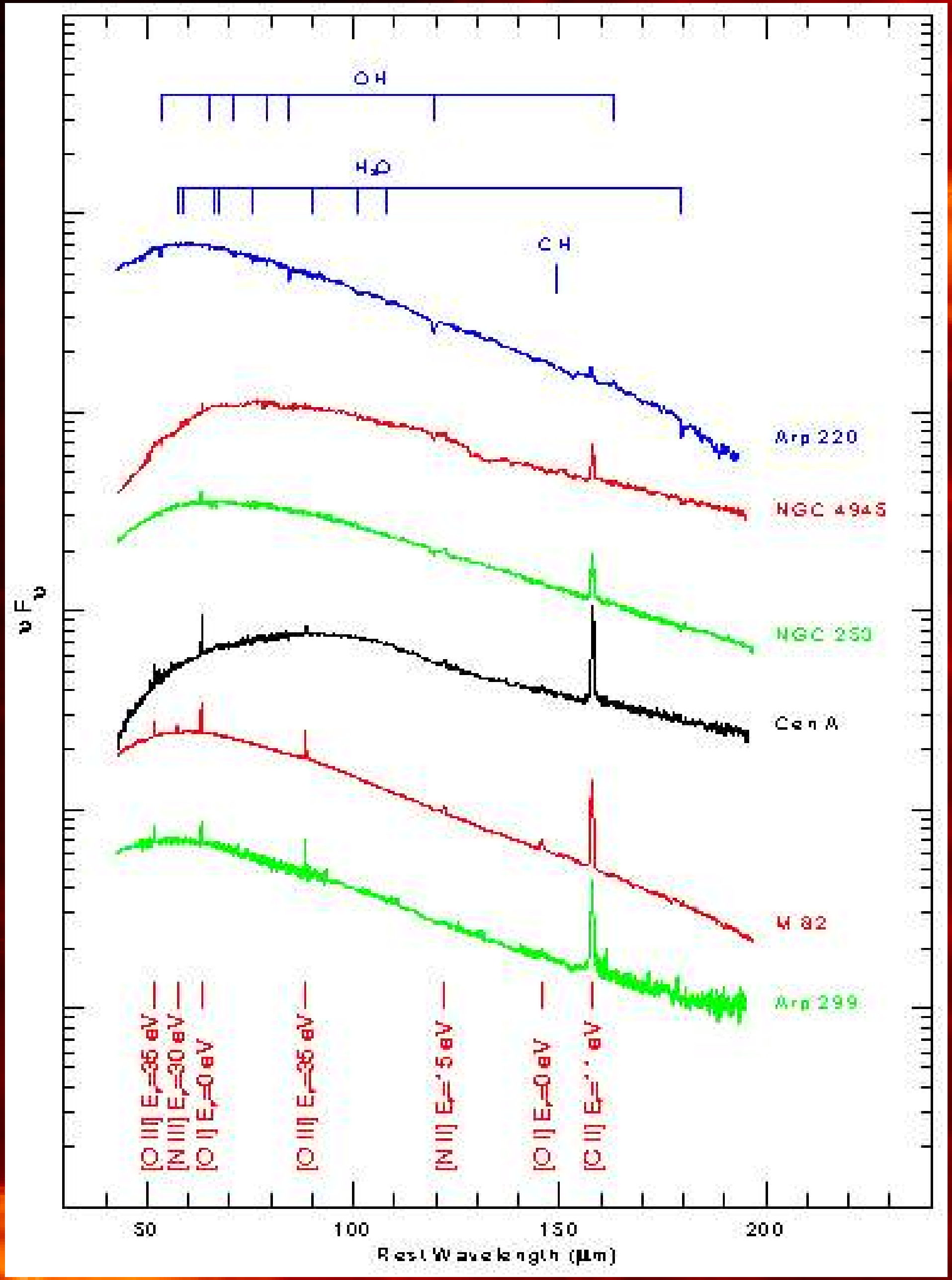
Although conceived long ago, Herschel keeps unique features among existing projects to sample the peak of dust emission with enough spatial resolution

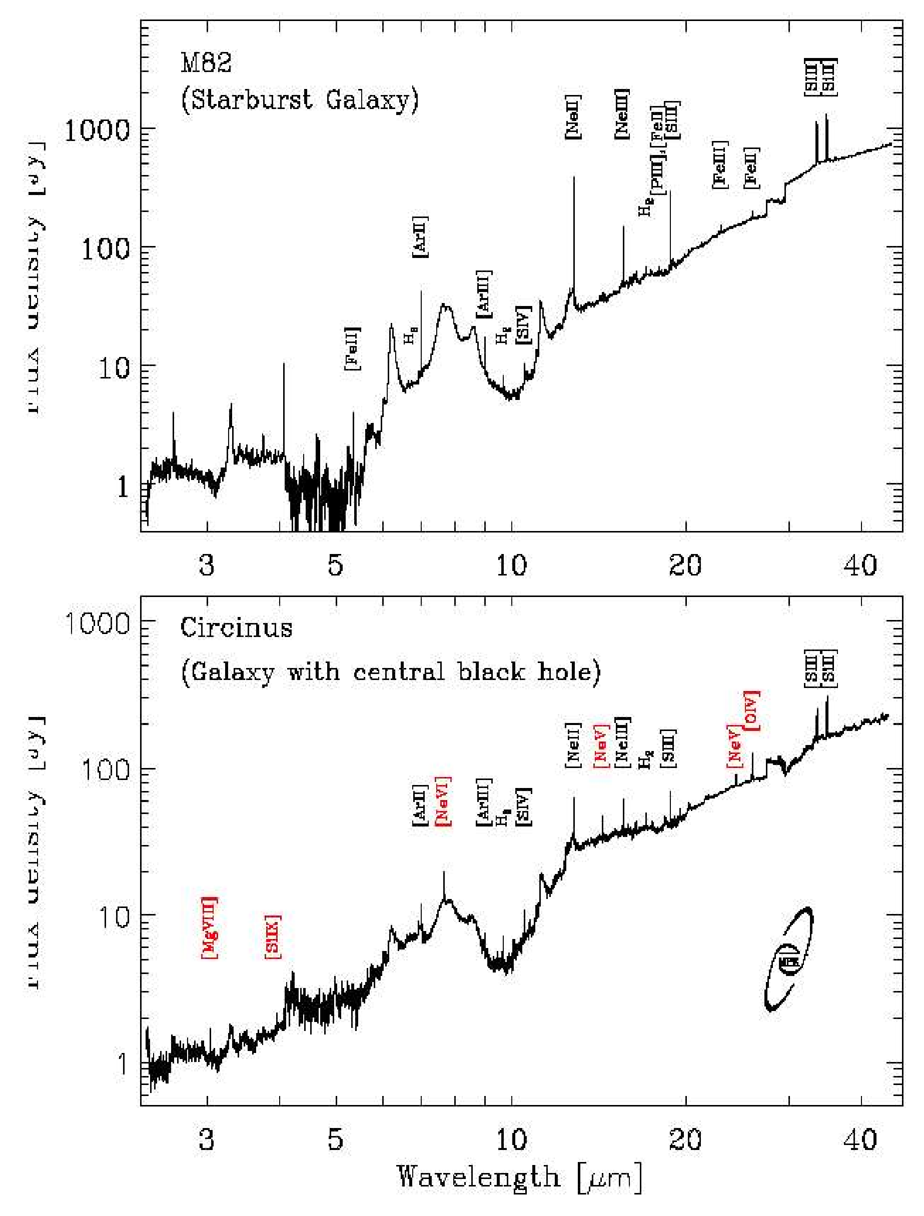
Deep "cosmological" imaging surveys (+ spectroscopic follow-up of significant sub-samples of detected sources) over large sky areas are among the main motivations for PACS & SPIRE and for the mission itself

The Herschel Window



Herschel spectroscopy of long-λ ionic lines





Fischer 2000

OPEN ISSUES TO BE ADDRESSED BY HERSCHEL EXTRAGALACTIC SURVEYS

- BASICALLY, THEY WILL ALLOW TO ***MEASURE*** THE BOLOMETRIC EMISSION BY DISTANT GALAXIES IN A COMPLETELY UNBIASED WAY

- **NATURE OF IR EMISSION BY FAINT IR SOURCES AND ORIGIN OF CIRB: STARBURSTS OR AGNS ?**

- **ORIGIN OF SPHEROIDAL GALAXIES**

- **ONSET OF QUASARS**

- **LARGE SCALE STRUCTURE**

- **HOW MUCH FIR OBSERVATIONS ARE NEEDED TO TRACE THE ACTIVE PHASE ?**

ISO SURVEYS

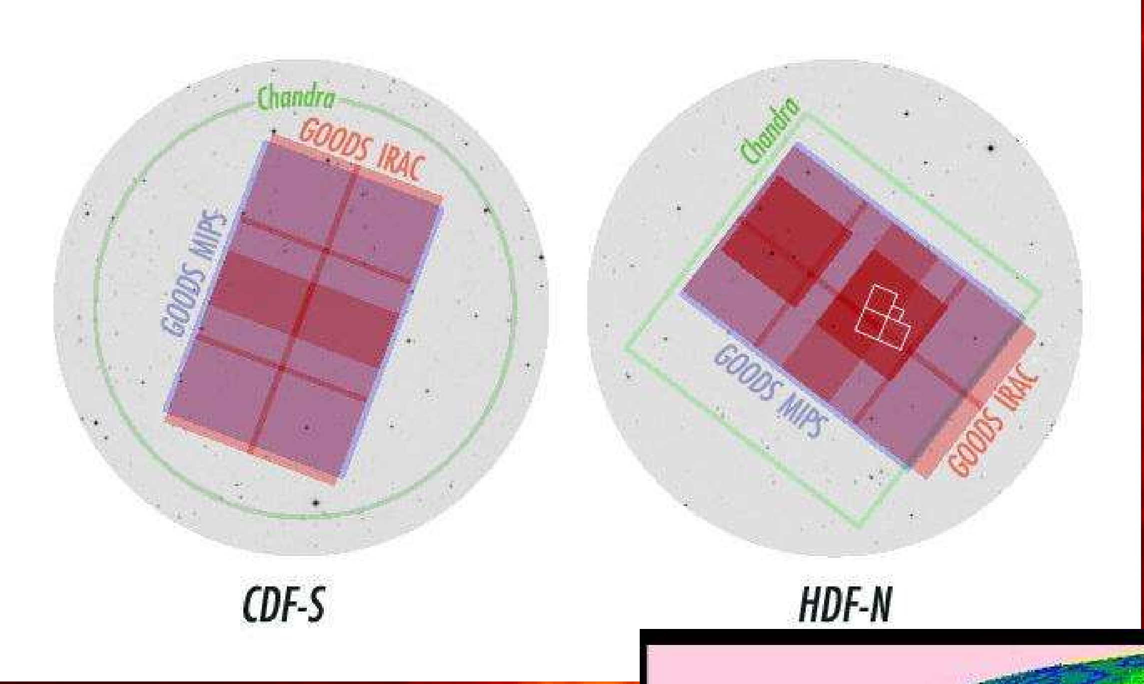
Name	λ (μm)	Integration (s)	Area (deg²)
PHT Serendipity	175	0.5	7000
CAM Parallel	7, 15, 90, 175	40, 40, 24, 128	6, 11, 12, 1
ELAIS	7, 15, 90, 175	40, 40, 24, 128	6, 11, 12, 1
CAM Shallow	15	180	1.3
FIRBACK	175	256, 128	1, 3
IR Back	90, 135, 175	23, 27, 27	1, 1, 1
SA 57	60, 90	150, 50	0.42, 0.42
CAM Deep	7, 15, 90	800, 990, 144	0.28, 0.28, 0.28
Comet Fields	12	302	0.11
CFRS	7, 15, 60, 90	720, 1000, 3000, 3000	0.067, 0.067, 0.067, 0.067
CAM Ultra Deep	7	3520	0.013
ISOHDF South	7, 15	> 6400, > 6400	0.0047, 0.0047
Deep SSA13	7	34000	0.0025
Deep Lockman	7, 90, 175	44640, 48, 128	0.0025, 1.2, 1
ISOHDF North	7, 15	12800, 6400	0.0014, 0.0042

SIRTF LEGACY SCIENCE PROGRAM

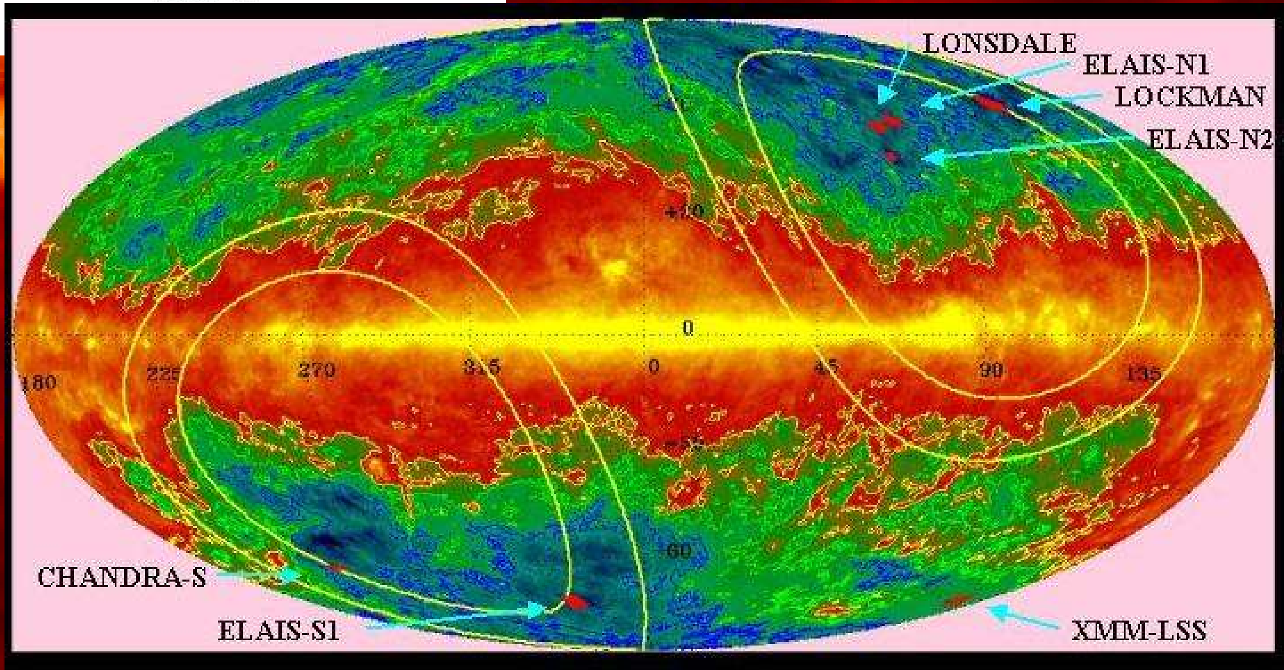
Program Name	Time	PI
GLIMPSE (Galactic Plane)	400h	Churchwell
GOODS (Ultra Deep EG Survey)	647h	Dickinson
Molecular Clouds & Planetary Disks	400h	Evans
SINGS (Nearby Galaxies ISM)	512h	Kennicutt
SWIRE (Deep EG Survey)	851h	Lonsdale
Planetary Systems	350h	Meyer

About 50 % of the allocated observing time will be devoted to GOODS and SWIRE cosmological surveys

GOODS vs. SWIRE



3.6, 4.5, 5.8, 8.0 (+ 24 ?) μm on 300 arcmin² / 2 fields



3.6, 4.5, 5.8, 8.0, 24, 70, 160 μm on 70 deg² / 7 fields

ISO+SIRTF-RELATED ITALIAN CONTRIBUTION/EXPERTISE

- Post-Mission Data Reduction
  - LARI Method
  - ELAIS Shallow Fields at 15 and 90 μm
  - Deep Fields (LH, HDFs, CAM ELAIS N1 UltraDeep)
- Multi-Wavelength Follow-Up
  - Radio (ELAIS + LH + Marano)
  - NIR (JHK in ELAIS)
  - Optical (BVRIZ in ELAIS)
  - X-rays (XMM in ELAIS)
  - Spectroscopy of IR-selected sub-samples

HERSCHEL SURVEYS

- Dedicated panel discussion at Toledo ESA Symposium in Dec. 2000 (Proceedings available at Herschel web page)
- Baseline: Herschel will be the ONLY space mission observing large areas at FIR λs with ground-like imaging quality in the next 15-20 years. This leads to:
- - Detection of the bulk of dust emission from high-z sources
- - Resolution of most long-λ CIRB before confusion sets in
- - Bolometric luminosities and thus evolutionary properties
- - Active phases of galaxy evolution along cosmic history
- PACS and SPIRE are both suited to cover large areas, albeit with a different (PACS's < SPIRE's, both TBD) mapping speed ⇨ PACS/SPIRE multi-λ mapping
- The issue of large-area survey (Key vs. Legacy) programs data policy is closely related to Science Management Plan

SURVEY TYPES

Unbiased "proper" surveys of "blank" fields

&

Deep integrations on pre-selected high-z targets

IN BOTH CASES

PACS + SPIRE coverage is highly desirable

BUT

PACS higher resolution will bring along deeper observations and smaller error boxes but lower mapping speed

↓

PACS survey areas as subsets of SPIRE's?

UNBIASED SURVEYS: OPTIONS

- Confusion will severely limit the Depth-Area plane coverage (e.g. no GOODS-like survey)
- Built-in simultaneous observations at different λs
- Low cirrus emission, no known bright sources...
- Observing areas not covered at some (many) other wavelength(s) would be of little use
- SWIRE fields are most natural and straightforward (thus highly competitive!) choice

PACS + SPIRE SURVEYS

- Two SPIRE survey strategies employing ~ *2 months* each were identified in Toledo:
  - A deep survey reaching down to SPIRE confusion limit (~ 10 mJy) over a total area of ~ 50 deg²
  - A shallower survey (~ 50 mJy) over ~ 500 deg², thus looking for intrinsically rare and bright objects (for e.g. ALMA follow-up)
- The prospect of deep surveys by PLANCK with an optimistic sensitivity limit of ~100 mJy at 350 and 550 ? m may indicate the second as a lower priority task?
- PACS could reach ~ 10 mJy over ~ 20 deg² in ~ *2 months*, i.e. with a 4-month two-consortia PACS+SPIRE program!
- Smaller (possibly "national") programs must be carefully devised and planned in order to be competitive!

At the almost-common wavelength of 200 μm

- PACS Mapping Speed: 1/12 deg²/day at 5 mJy (5σ)
  1/3 deg²/day at 10 mJy (5σ)
  4/3 deg²/day at 20 mJy (5σ)

- SPIRE Mapping Speed: ~ 1 deg²/day at 10-20 mJ y (5σ)
  10 deg²/day at 50 mJy (5σ)

Comparable mapping speeds at about the same λ!

??? Uncertainties in the estimation ???