Space Infrared Extragalactic Surveys

Results from ISO and Future Prospects

Mattia Vaccari

Tesi di Dottorato di Ricerca in Scienze e Tecnologie Spaziali
XVI Ciclo
CISAS “G. Colombo” - Università di Padova

Padova - 21 Maggio 2004

What's it all about? - Thesis Framework

SPACE - INFRARED - EXTRAGALACTIC - SURVEYS

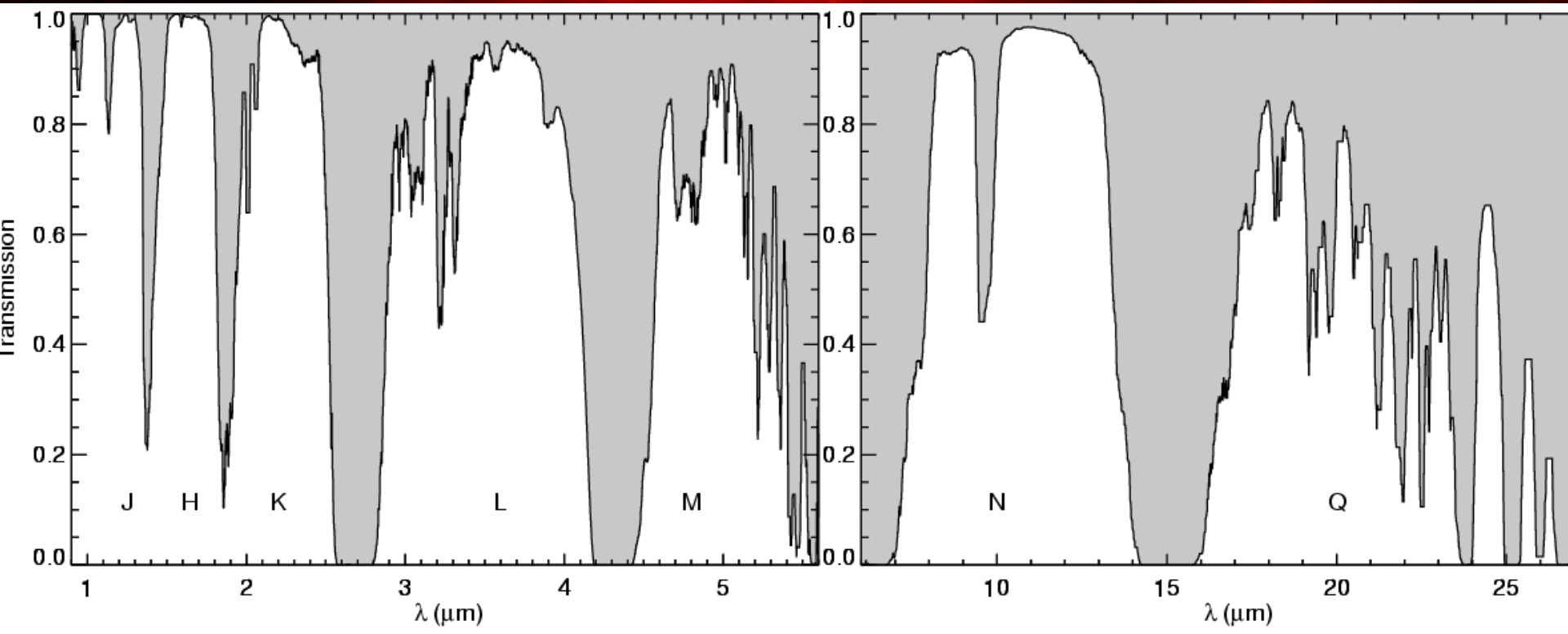
1) SPACE : above the Earth's atmosphere

2) INFRARED : wavelengths approximately from 1 to 300 μm

3) EXTRAGALACTIC : looking for “objects” outside our Galaxy

4) SURVEYS : large and coordinated sets of observations

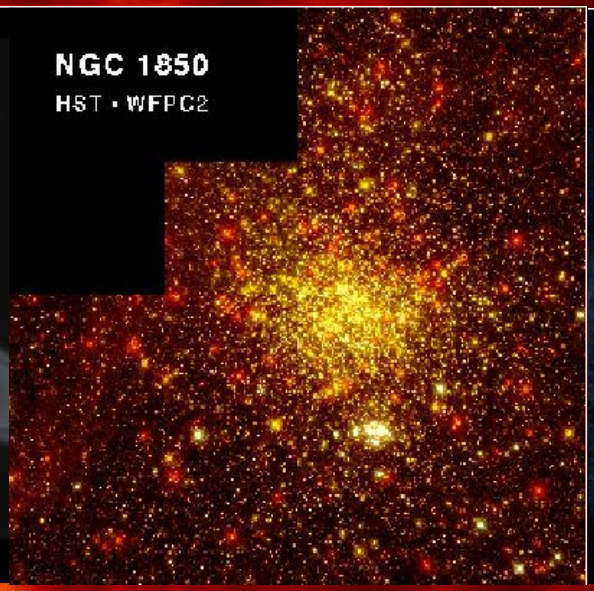
1) SPACE : Atmosphere and Infrared



Atmospheric transmittance in the Near- and Mid-Infrared

Even in high-trasmittance regions, atmospheric and telescope emission make sensitive observations extremely difficult to perform

2) Infrared : the Young, Cold and Dusty Universe



Probe regions and times where Planets, Stars and Galaxies form

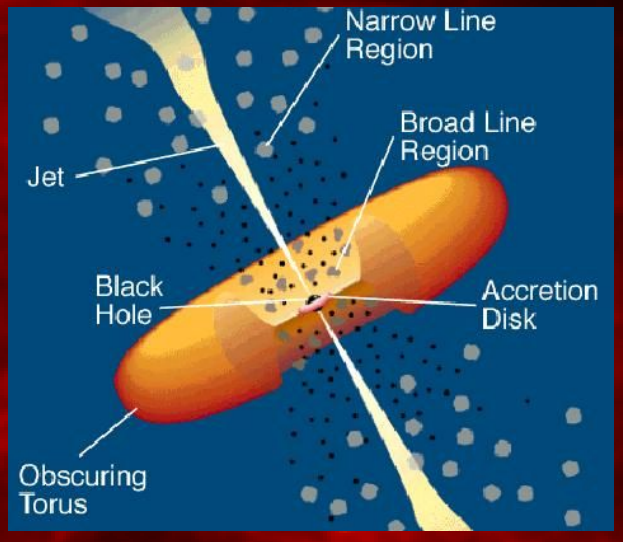
Cold temperatures, dust and “redshift” call for infrared observations

A key element in the ambitious “Search for the Origins”

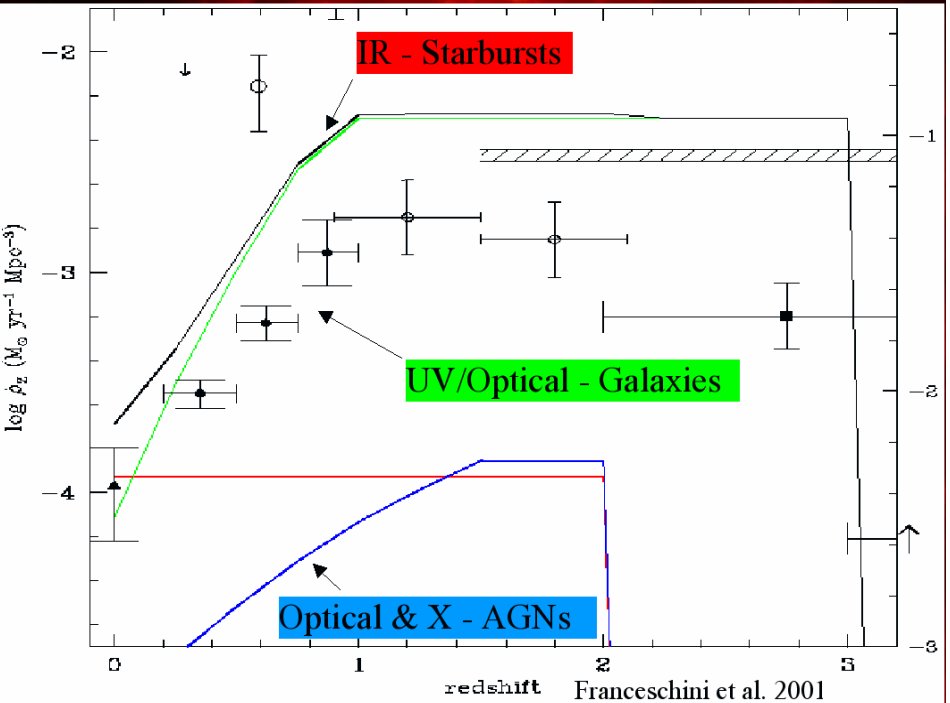
Emphasis of current space astronomy on infrared missions

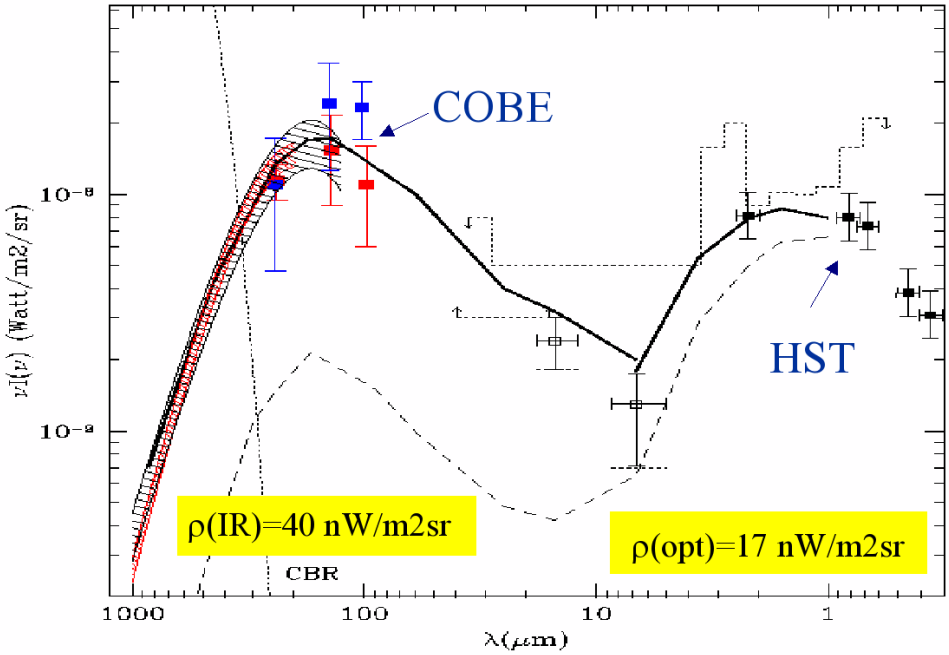
3) Extragalactic : Galaxies and the Universe

- Starlight Obscuration by Dust
- Star Formation vs. Black Hole Accretion
- Galaxy Formation and Evolution
- Cosmic Star Formation History
- Cosmic Background Radiation



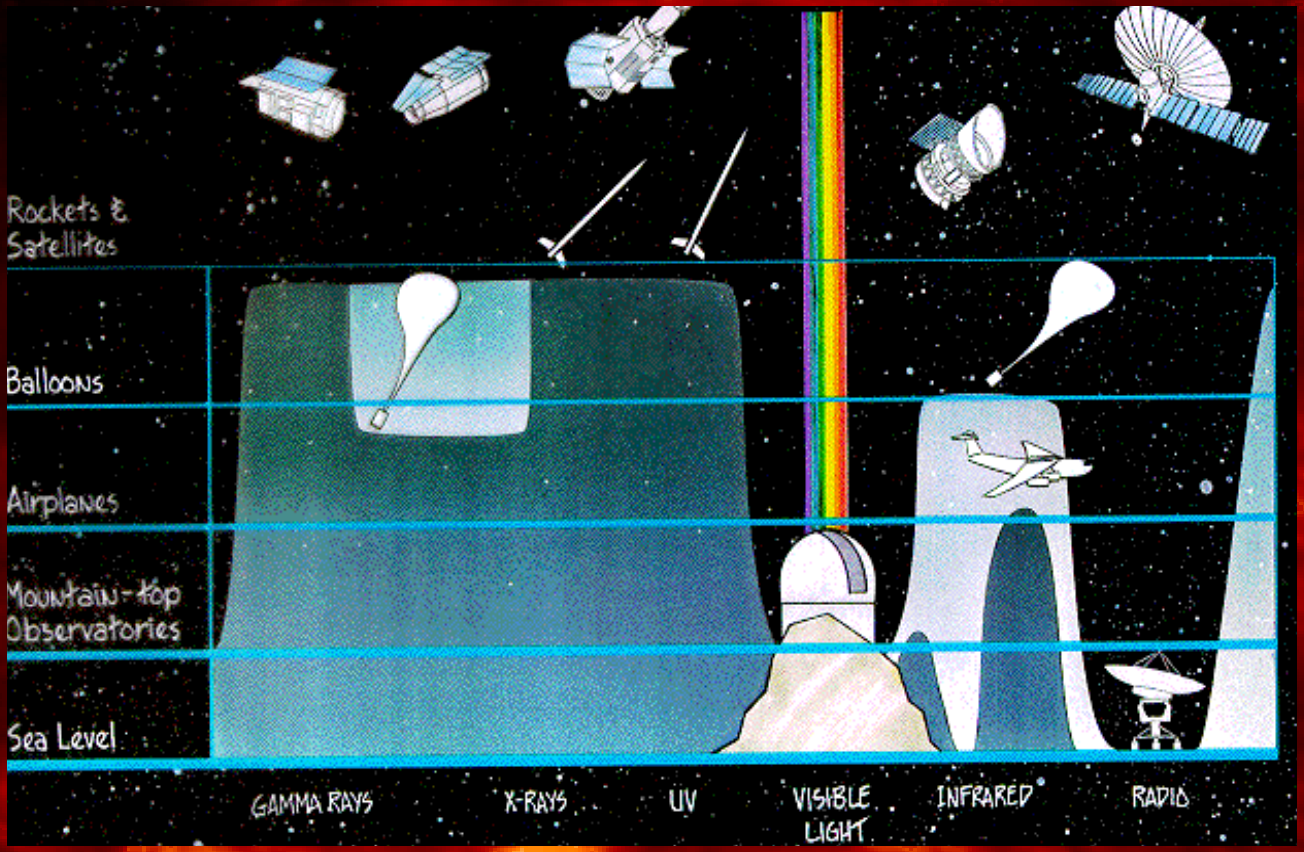
Comoving Star Formation Rate Density





The Infrared and Optical Background Radiations

4) Surveys : The Era of "Big Science"



Increasing complexity and budget limitations led to a new long-term strategy of fewer large (mostly international) space science projects

Advent of space observatories covering various portions of the electromagnetic spectrum mean that data are less important in their own right than as an element of a multi-wavelength approach

What's in it? - Thesis Structure

- "Case Study" : ISO, its Imaging Observations and the ELAIS Project
  - Method : The LARI Method and related Techniques and Tools
  - Data Reduction and Analysis : ELAIS 15 μm Final Analysis
  - Multi-Wavelength Identification of ELAIS 15 μm Sources
  - ELAIS Band-Merged Catalogue
  - Early Scientific Results
  - Future Work : ELAIS Follow-Up, Spitzer, Herschel and Beyond

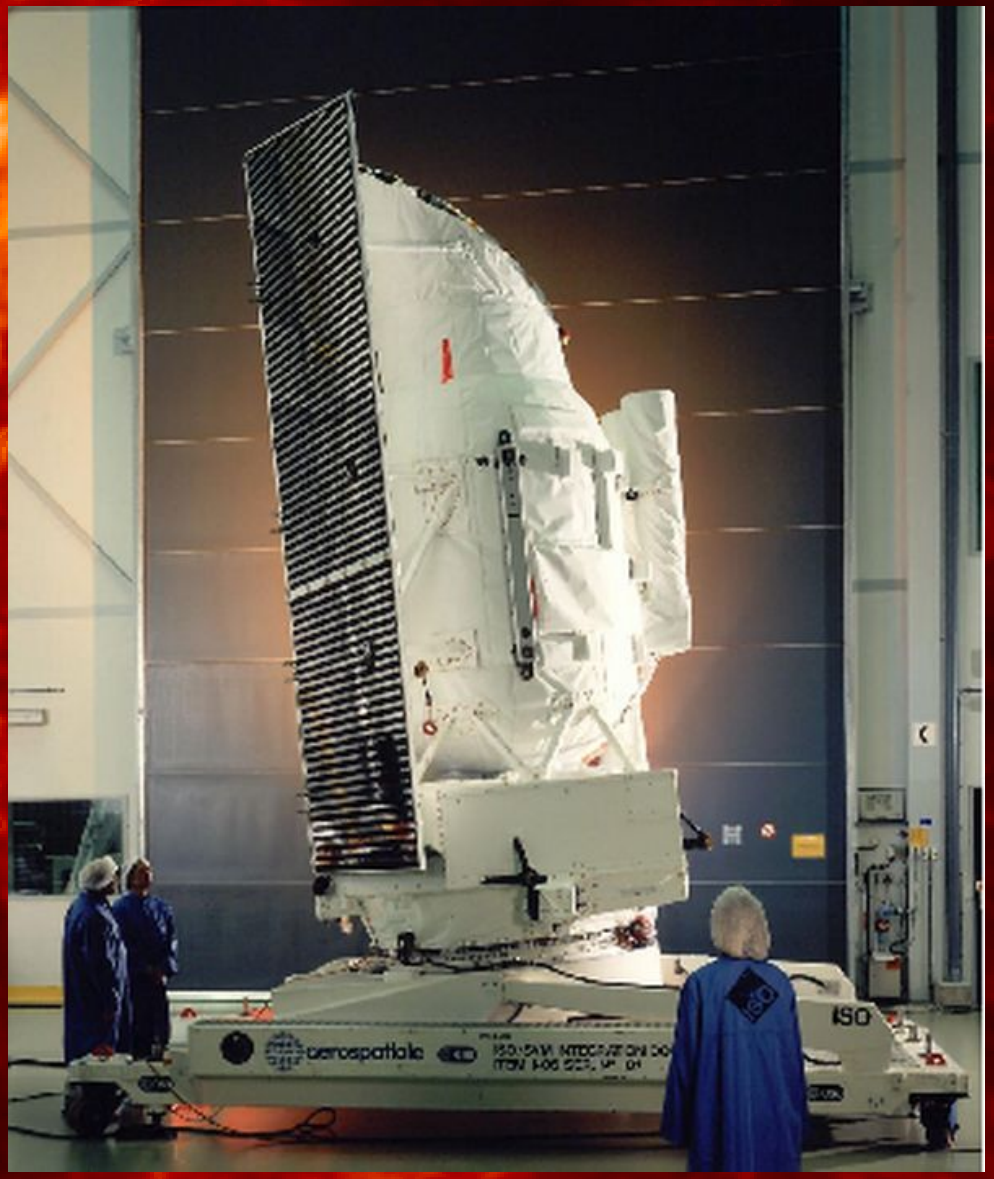
ISO : The Infrared Space Observatory

- The first space infrared "observatory" ever

- Imaging and spectroscopy between 2 and 200 μm

- Nearly-all-ESA mission

- Operated in 1995-1998



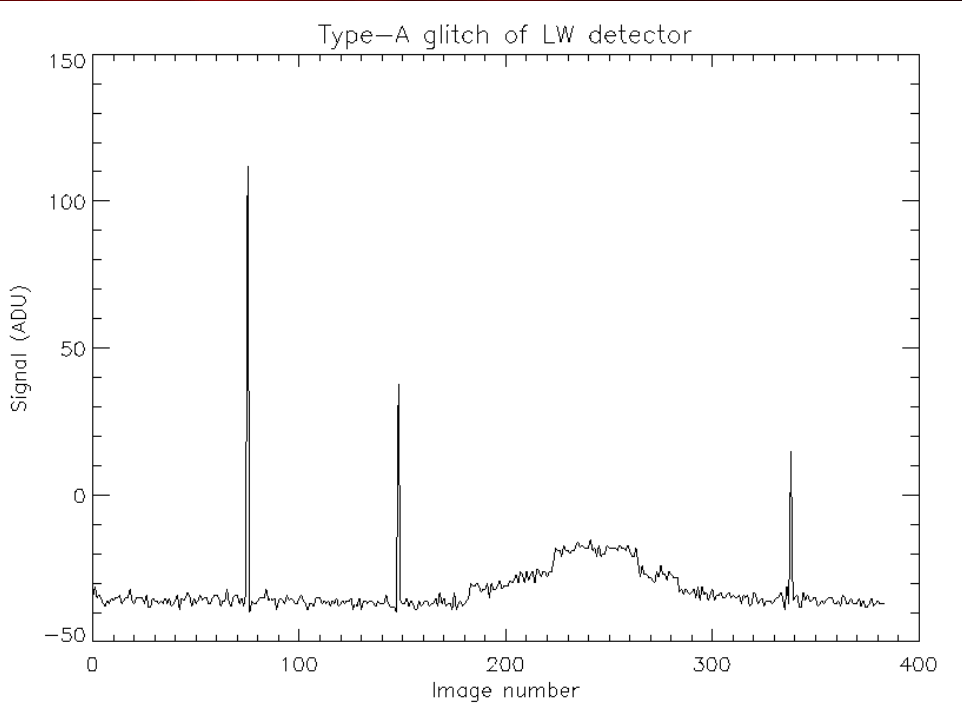
ISO Imaging Data and The LARI Method

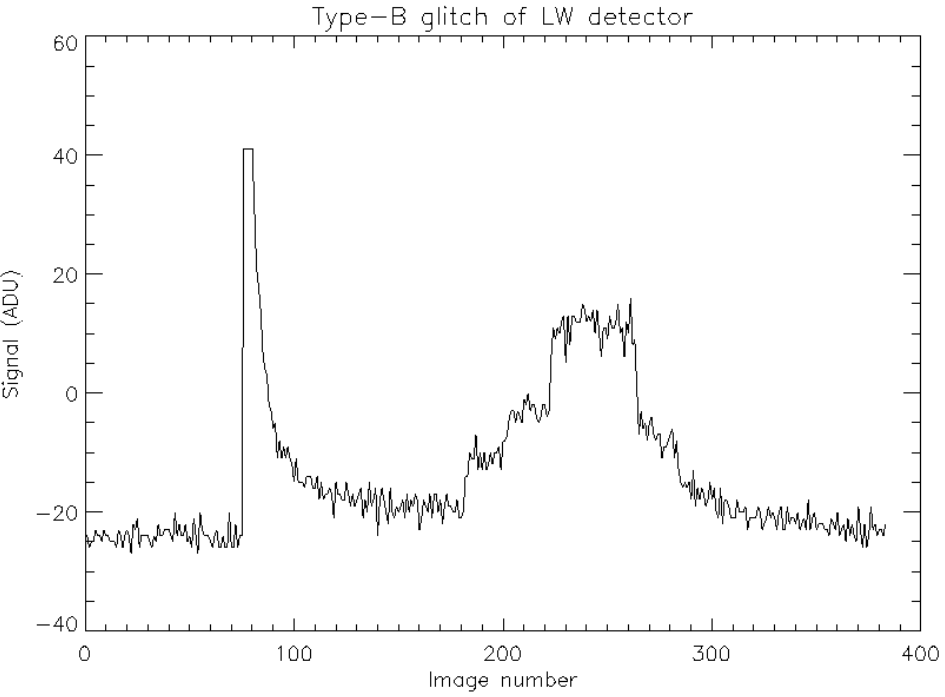
- The LARI Method was developed to overcome the main difficulties affecting ISO-CAM/PHOT imaging data:
  - Poor spatial sampling and redundancy
  - Sizeable transient behaviour after a flux change
  - Cosmic ray hits and "glitches"

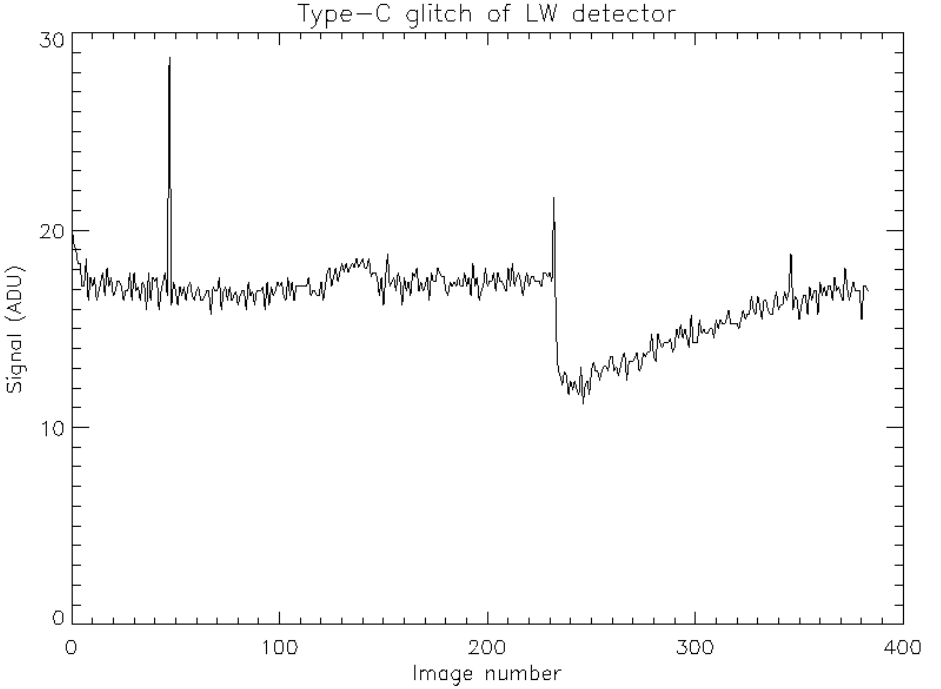
- These severe issues make the use of conventional imaging data reduction techniques unpractical and rather call for a sequential procedure consisting in:
  - the individual treatment of the "time history" of each pixel, in order to model the effects of transients and glitches
  - the determination of pixel-per-pixel and pointing-per-pointing flux excesses ascribable to potential sources
  - the projection of flux excesses onto the sky as a map

Glitches

Cosmic ray impacts on ISO detectors spawned a whole "zoology" of features of various shapes and strengths







Mathematical Model for Charge Release

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

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

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

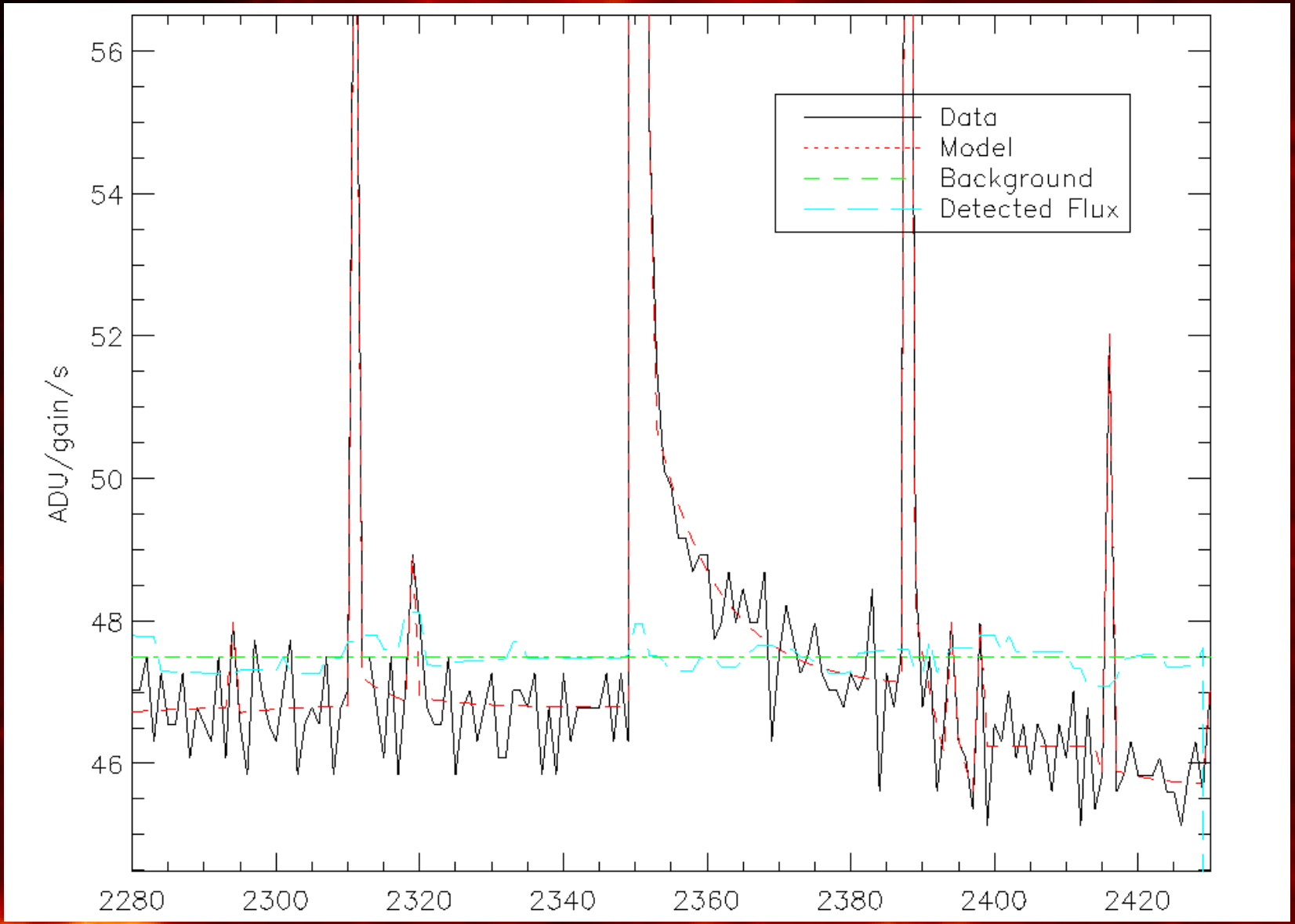
***S* = Signal *I* = Incident Flux *Q* = Accumulated Charge**

Completely conservative model

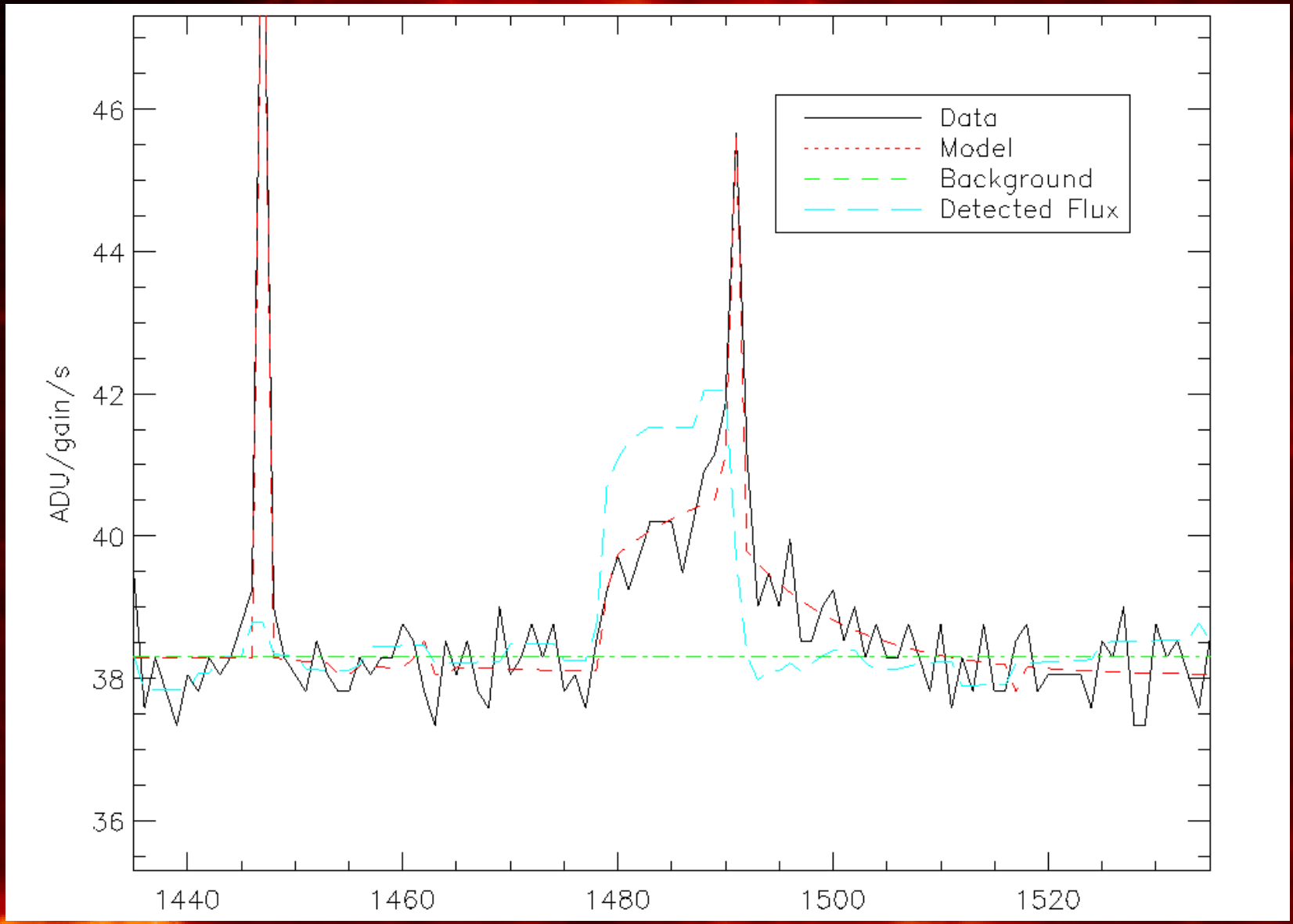
Charge is released with two different time scales

Glitches as discontinuities in charge release

Pixel Time History Fitting : Glitches



Pixel Time History Fitting : Sources



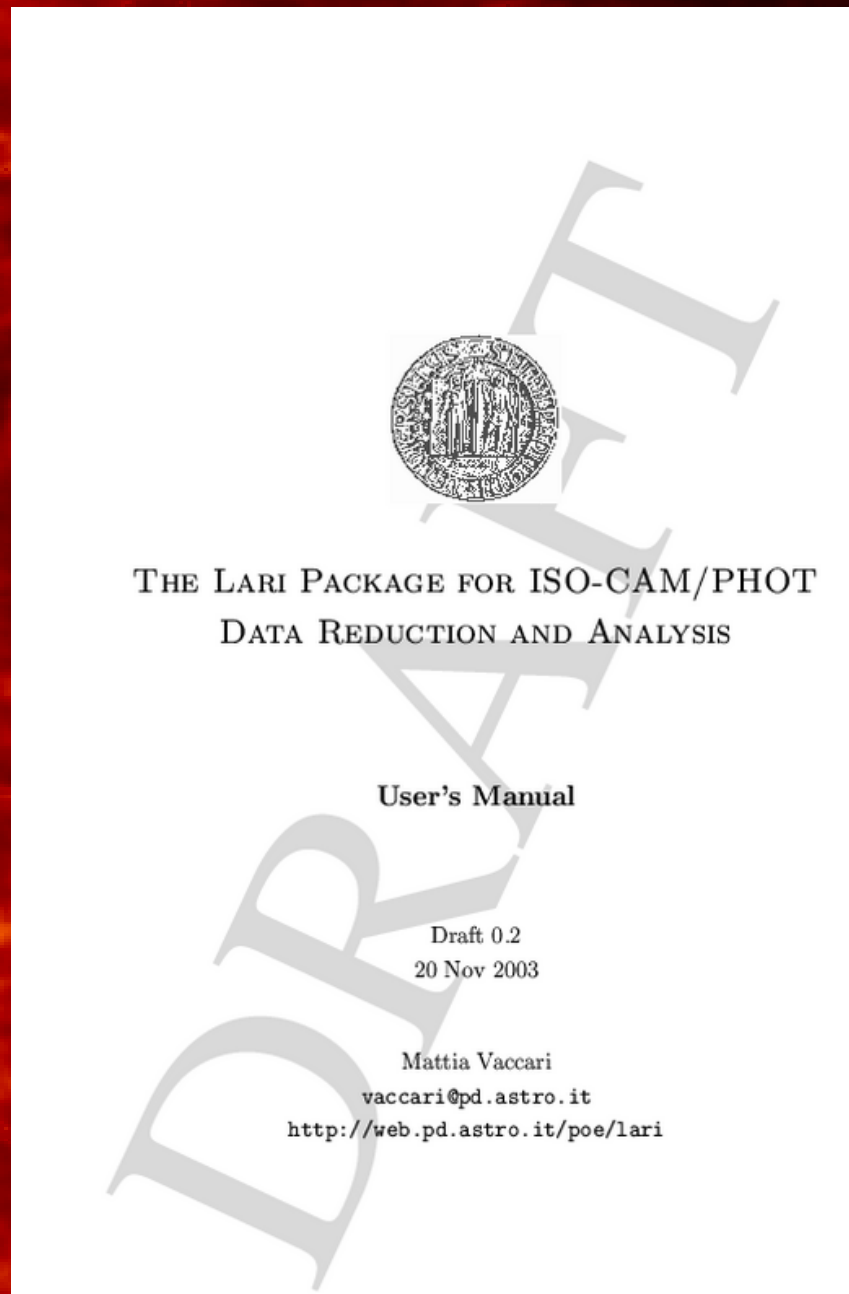
IDL Developed Programs

- Raw data import 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 for performance evaluation
  - Astrometric and Photometric Accuracy
  - Reliability and Completeness

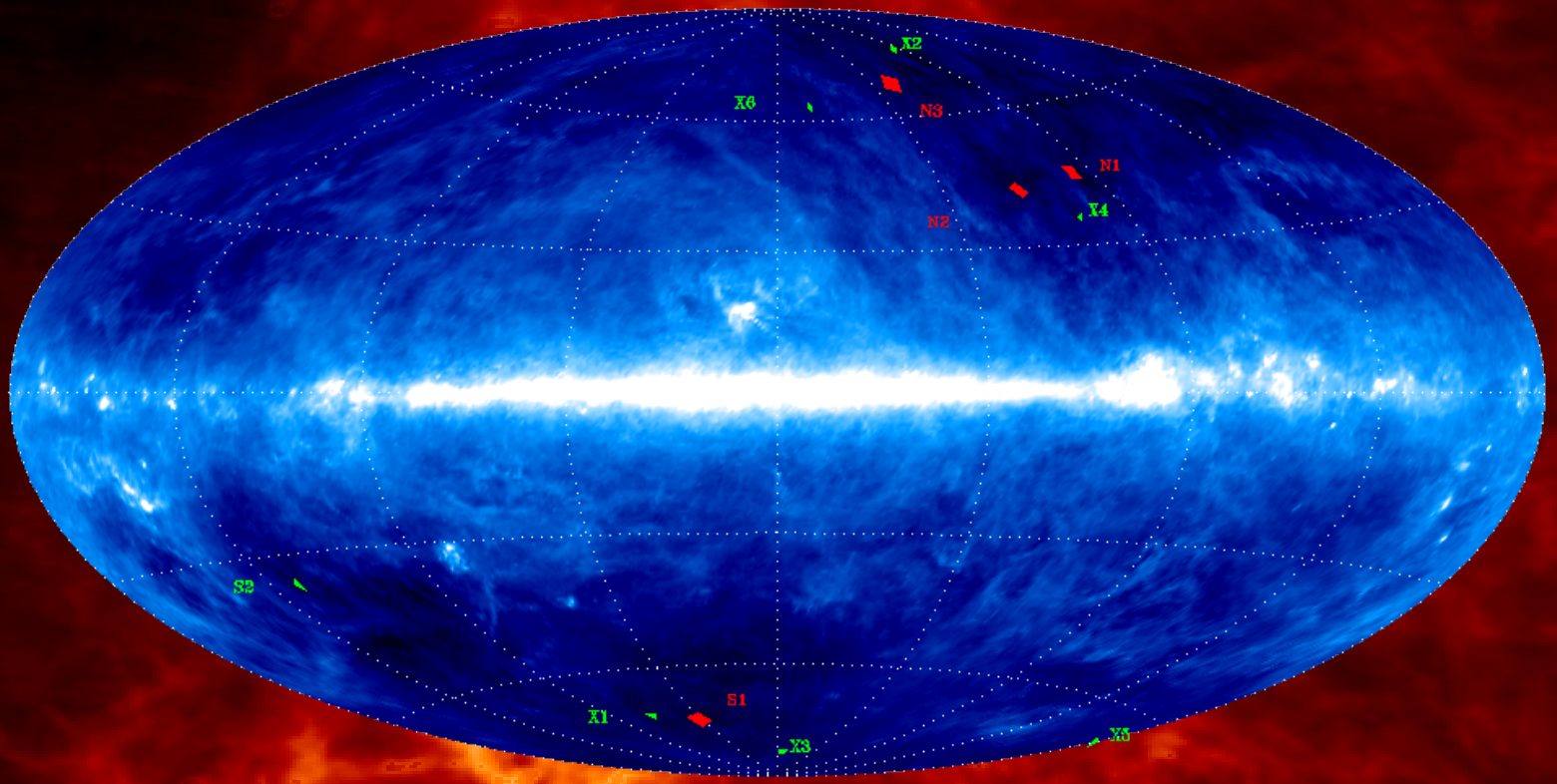
The LARI Package

- Package
  - all ISO-CAM software used in ELAIS 15 μm Final Analysis
  - extensively commented
  - fully documented
  - variously upgradable but already usable in its present form

- User's Manual
  - package contents
  - package installation
  - software use
  - data reduction examples
  - software testing and performance



ELAIS : The European Large Area ISO Survey



The largest project carried out by ISO with ~375 h of observing time

~ 10 deg² observed at 15 and 90 μm, 5 deg² at 7 and 1 deg² at 175 μm

4 high-latitude low-background blank fields (N1, N2, N3 and S1)

Extensive multi-wavelength coverage by present and future telescopes

ELAIS within ISO Extragalactic Surveys

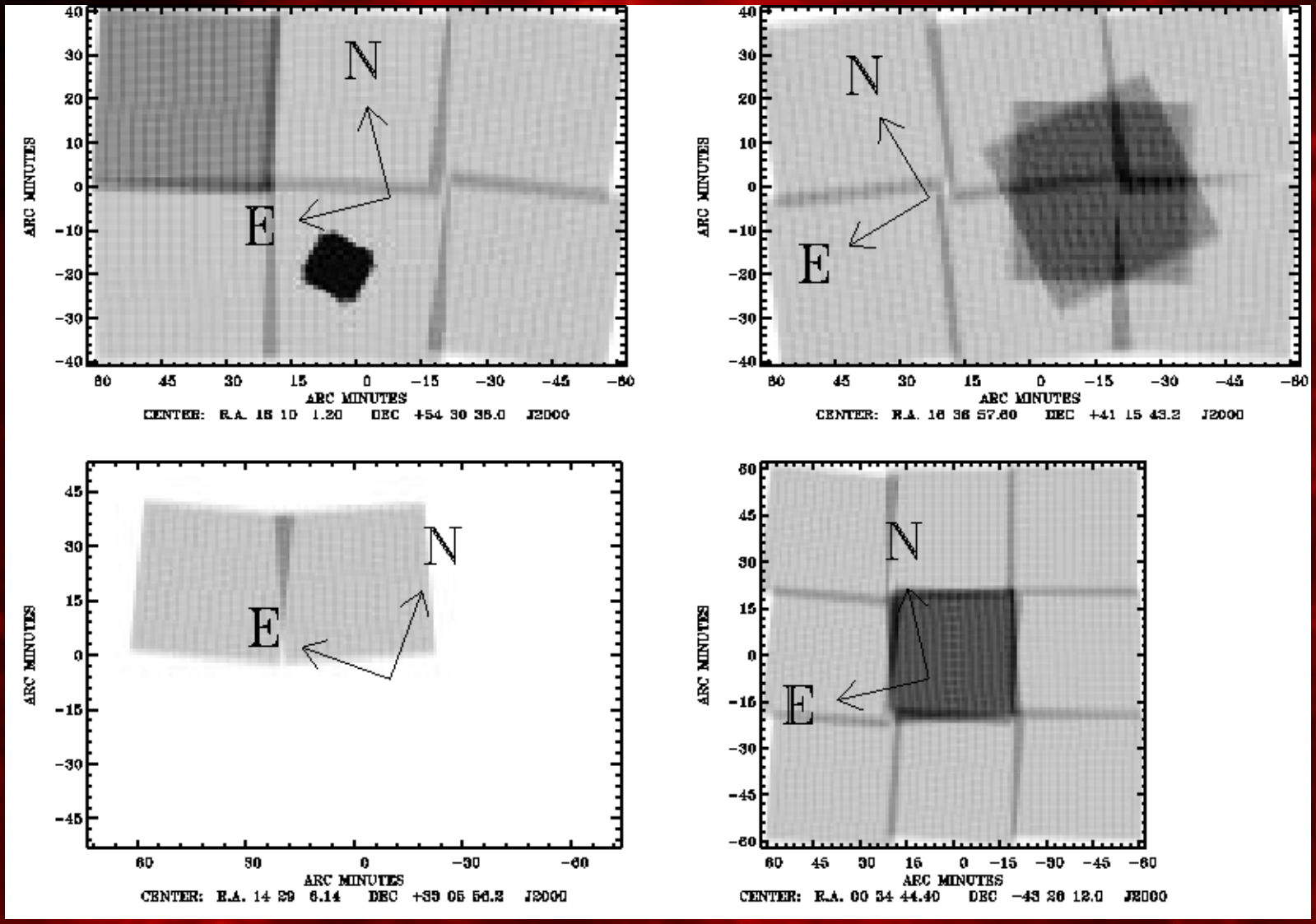
Name	λ (μm)	Integration (s)	Area (deg²)
PHT Serendipity	175	0.5	7000
CAM Parallel	7	150	33
ELAIS	7, 15, 90, 175	40, 40, 24, 128	6, 11, 12, 1
CAM Shallow	15	180	1.3
FIRBACK	175	256, 128	1, 3
IR Back	90, 135, 175	23, 27, 27	1, 1, 1
SA 57	60, 90	150, 50	0.42, 0.42
CAM Deep	7, 15, 90	800, 990, 144	0.28, 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 UltraDeep	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

ELAIS Scientific Case

- Cosmic Star Formation History
- Cosmic Infrared Background
- Ultra Luminous Infrared Galaxies at High Redshift
- Emission from Dust Tori around AGN
- Dust in Normal Galaxies to Cosmological Distance
- Circumstellar Dust Emission from Galactic Halo Stars
- New Classes of Galactic and Extragalactic Objects

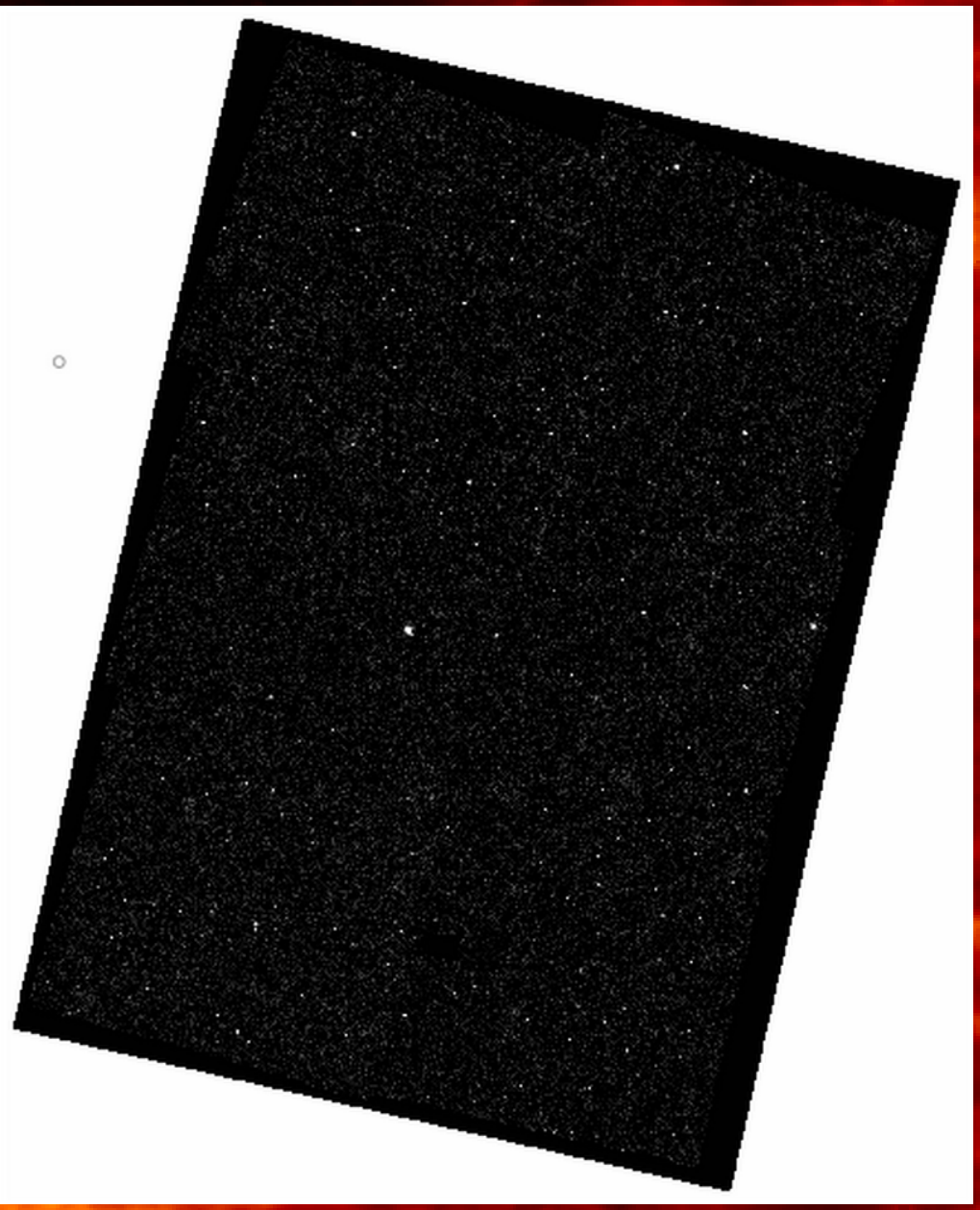
15 μm observations are particularly valuable to explore the phenomenon of galaxy activity and its evolution with redshift because combination of larger observing area and higher sensitivity with respect to other filters yields statistically significant samples

Final Analysis of ELAIS 15 μm Observations



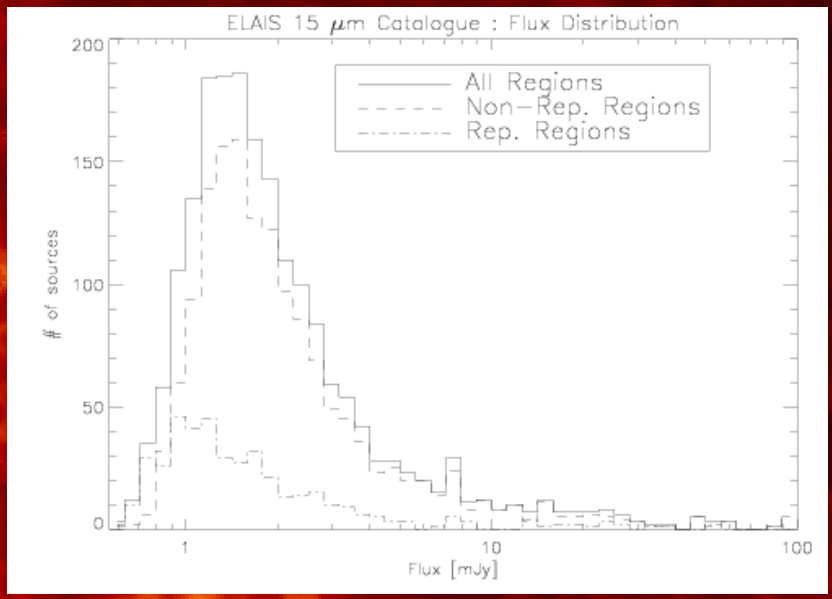
~10.85 deg² - 28 “rasters” - ~11,000 pointings - ~150,000 readouts

ELAIS 15 μm Final Analysis Catalogue



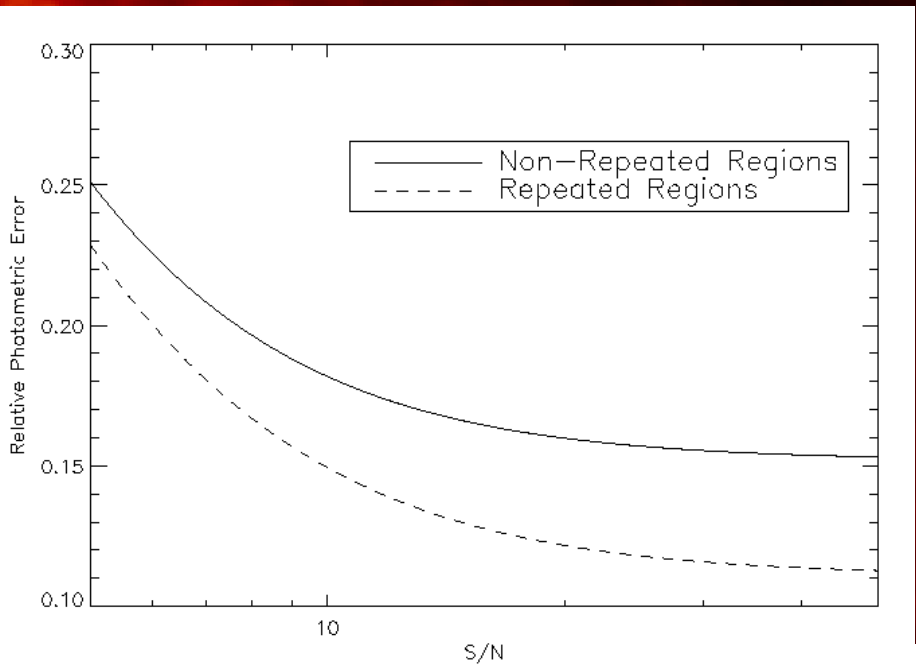
- 1923 sources with S/N > 5
- 0.5 – 100 mJy Flux Range
- Extensive set of simulations to assess the catalogue quality
  - 1-2 ” positional accuracy
  - 10-20 % flux error
  - 1 % error on flux calibration

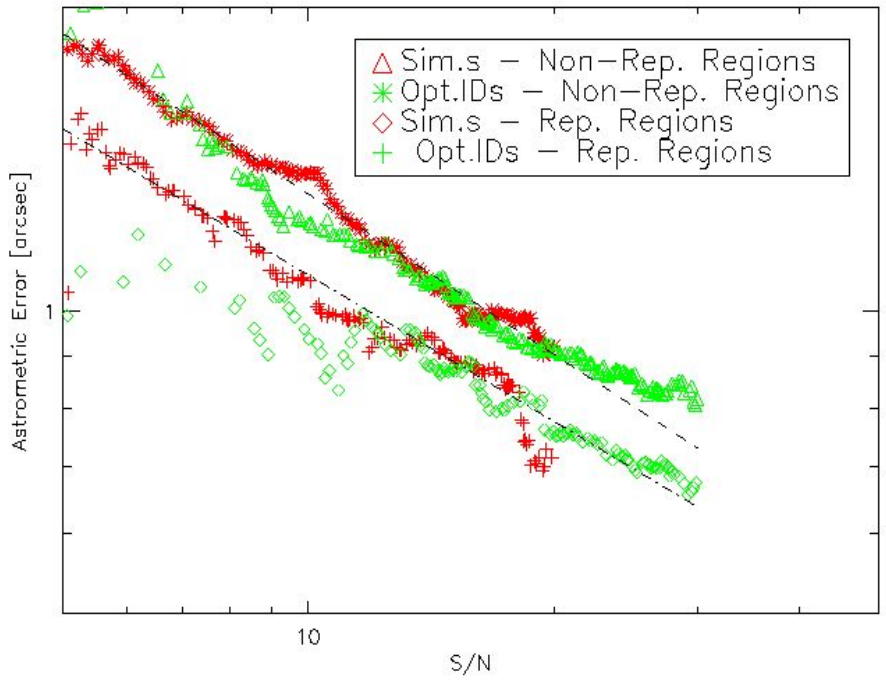
http://astro.ic.ac.uk/~vaccari/elais

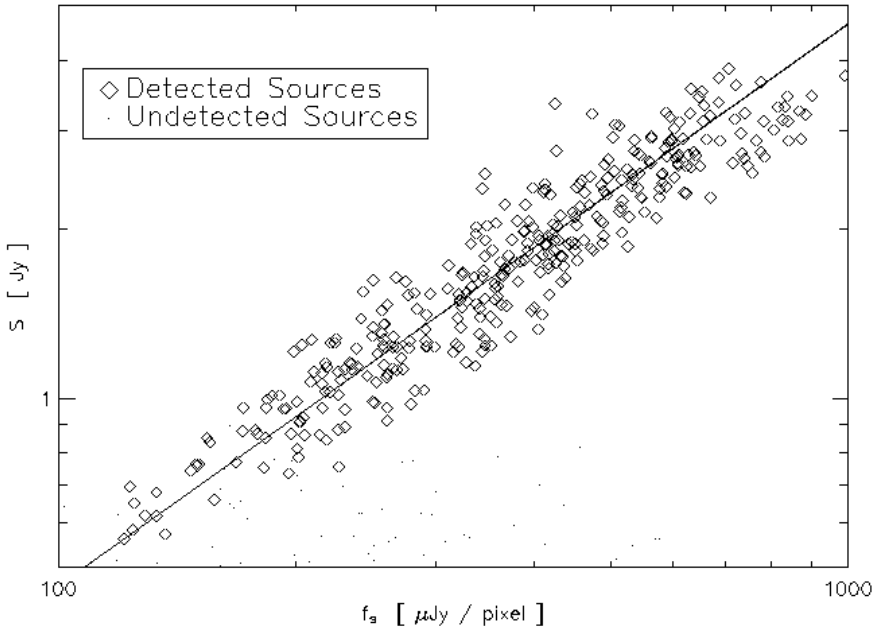


Data Reduction and Analysis Performance

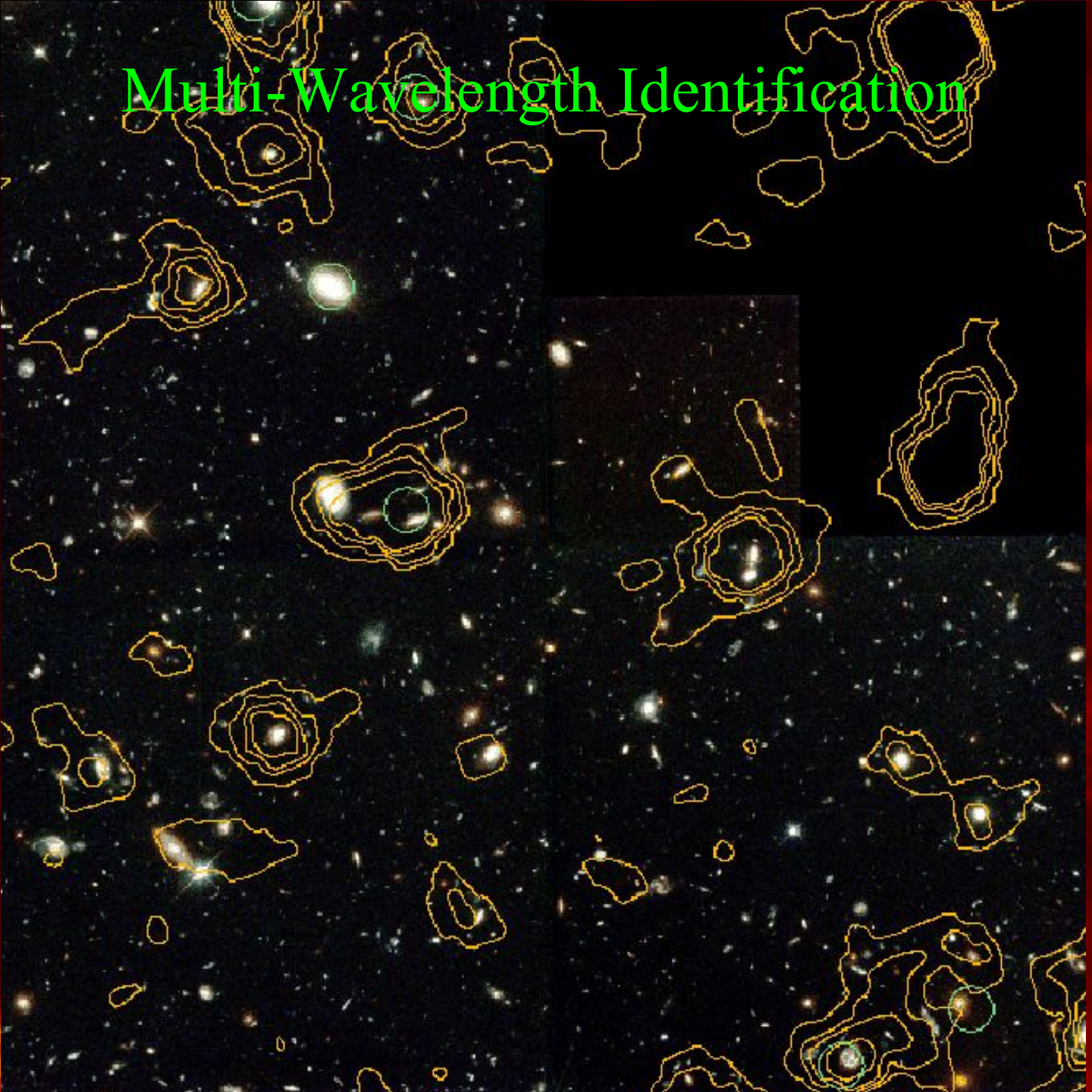
Simulation of additional sources on the top of observational data provides a realistic representation of practical data reduction issues







Multi-Wavelength Identification

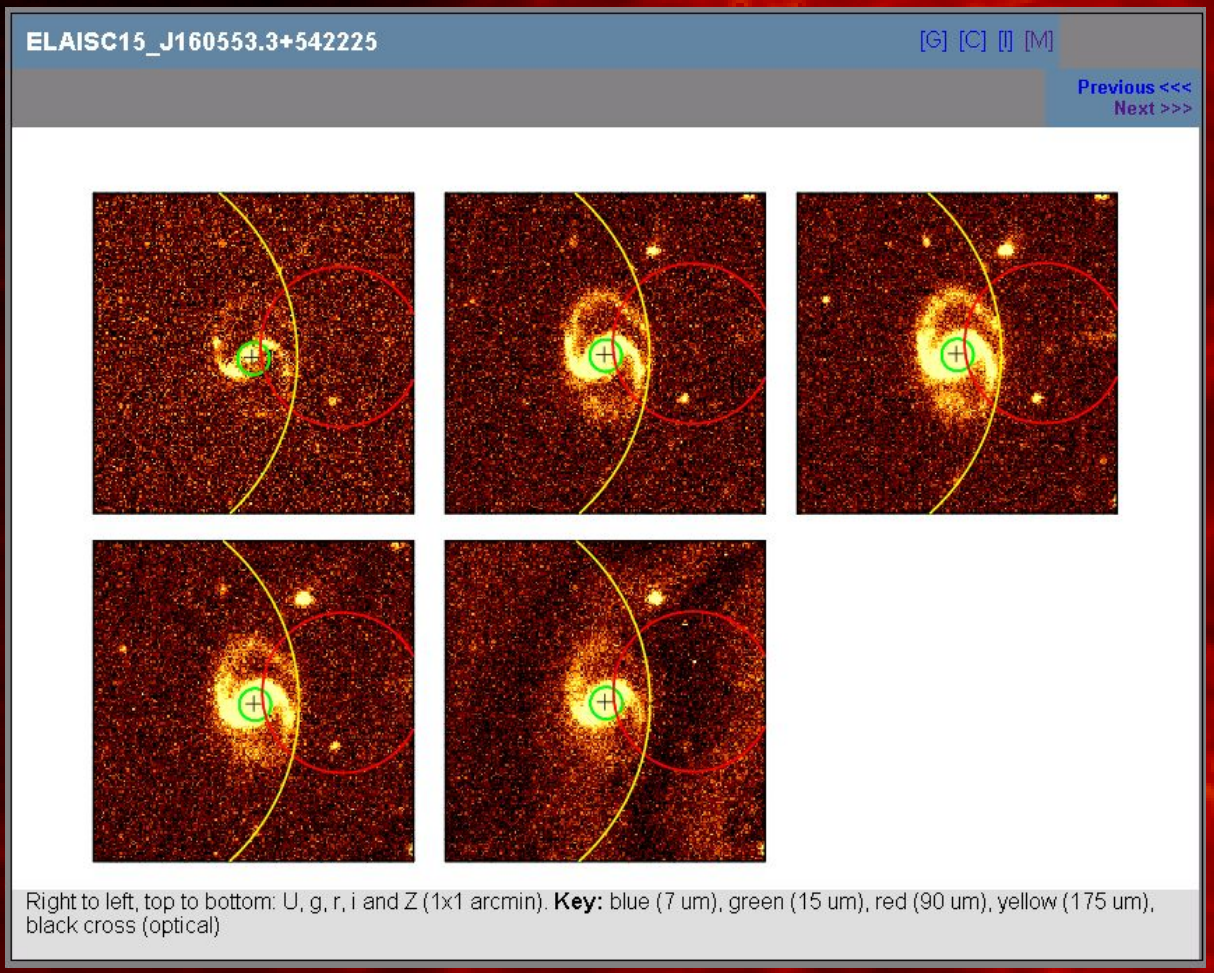


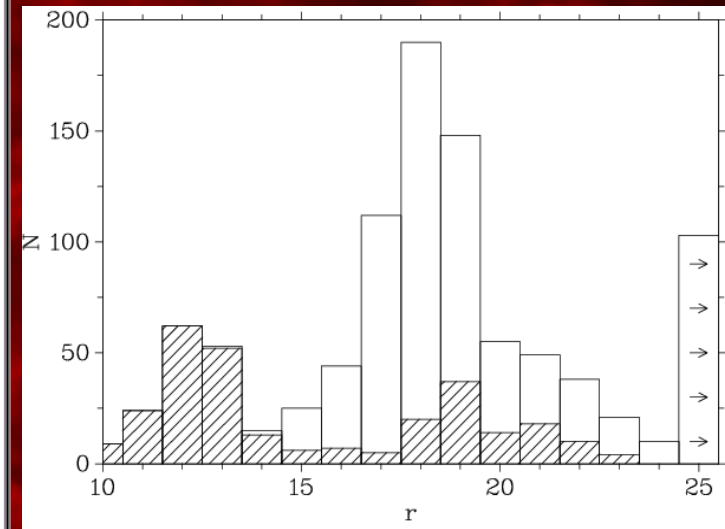
A key element to understand the nature of 15 μm sources

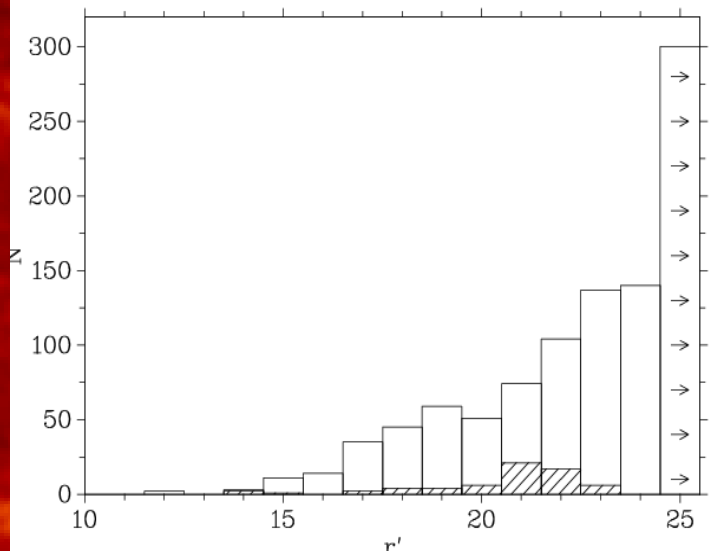
Seriously hampered by astrometric accuracy and spatial resolution of 15 μm maps

Optical Identification of N1 and N2 Sources

A robust statistical tool determines the most reliable optical countepart

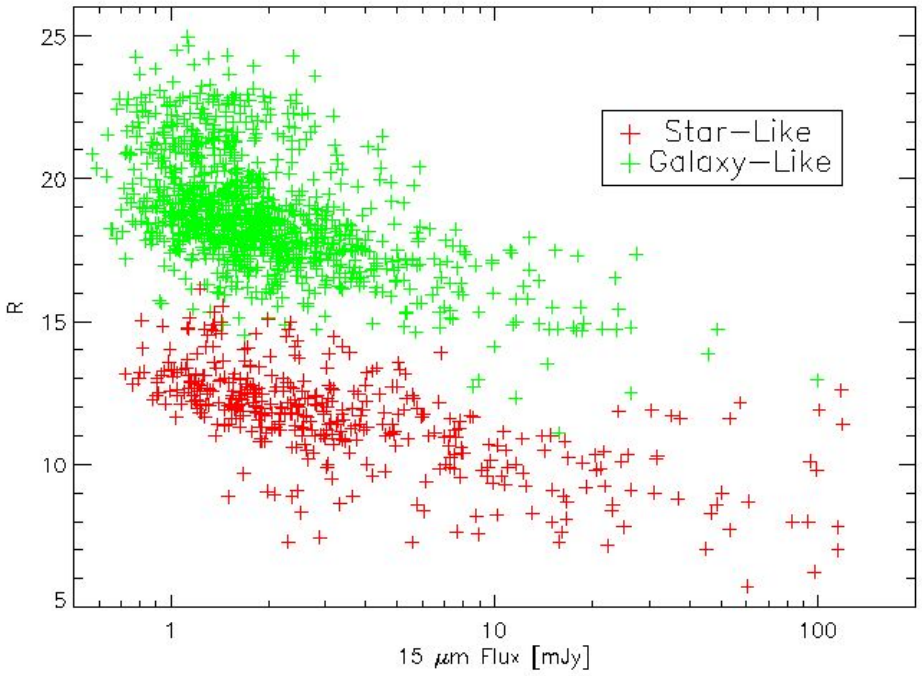


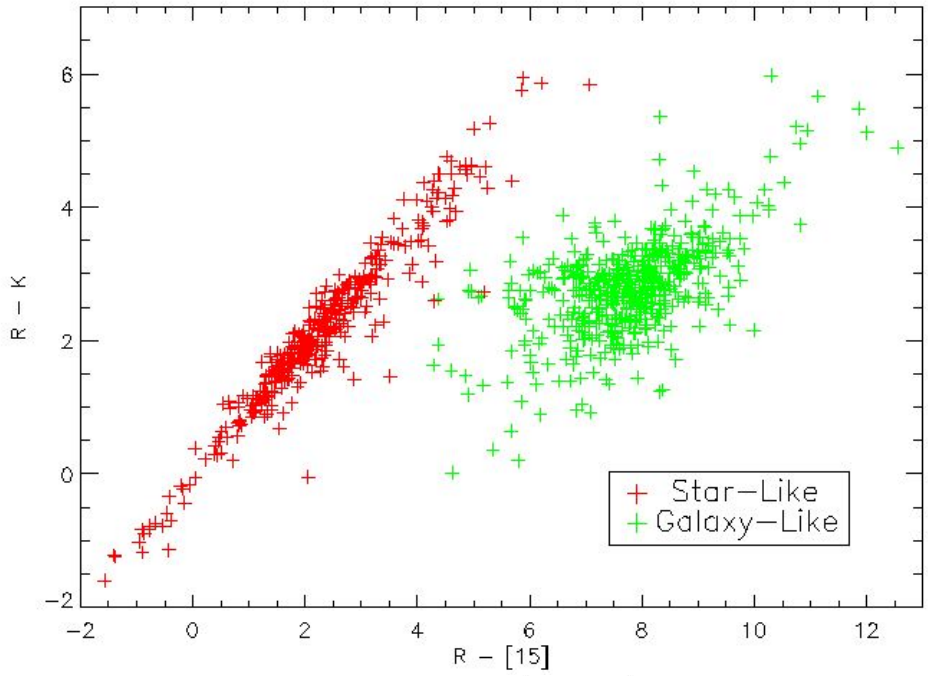




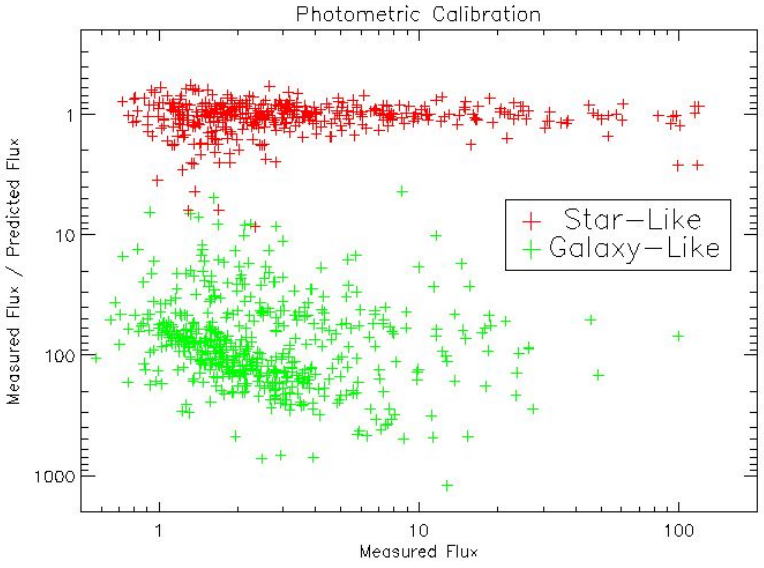
Five band deep optical imaging provides flux, colors, star-galaxy discrimination and morphological information

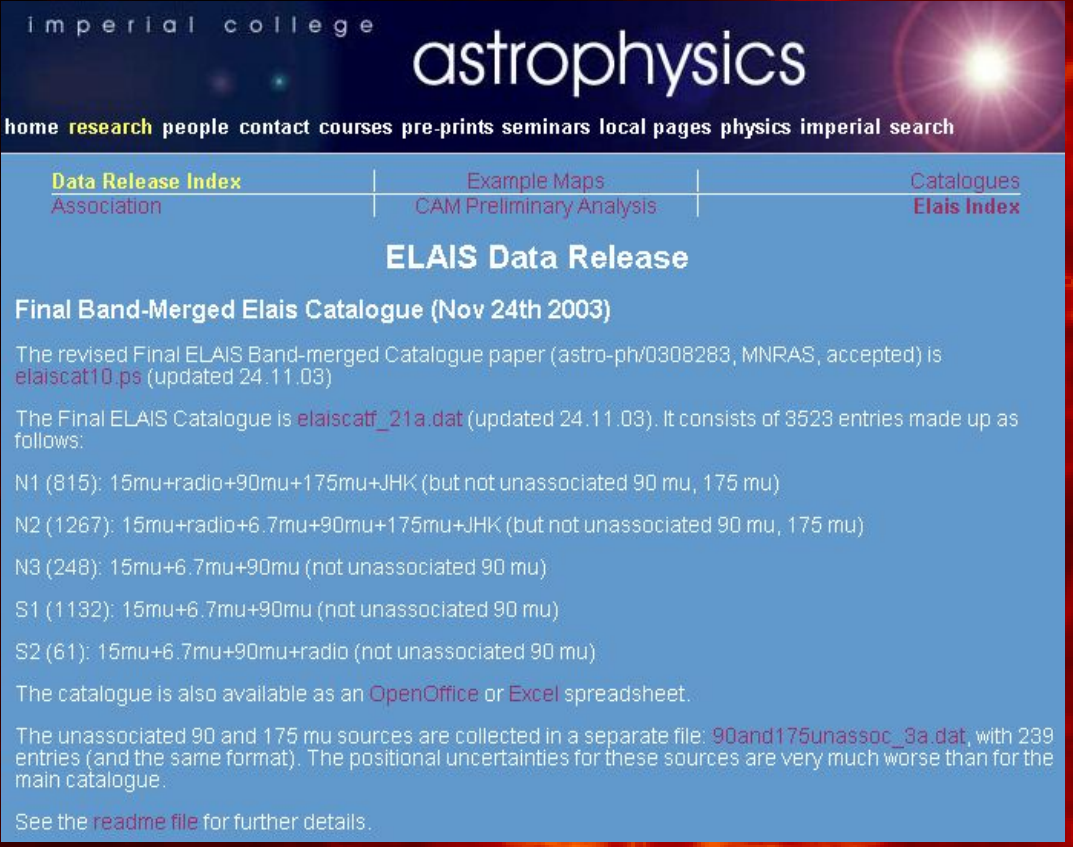
Star-Galaxy Discrimination and Flux Calibration





Optical, near-infrared and 15 μm photometry together provide reliable discrimination between stars and galaxies and accurate flux calibration based on predicted stellar fluxes



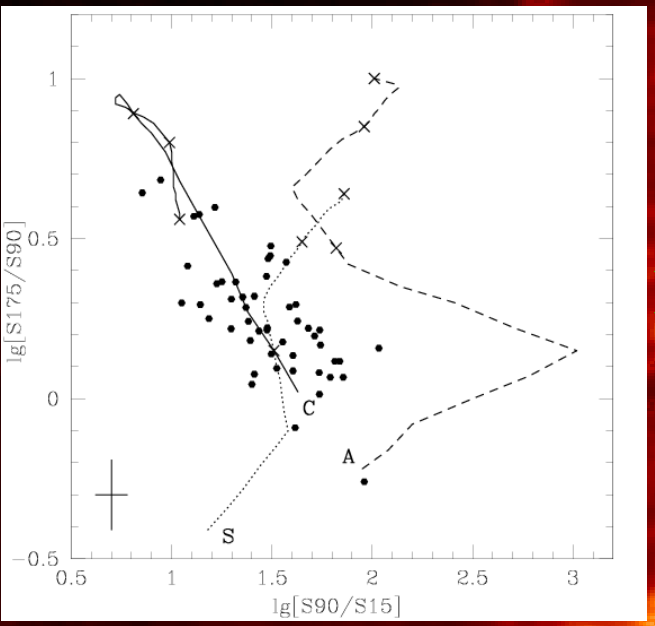


24 Nov 03 : ELAIS Band-Merged Catalogue

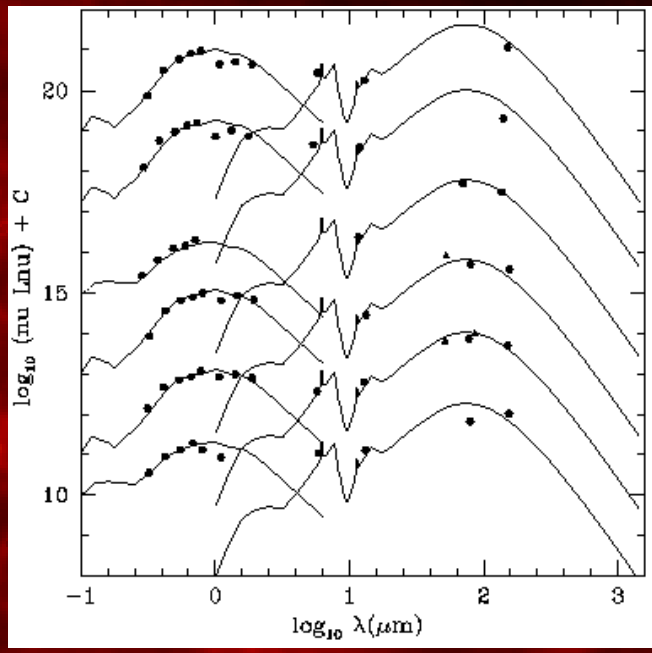
- 3792 sources, 3523 detected in at least two wavelengths
- *u, g, r, i, z, J, H, K*, 7, 15, 90, 175 μm, 1.4 Ghz Photometry
- Spectral Energy Distributions and Color-Color Diagrams
- Spectrometric/Photometric Redshifts and Absolute Luminosities

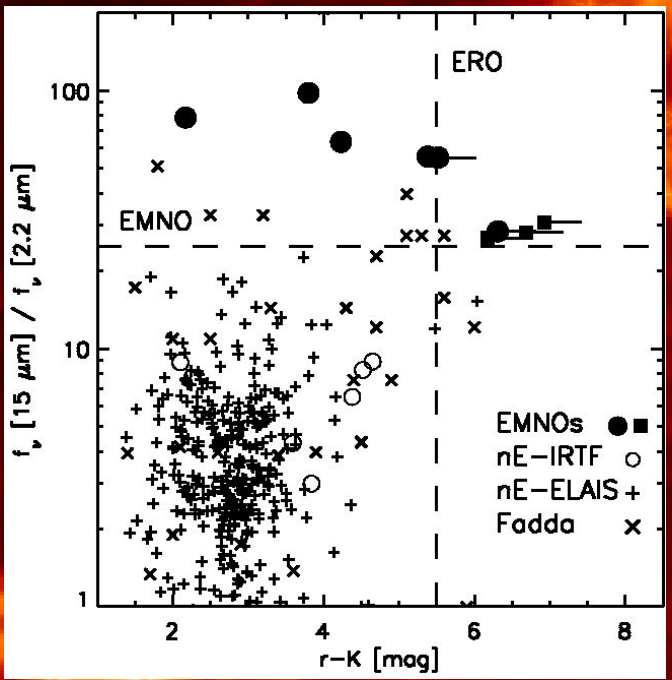
- A coherent summary of ELAIS observational campaigns
- An agreed-upon legacy from ELAIS & ISO as a whole!
- A useful pathfinder for future multi-wavelength projects

Early Scientific Results



Infrared sources in SED and color-color spaces



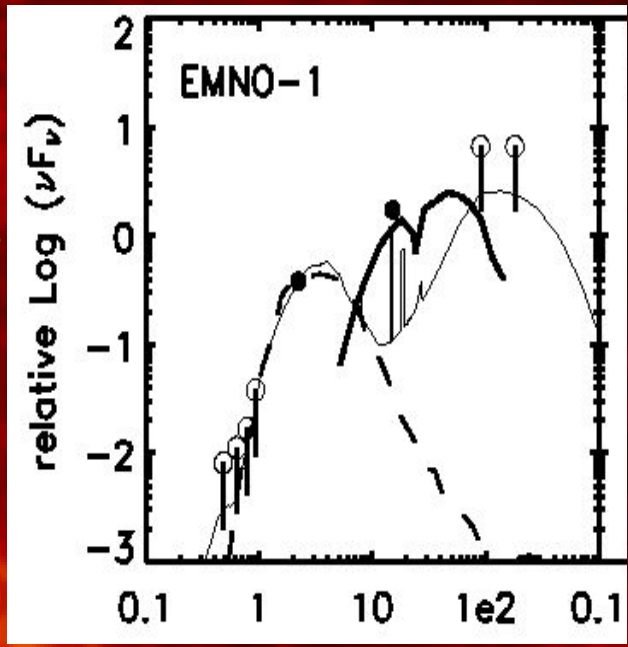


Rare and "New" objects

9 Extremely Red Objects

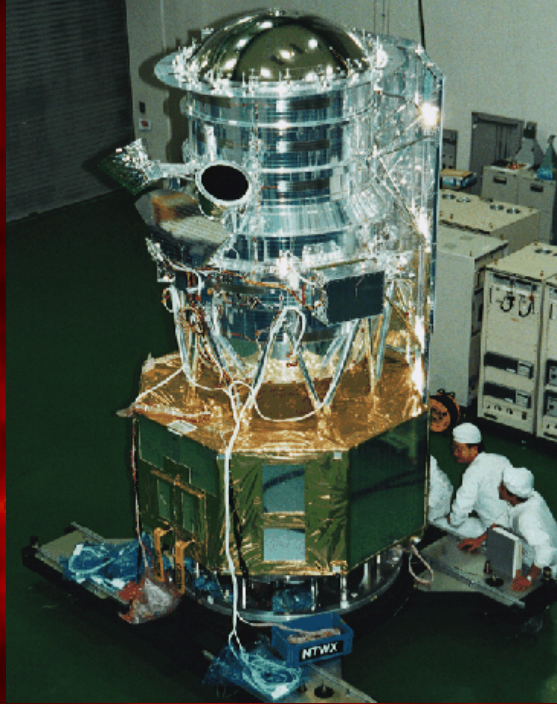
9 candidate HLIRGS

9 Extreme MIR/NIR Objects



Spitzer
(2003-...)

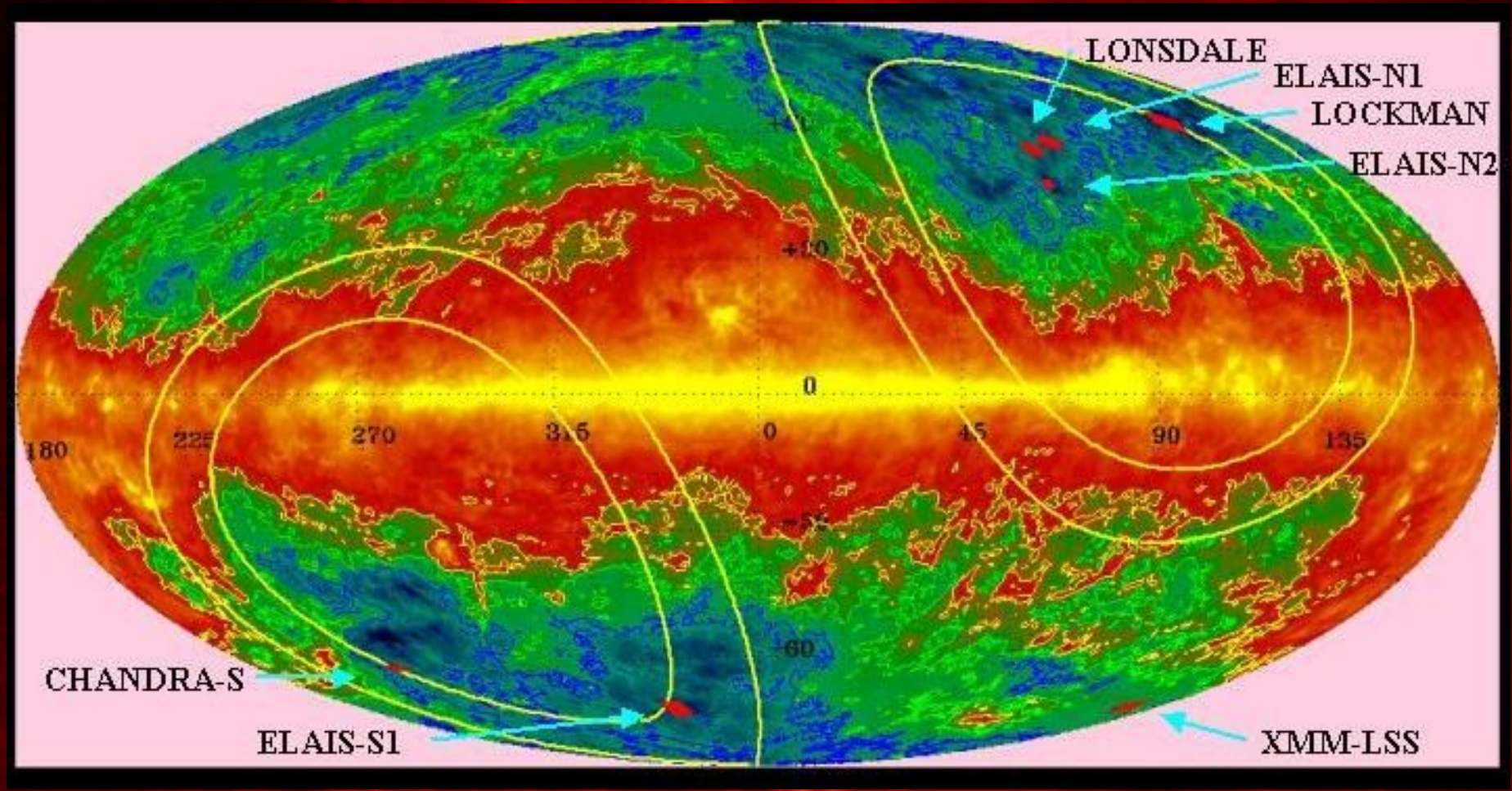
Astro-F
(2005)



Herschel (2007)

JWST
(2011)

SWIRE : Spitzer Wide-Area Extragalactic Survey



Imaging at 3.6, 4.5, 5.8, 8.0, 24, 70, 160 μm over 50 deg² divided into 6 fields

ELAIS S1, N1 and N2 included

Largest project within Spitzer Legacy Science Program

(850 h Observing Time)

What's Next? - Future Work

Technical Tools

Detector Modeling

Time History Deglitching

Automated/Interactive DA

Mapping/Mosaicing

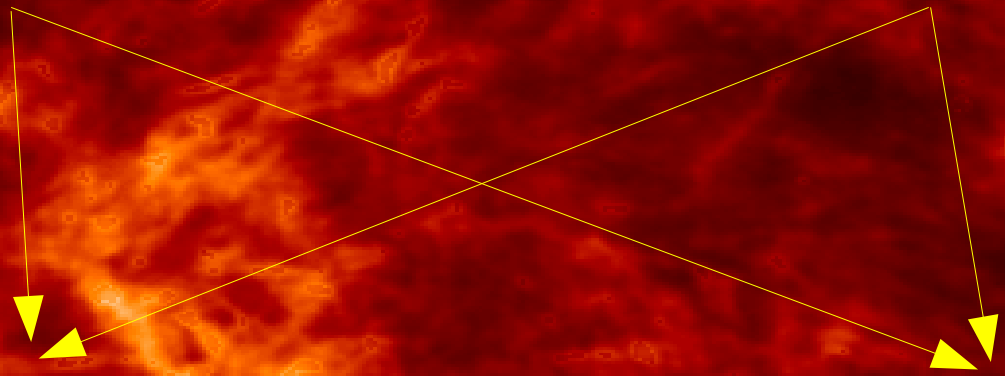
Scientific Insights

Colour-Colour Diagrams

Redhsift Distribution

Spectral Energy Distributions

Rare and “New” Objects



ELAIS Follow-Up

Clustering and its evolution with redshift

EMNOs : a new class of IR-selected objects

SWIRE SEDs of ELAIS objects

Spitzer, Herschel and Beyond

Data Reduction and Science

SWIRE and Spitzer Open Time

Herschel Software Development

Conclusions

The end-to-end realization of a space science observational project

- Refinement of an ad hoc data reduction and analysis method
  - Development of techniques and tools for automated and interactive data processing of space infrared data
  - Production of a usable software package
- Application to an ambitious extragalactic infrared survey
  - Data reduction and analysis of a vast dataset
  - Detailed estimates of performance through simulations
  - Versatile data products for follow-up studies
- Discussion of early scientific results
  - Multi-wavelength identification of infrared-detected sources
  - Isolation of contributing extragalactic infrared populations
- Future work : Spitzer and the “Golden Age” of space IR astronomy