BLAST

Dissecting the Far Infrared Background

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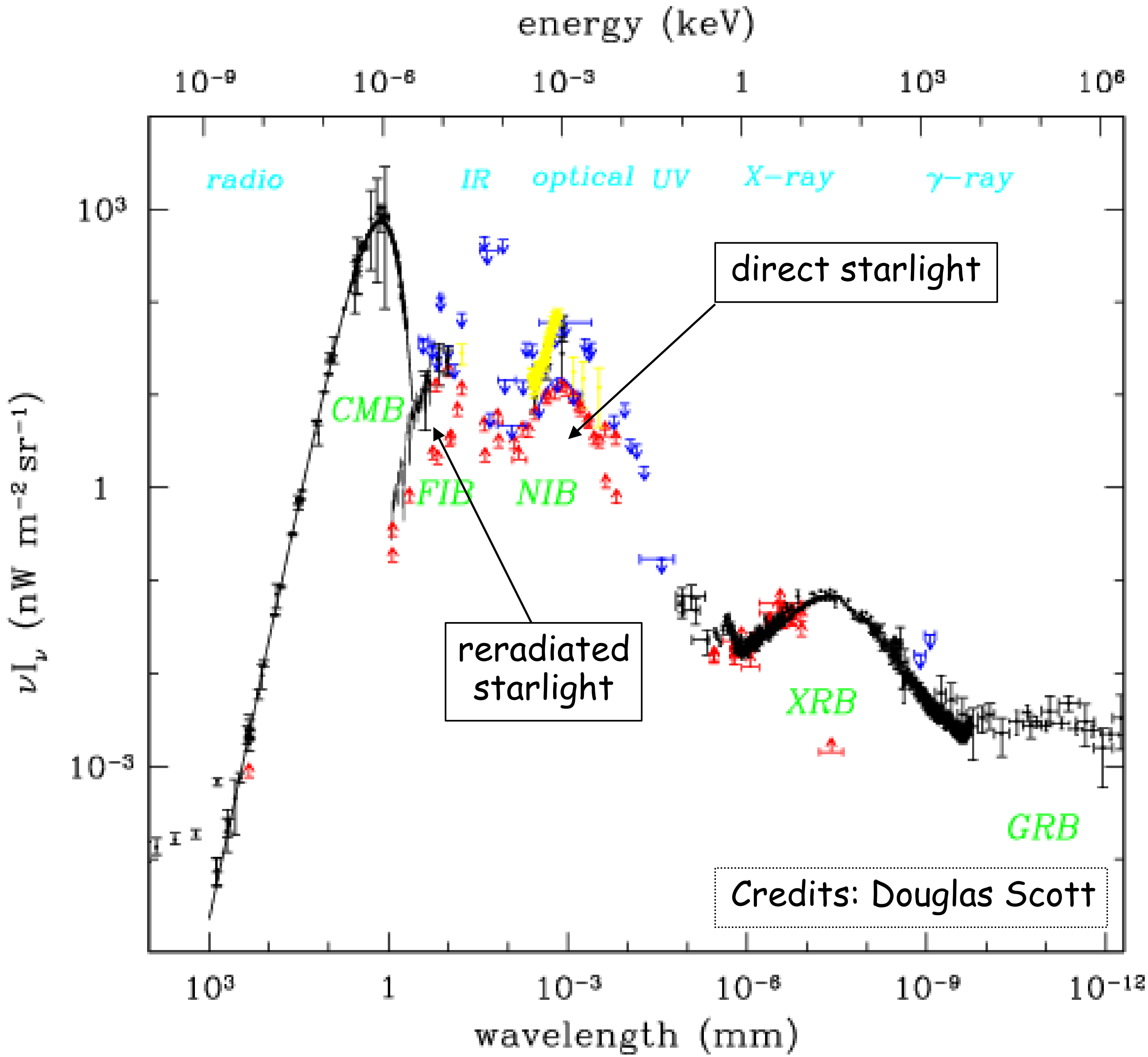
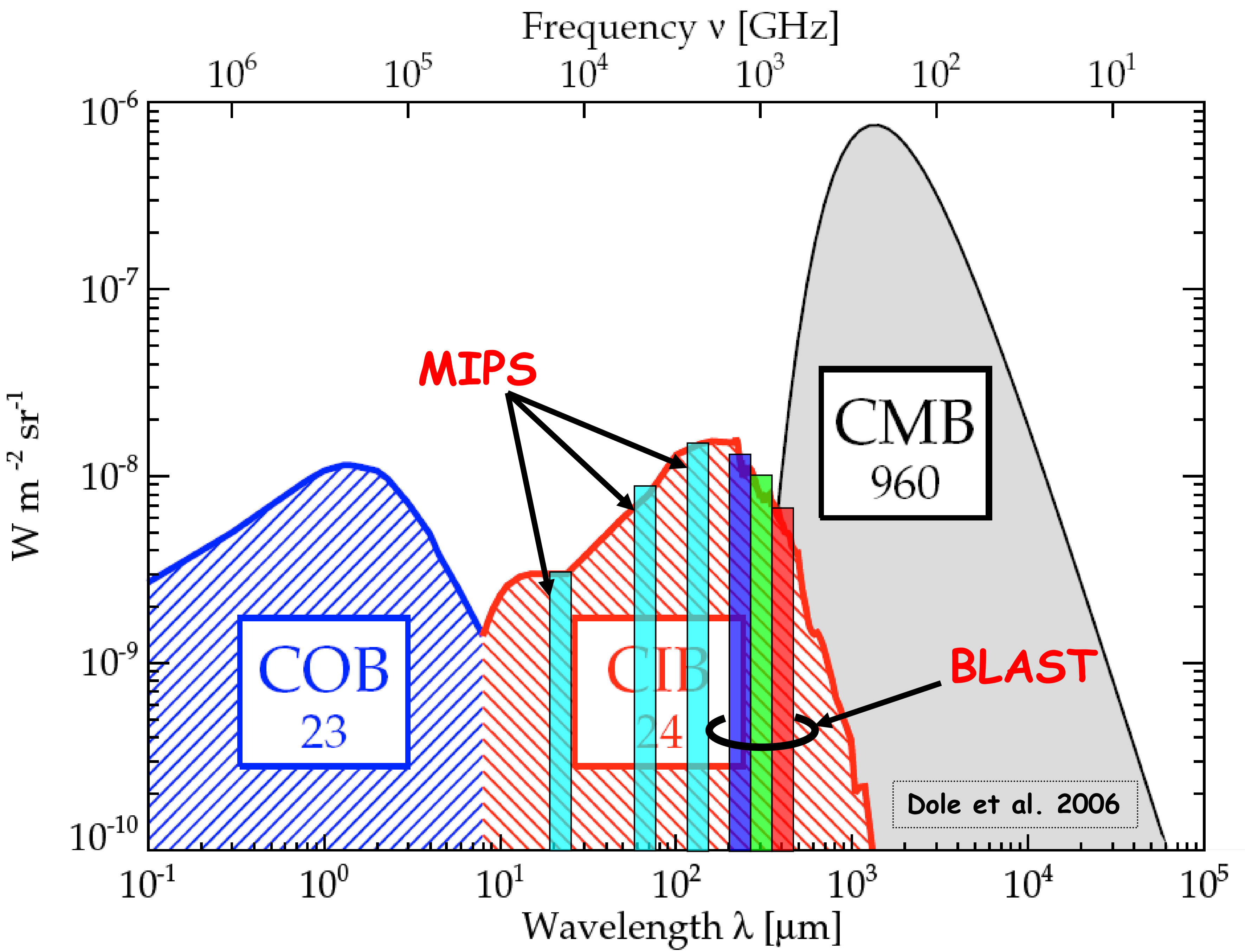
Summary

- Why? …the Far Infrared background
- Who/where/when? …BLAST
- How?
    - stacking analysis -> average properties of sources
    - P(D) analysis -> source counts
    - ID analysis -> counterparts
- So what? …lessons learned

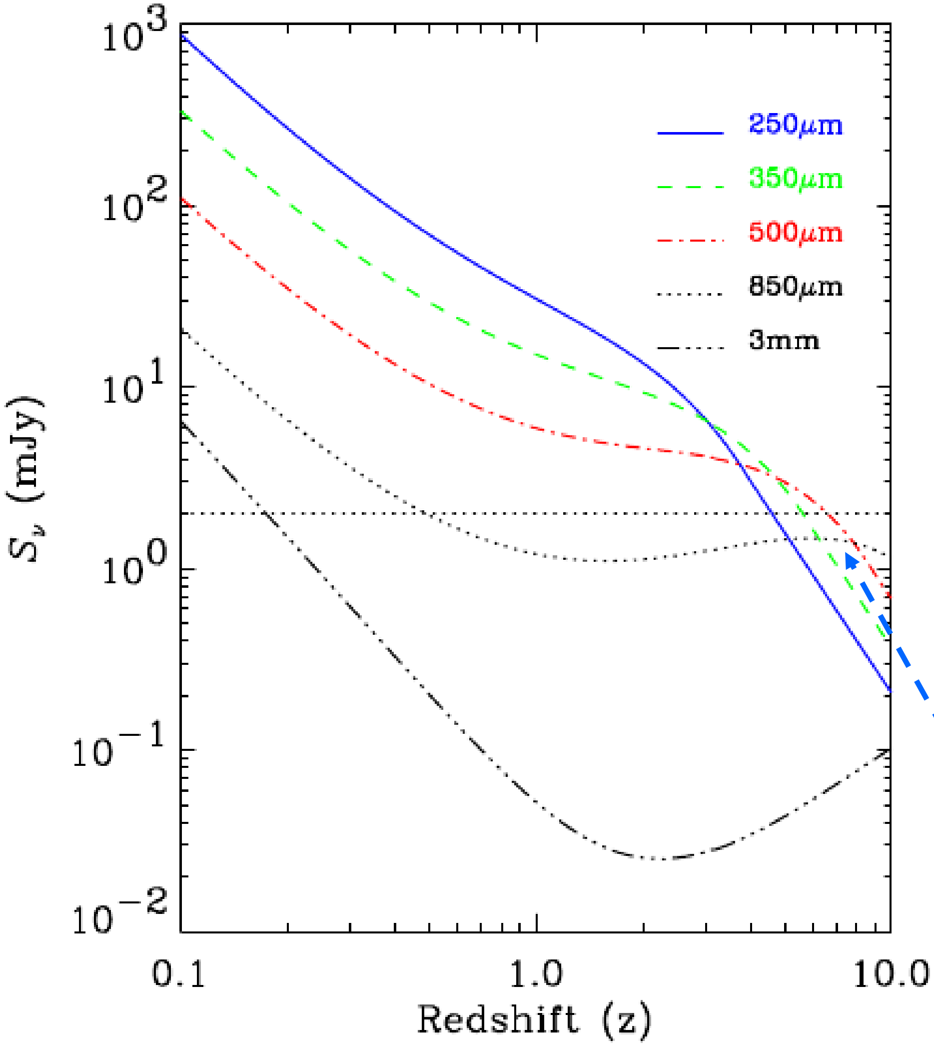
The Extragalactic Backgrounds

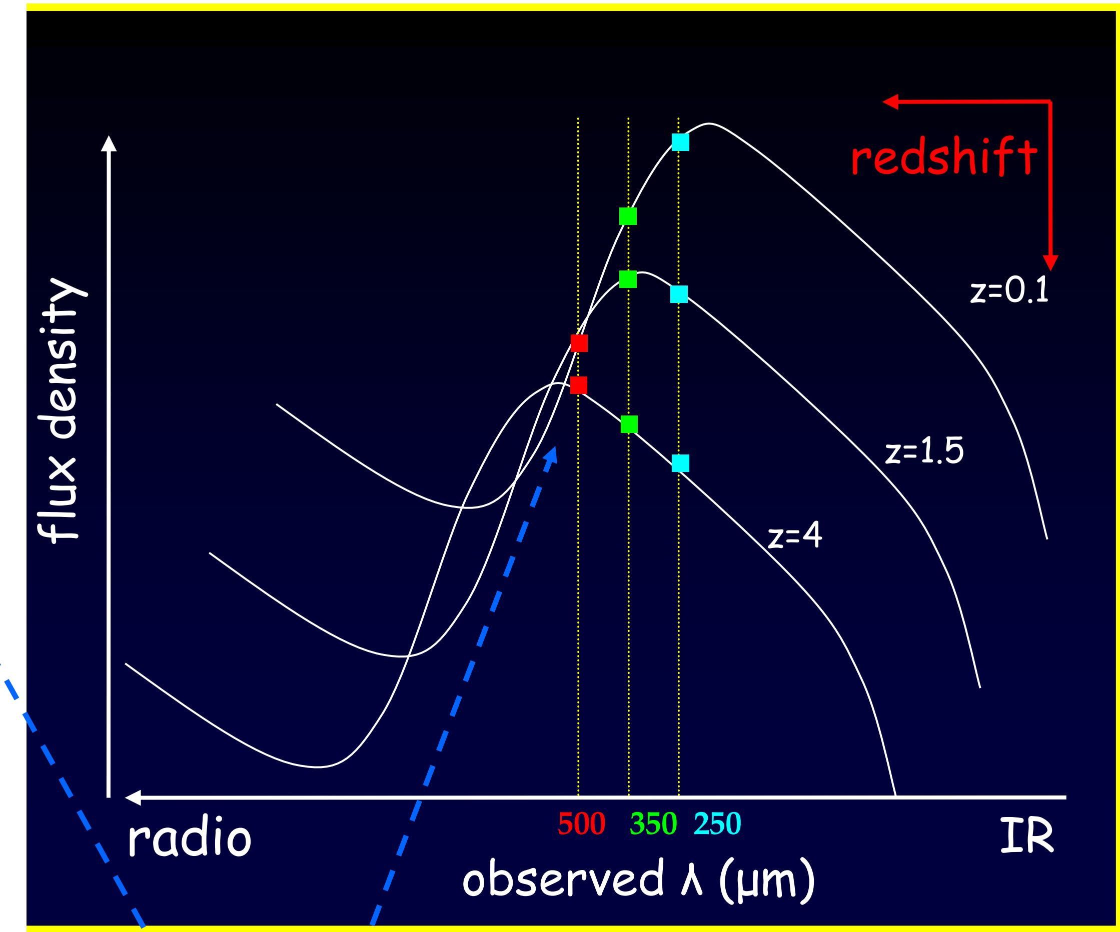


The CIB Background



BLAST bands: study star formation at high-z





negative K-correction

The BLAST bands are chosen to bracket the SED peak
for submm galaxies 1 < z < 4

- Evidence:
  - today: SFR ~ few M_{sun}/year
  - past (z > 1): SFR > 100 M_{sun}/year
- SF is dust enshrouded and brigt in FIR
- At high z, FIR is redshifted into Sub-mm

BLAST

completed confusion-limited observations

- Detection of hundreds of optically obscured galaxies
- How are they distributed ?
- What makes up the far infrared background near its peak ?
- Constrain the history of the far infrared energy of the universe
- Constrain the history of star formation in the universe
- Constrain clustering of sources
- What is the connection btw BLAST sources and SCUBA ULIRGs ?

BLAST

Who/where/when?

BLAST: The Balloon-borne Large-Aperture Sub-millimeter Telescope

Univ. of Pennsylvania
Mark Devlin
Jeff Klein
Marie Rex
Christopher Semisch
Matthew Truch

Brown University
Greg Tucker

University of Miami
Josh Gundersen
Nick Thomas

Univ. of British Columbia
Ed Chapin
Mark Halpern
Gaelen Marsden
Douglas Scott
Don Wiebe
Henry Ngo

University of Toronto
Peter Martin
Barth Netterfield
Marco Viero

JPL
Jamie Bock

INAOE (Mexico)
David Hughes

Cardiff University
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Simon Dye
Steve Eales
Matt Griffin
Peter Hargrave
Phil Mauskopf
Lorenzo Moncelsi
Enzo Pascale
Carole Tucker

Laboratoire APC
Guillaume Patanchon

University of Puerto Rico
IRA-INAF
Luca Olmi

The Royal Observatory, Edinburgh
Jim Dunlop
Rob Ivison
Bruce Sibthorpe

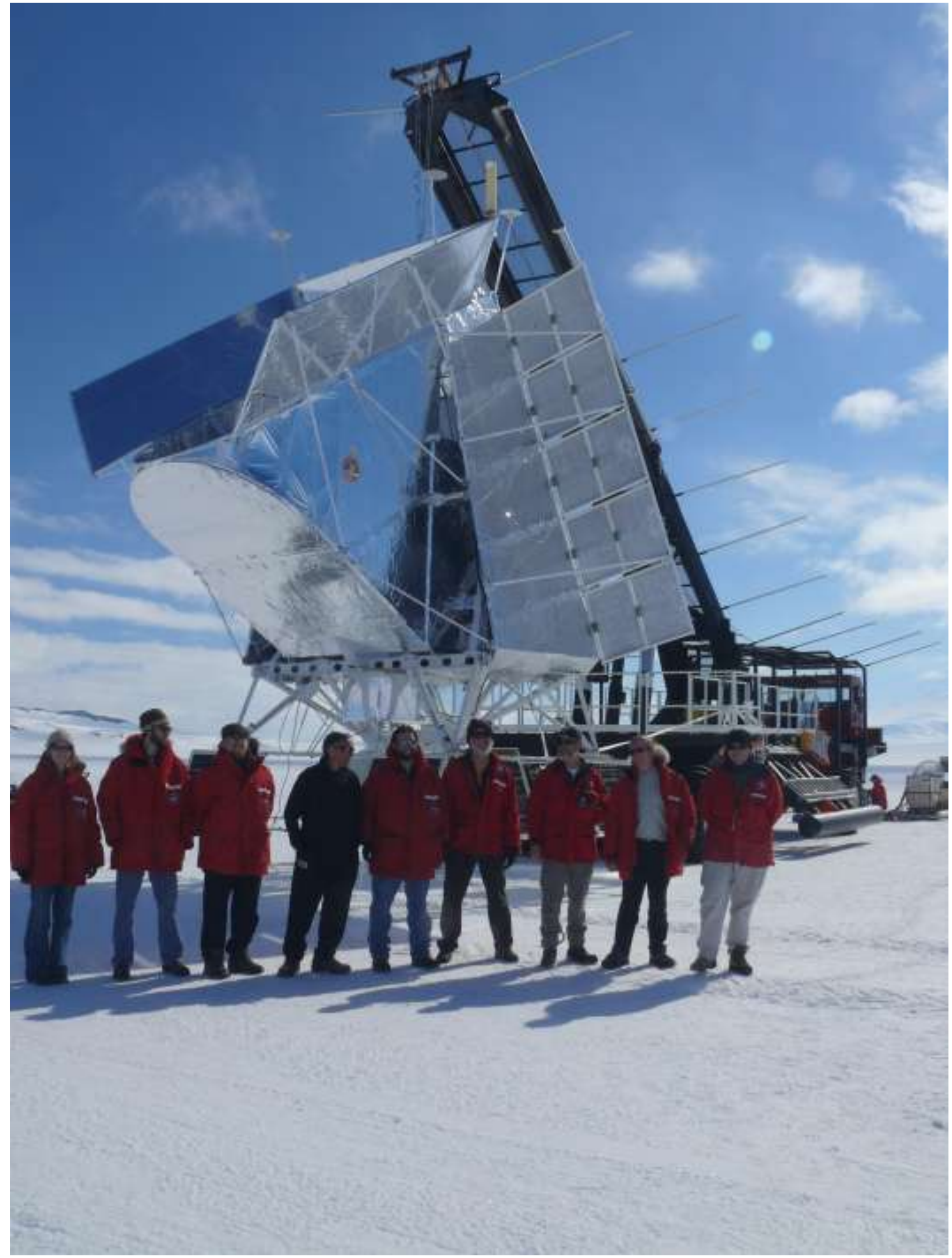
Blast as a pathfinder for SPIRE

- Same Focal Plane Technology
- Similar Science Motivation

Study the evolutionary history and processes of star formation in our Galaxy and in galaxies at cosmological distances

BLAST: A Submillimetre Observatory

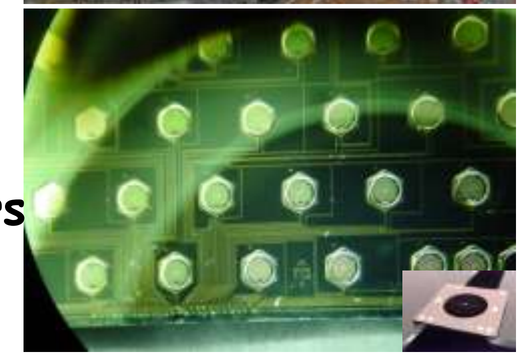
- Arrays of 270 bolometers 250 μm, 350 μm, 500 μm
- 2m Cassegrain Telescope
- Diffraction limited beams 30'', 42'' and 60'' FWHM
- Flown on a high altitude balloon platform
- SPIRE has larger mirror, higher resolution, and has access to more sky
- Most science is accessible to both BLAST & SPIRE



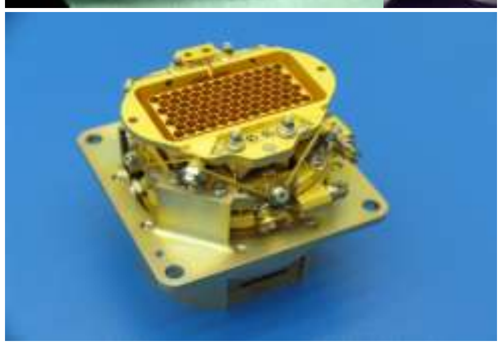
The instrument in a nutshell

2m telescope
and focusing
system

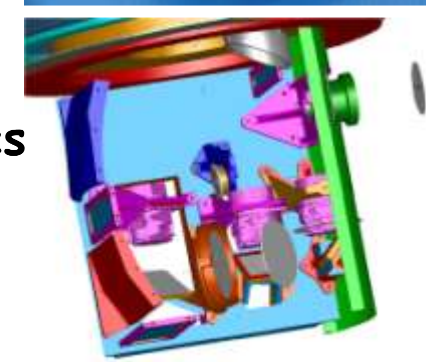
Arrays
of 270 detectors



Feed horns



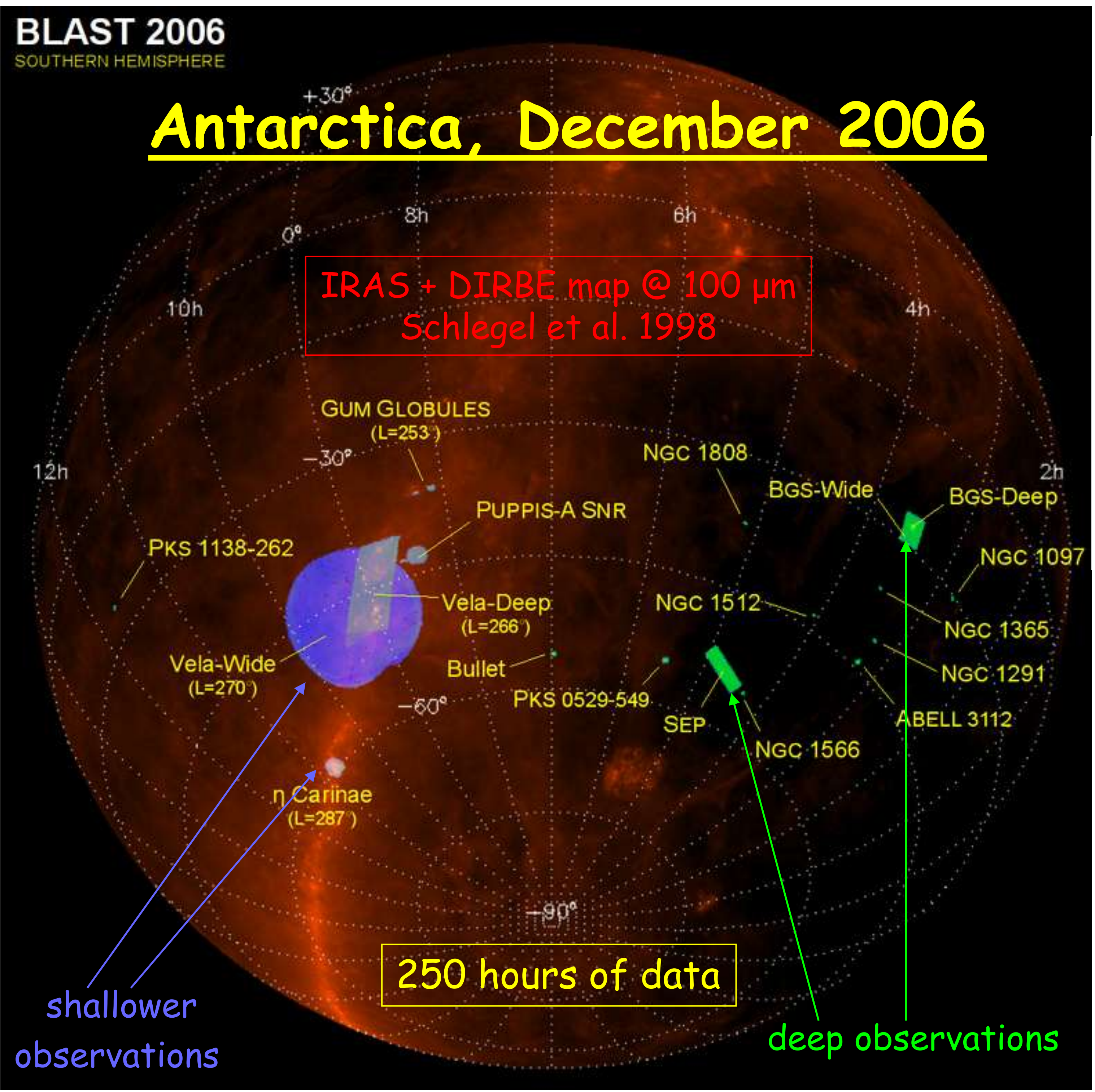
re-imaging optics
and filters



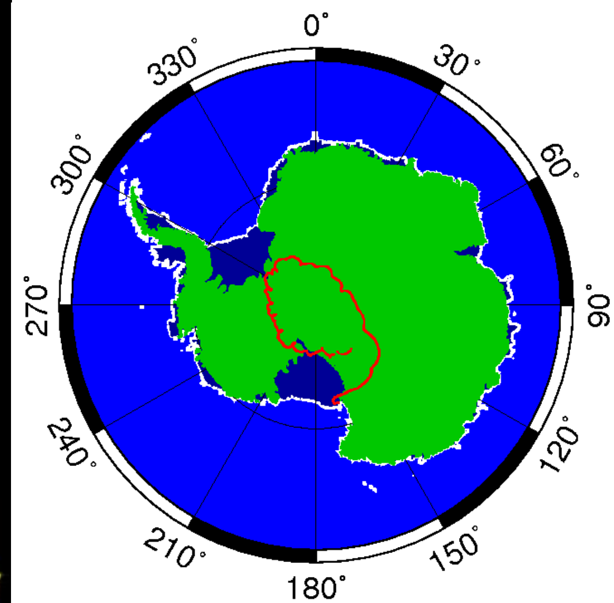
Cryogenics:
11 days hold
time

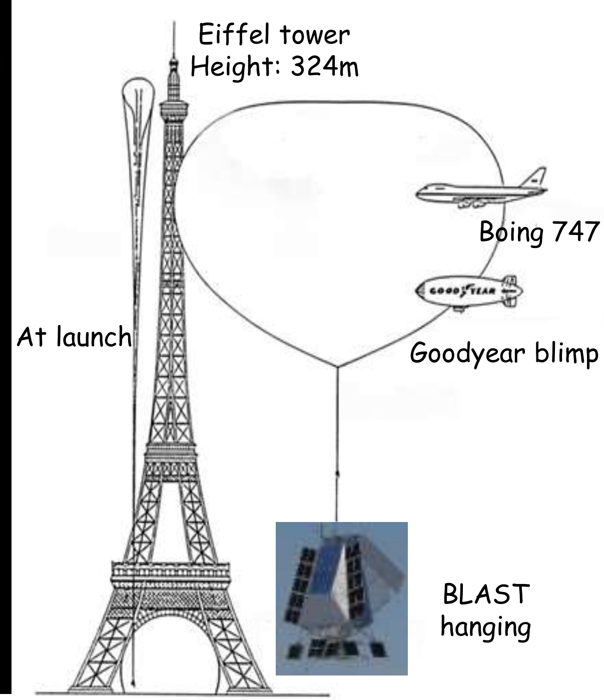
Pointing System:
11 Sensors
3" reconstruction

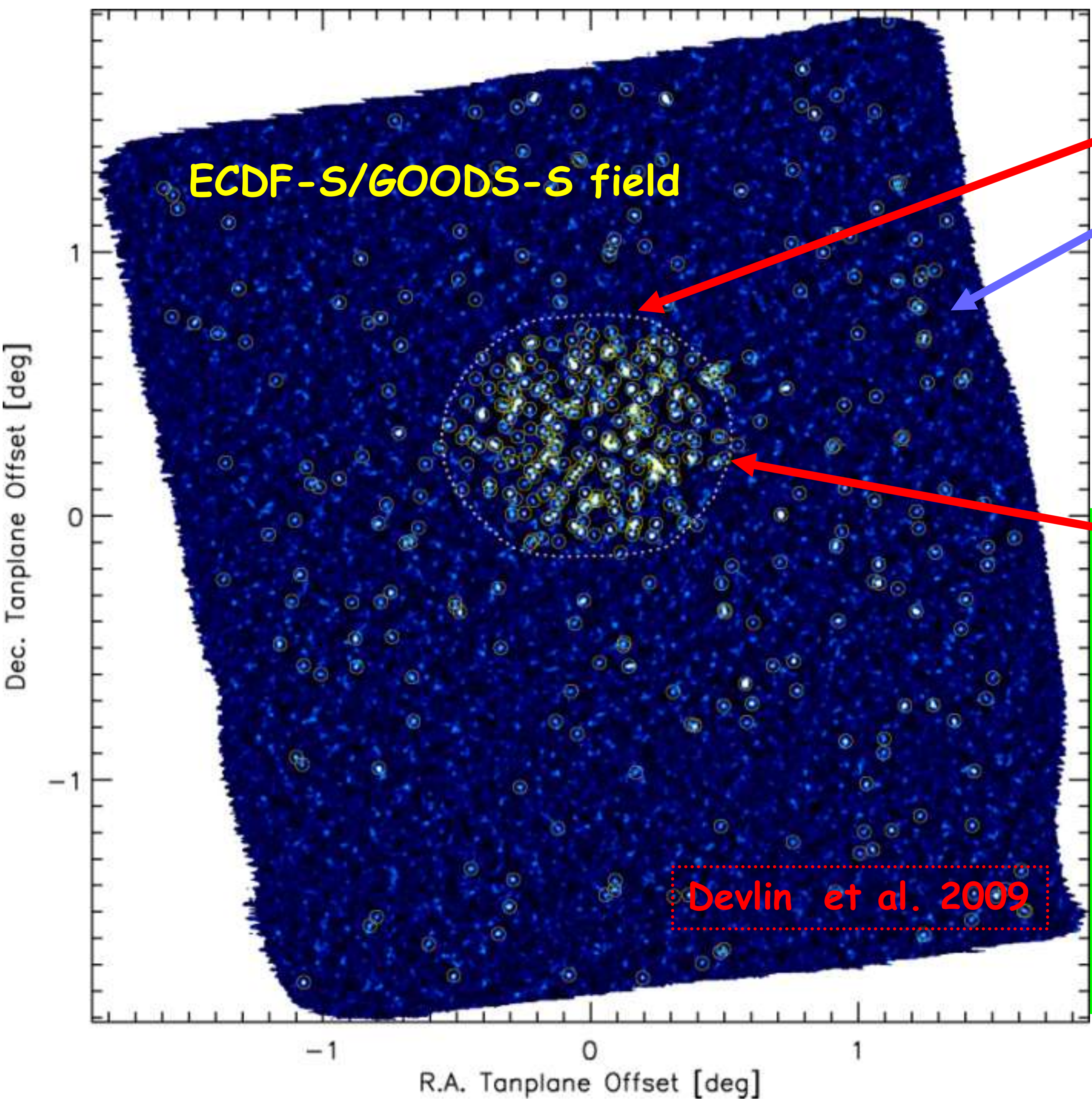
Software:
115,000 lines
on 43 processors



11-day flight at ~39 km
99.5% of the atmosphere







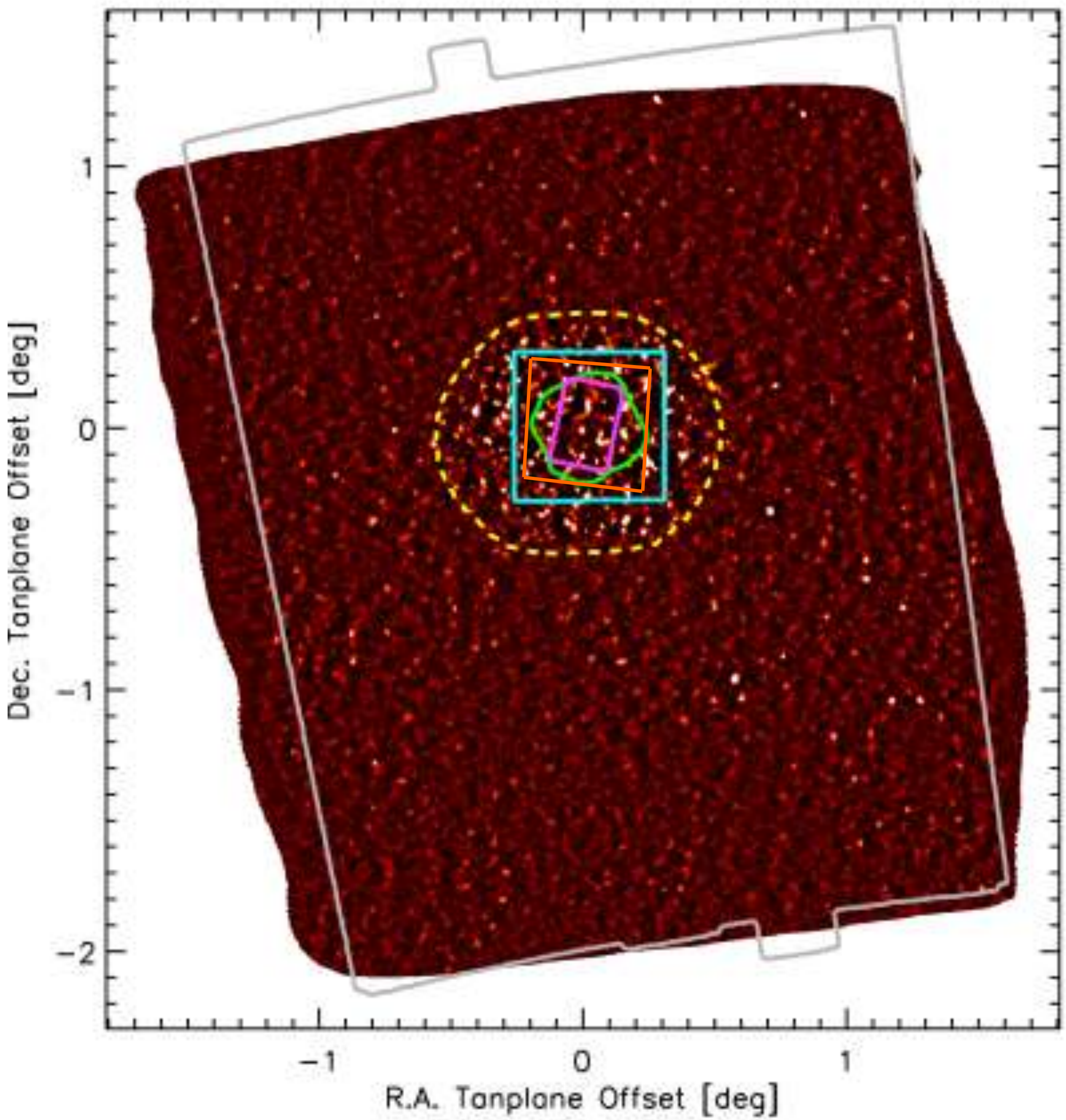
combined map
Deep (0.8 deg^2) +
Wide (9 deg^2)

Hundreds of >5.0σ sources

DEEP REGION

- Signal dominates over instrumental noise
- Source confusion arises from finite instrumental resolution
- Cannot resolve individual sources at very faint flux densities

Great ancillary data!



multi-wavelength coverage

SWIRE (24, 70, 160 μm)

BLAST DEEP

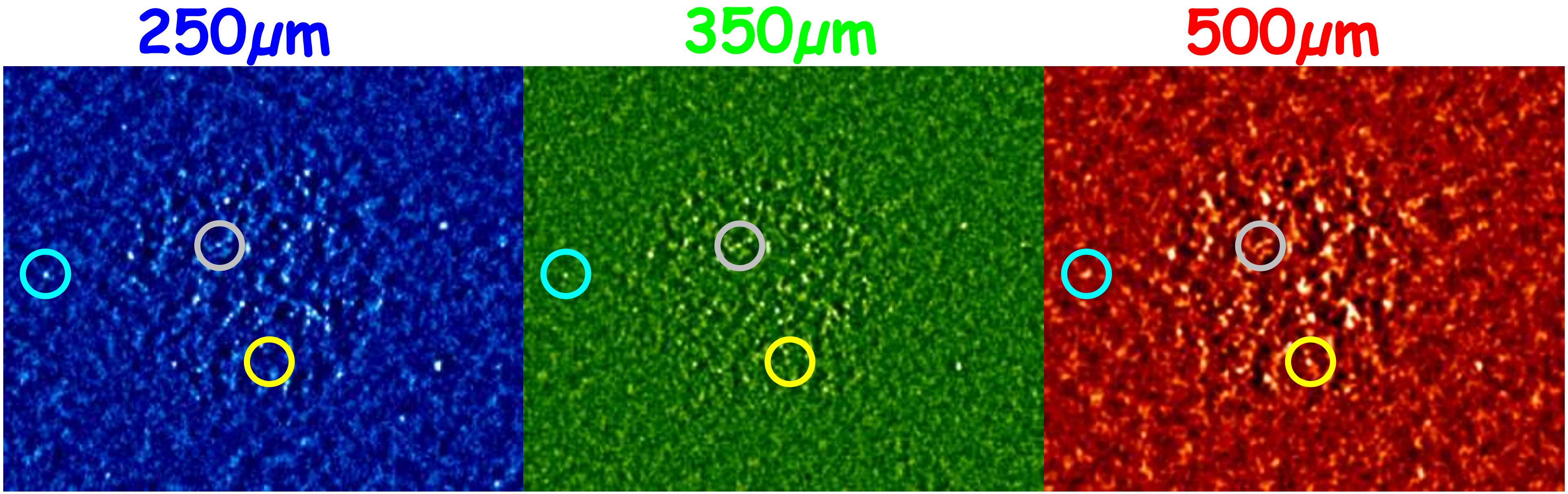
VLA (radio, 1.4 GHz)

FIDEL (24 μm)

CHANDRA 2Ms (X-ray)

GOODS (24 μm)

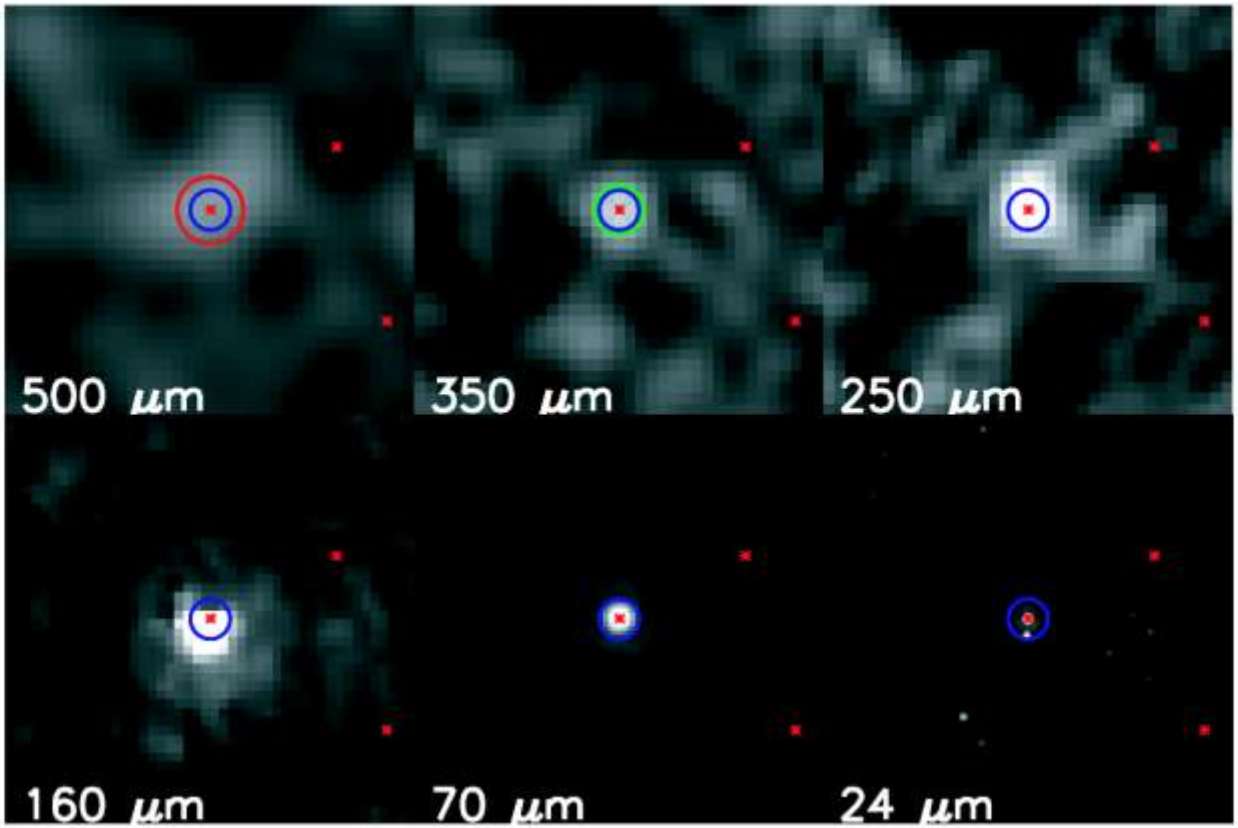
How detected sources look like

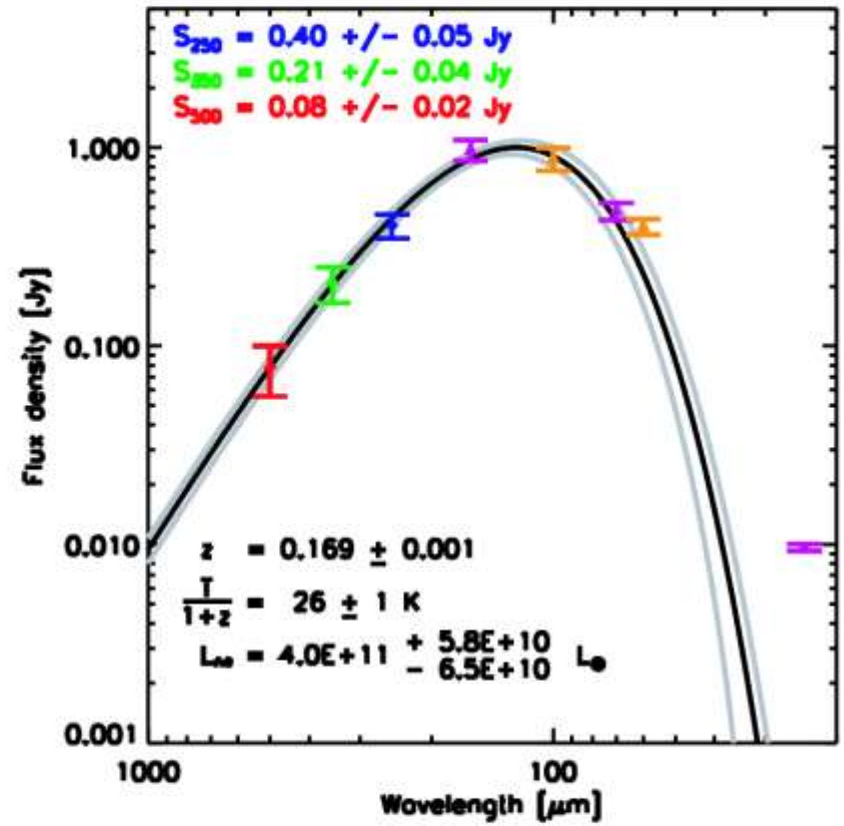


z=0.169	IRAS galaxy
z=1.1	galaxy from the SWIRE survey
z~3	galaxy selected by strong BLAST 500μm emission

z = 0.169 IRAS galaxy

- Clear radio detection (ATCA survey)
- Detected in all Spitzer & IRAS bands
- BLAST data constrain Rayleigh-Jeans tail



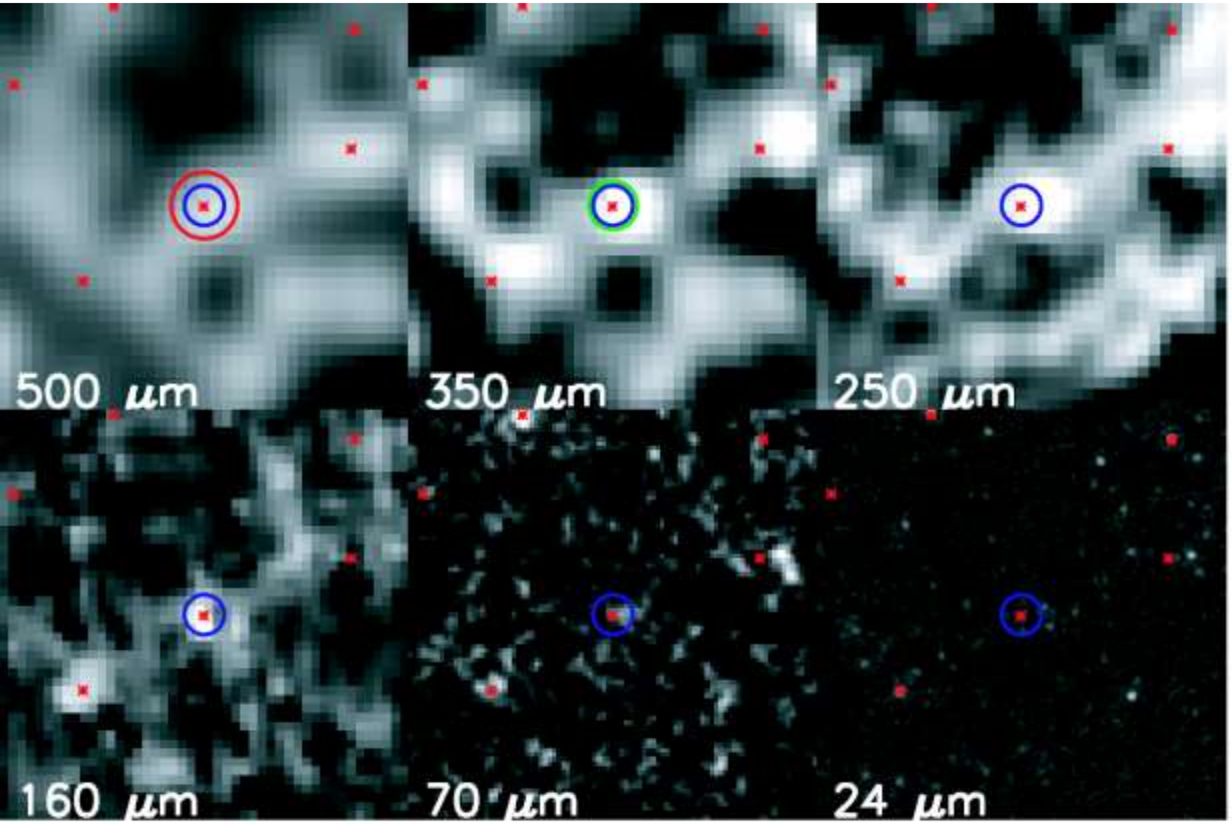


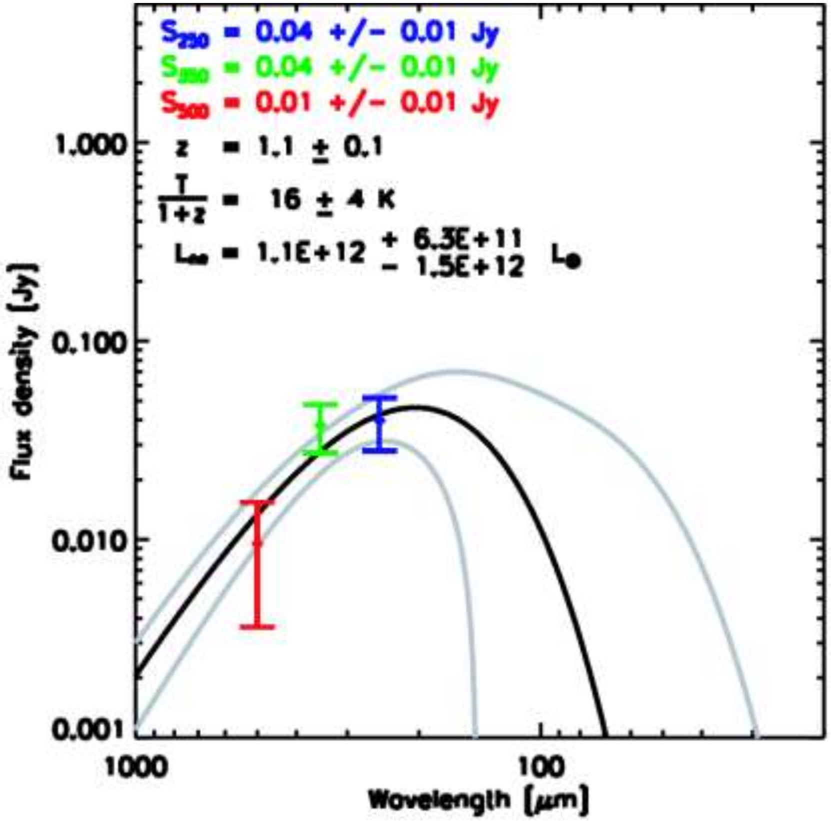
T_{OBS} = 26 K
T_{REST} = 30 K

$L_{BOL} = 4 \times 10^{11}\ L_{SUN}$
SFR ~ 70 $M_{SUN}\ yr^{-1}$

z = 1.1 SWIRE galaxy

- Clear radio detection (ATCA Survey)
- Spitzer 24μm + IRAC, faint at 160 and 70 μm
- BLAST detects SED *peak*, constrains temperature

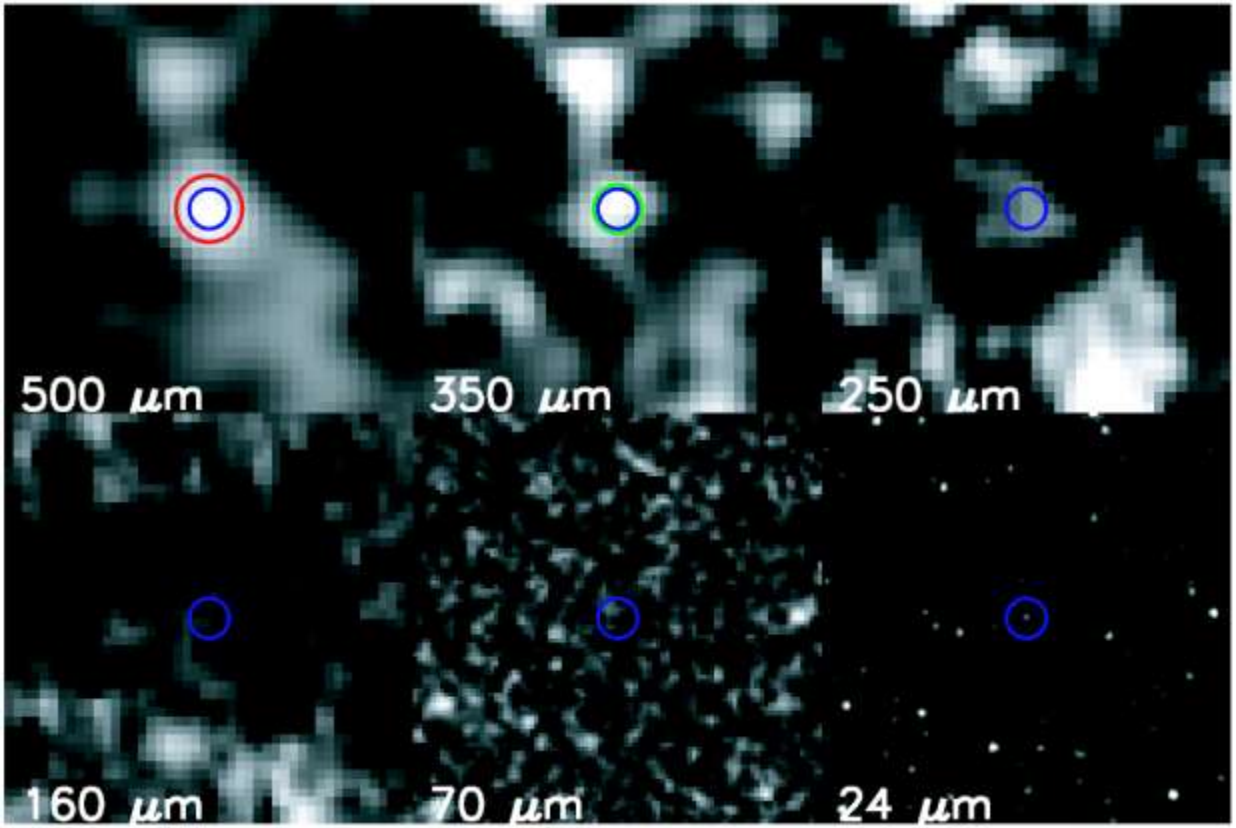


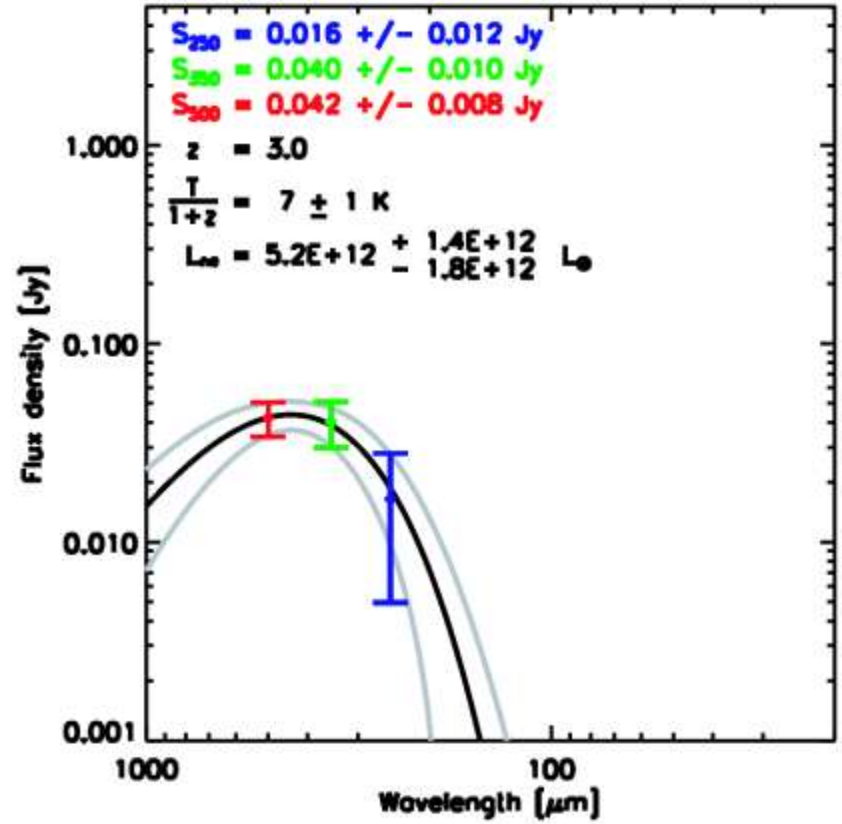


T_{OBS} = 16 K $L_{BOL} = 1.1 \times 10^{12}\ L_{SUN}$
T_{REST} = 34 K SFR ~ 200 $M_{SUN}\ yr^{-1}$

z ~ 3 galaxy selected by strong BLAST 500μm emission

- BLAST detects SED *peak*, constrains temperature
- Expected 850 μm flux density ~20 mJy – a bright SCUBA galaxy?





Photometric Redshift:
assume T_{REST} to infer z

T_{OBS} = 7 K
T_{REST} = 28 K

$L_{BOL} = 3.3 \times 10^{12}\ L_{SUN}$
SFR ~ 940 $M_{SUN}\ yr^{-1}$

HOW?

stacking analysis

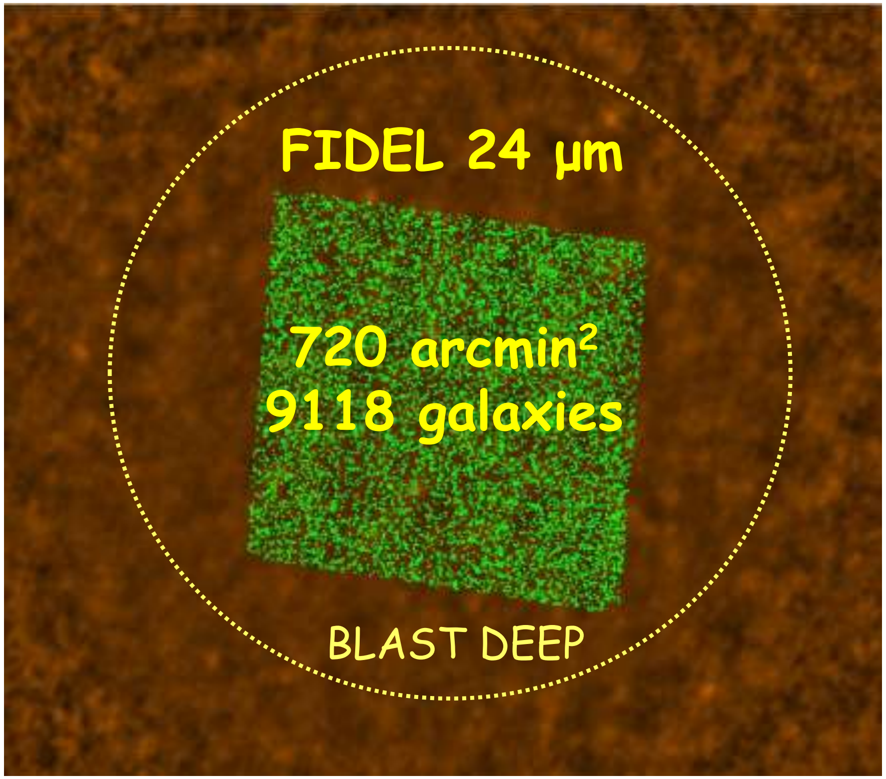
average properties of sources

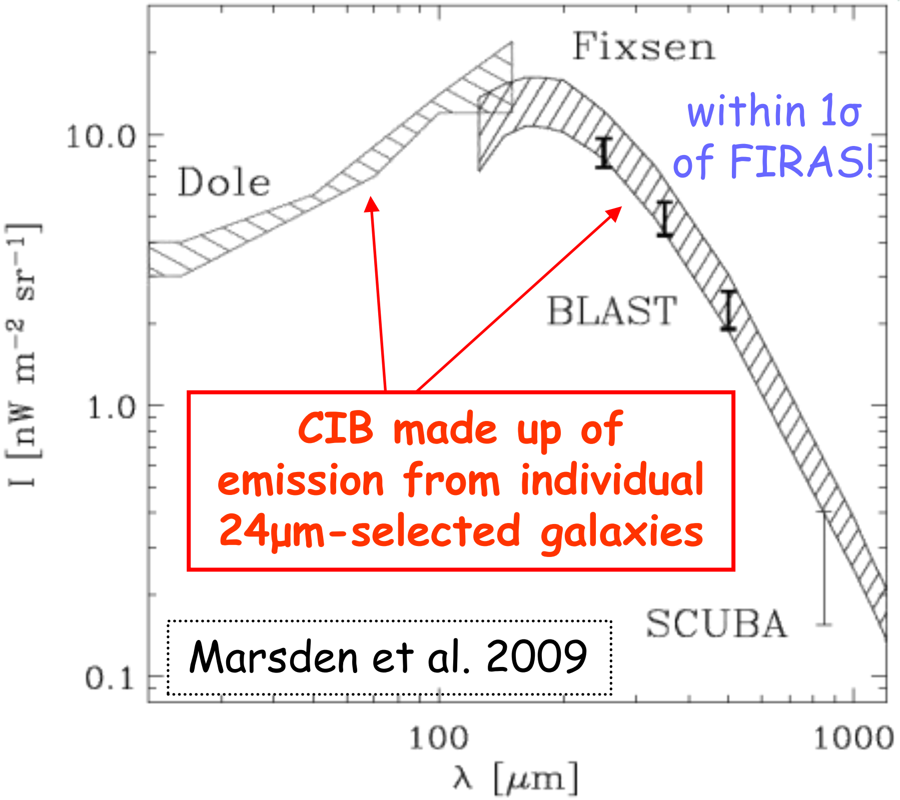
Total stacking

-Stack BLAST maps at positions provided by external 24μm, radio, and X-ray catalogues

- Measuring the mean flux density at BLAST wavelengths of an externally-selected population of sources individually too dim to be detected by BLAST

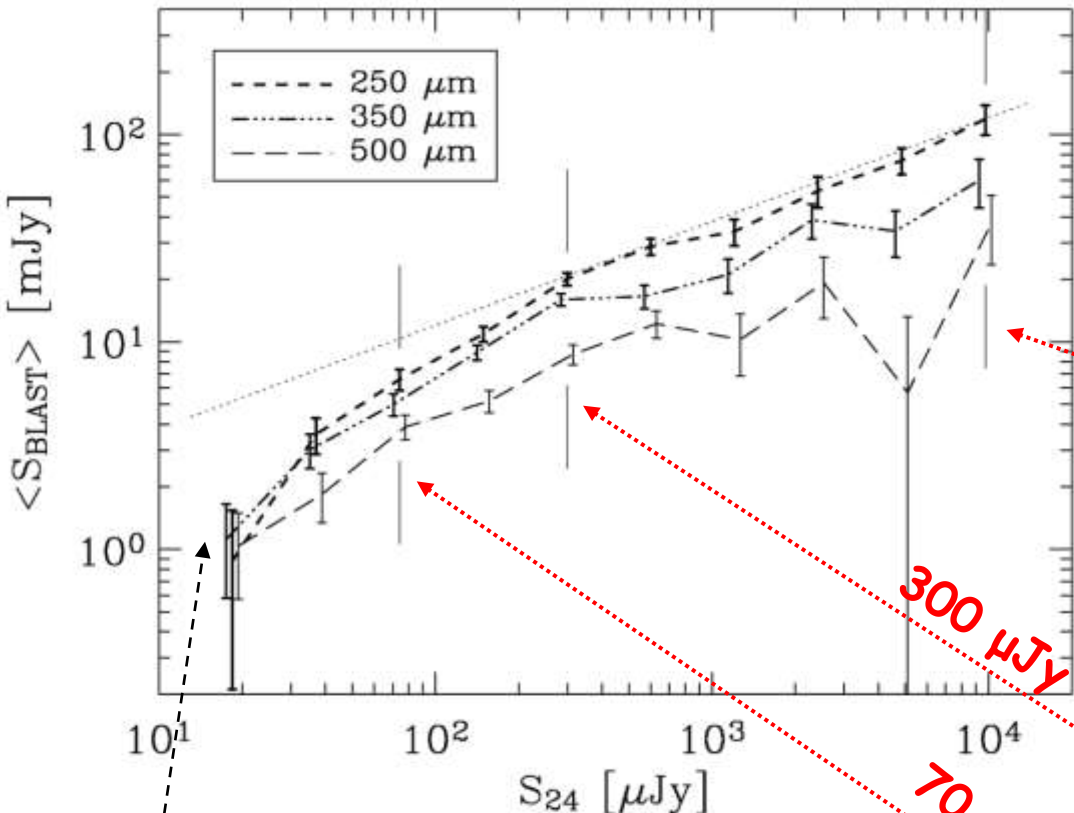
- stacking allows to beat the confusion noise: 24 μm source density is 4 sources/beam at 250 μm. Yet we are safe as long as the <u>catalogue is NOT clustered</u>!!!





NOTE: BLAST bright sources detected at 4σ contribute 20% at 250μm, and 10% at 500 μm of the total CIB resolved by 24μm sources

Total stacking II



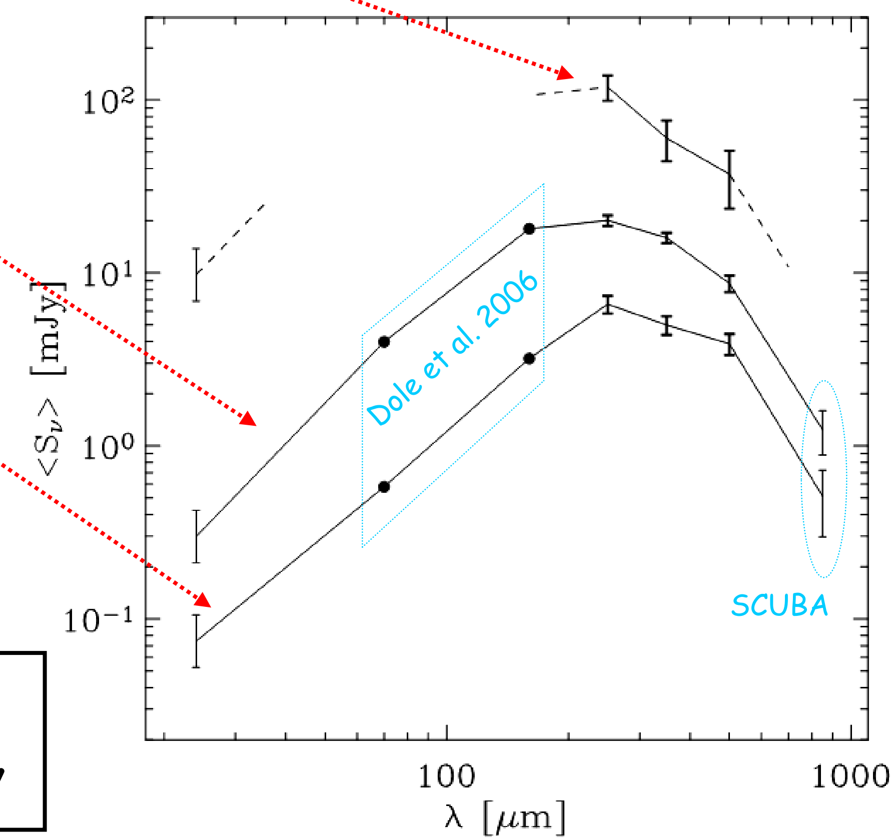
fainter 24 μm sources appear cooler

10 mJy

300 μJy

70 μJy

Marsden et al. 2009



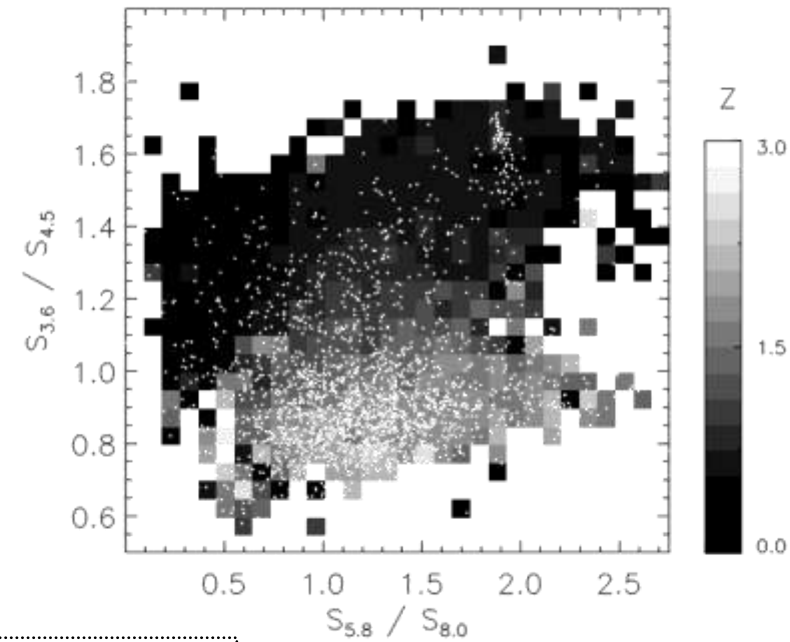
BLAST counts fit predicts 3x10^4 sources per square degree S > 1 mJy

Redshift distribution of the CIB

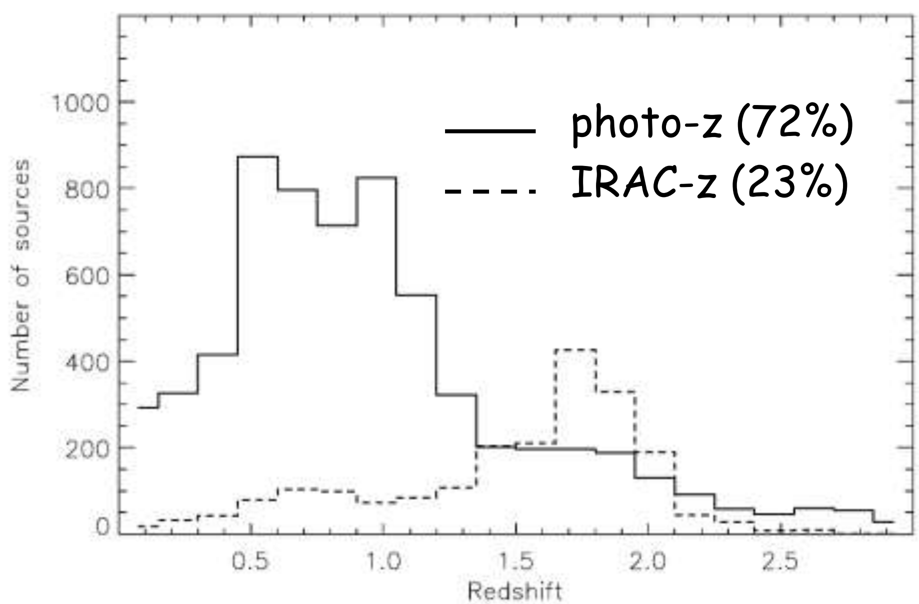
- 72% of 24 μm sources have photo-z from catalogues

- Use IRAC colours to statistically assign photo-z to an additional 23% of sources

→ 95% of sources have redshift ←



Pascale et al. 2009



- Distribution has median at z ~ 0.9

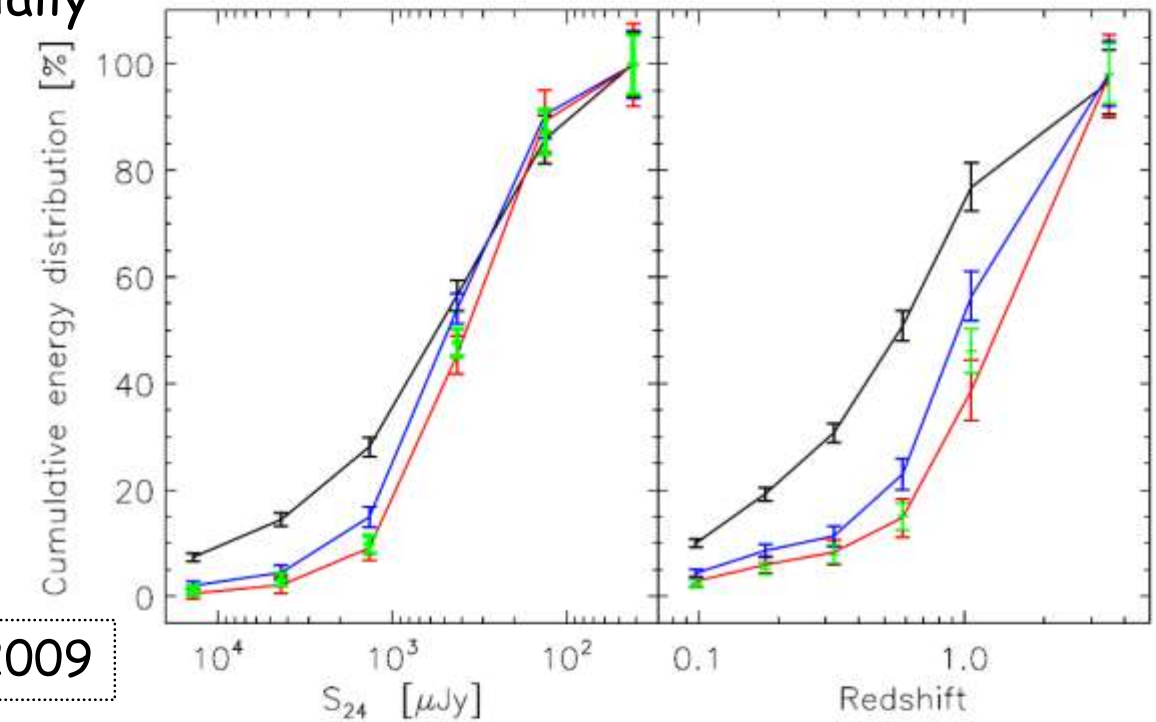
- We can study the contribution to CIB vs redshift

Redshift distribution of the CIB

- Different wavelengths preferentially probe different redshifts

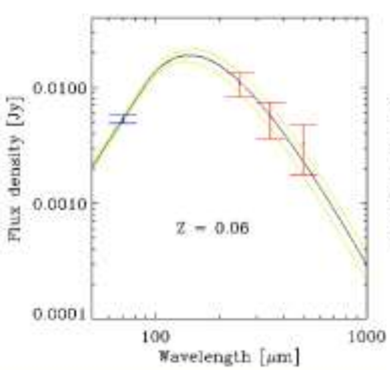
- Amount of CIB generated between $0 < z < 1.1$:

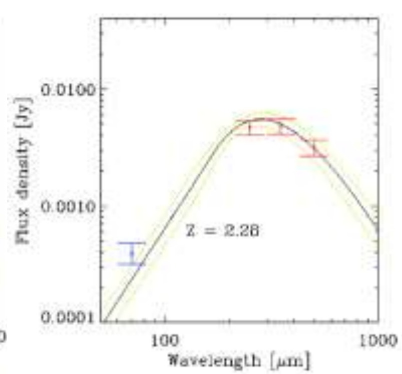
  75% @ 70 μm
  55% @ 250 μm
  45% @ 350 μm
  40% @ 500 μm

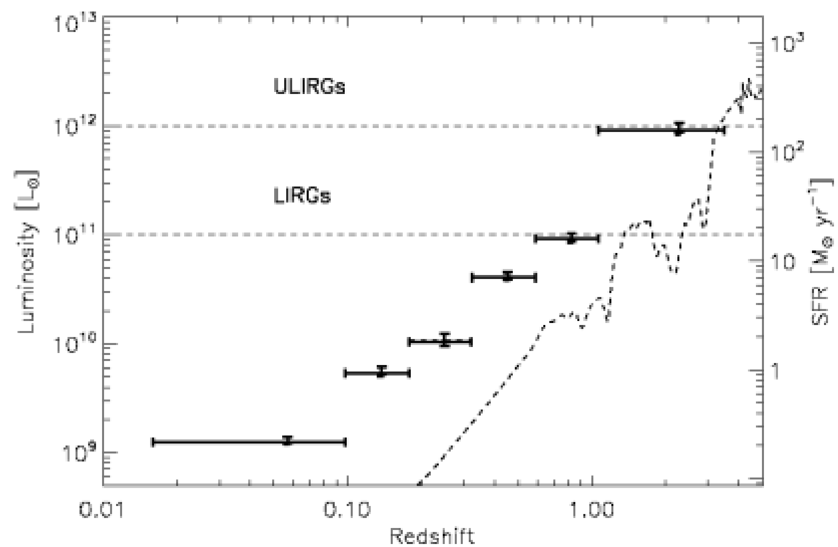


Pascale et al. 2009

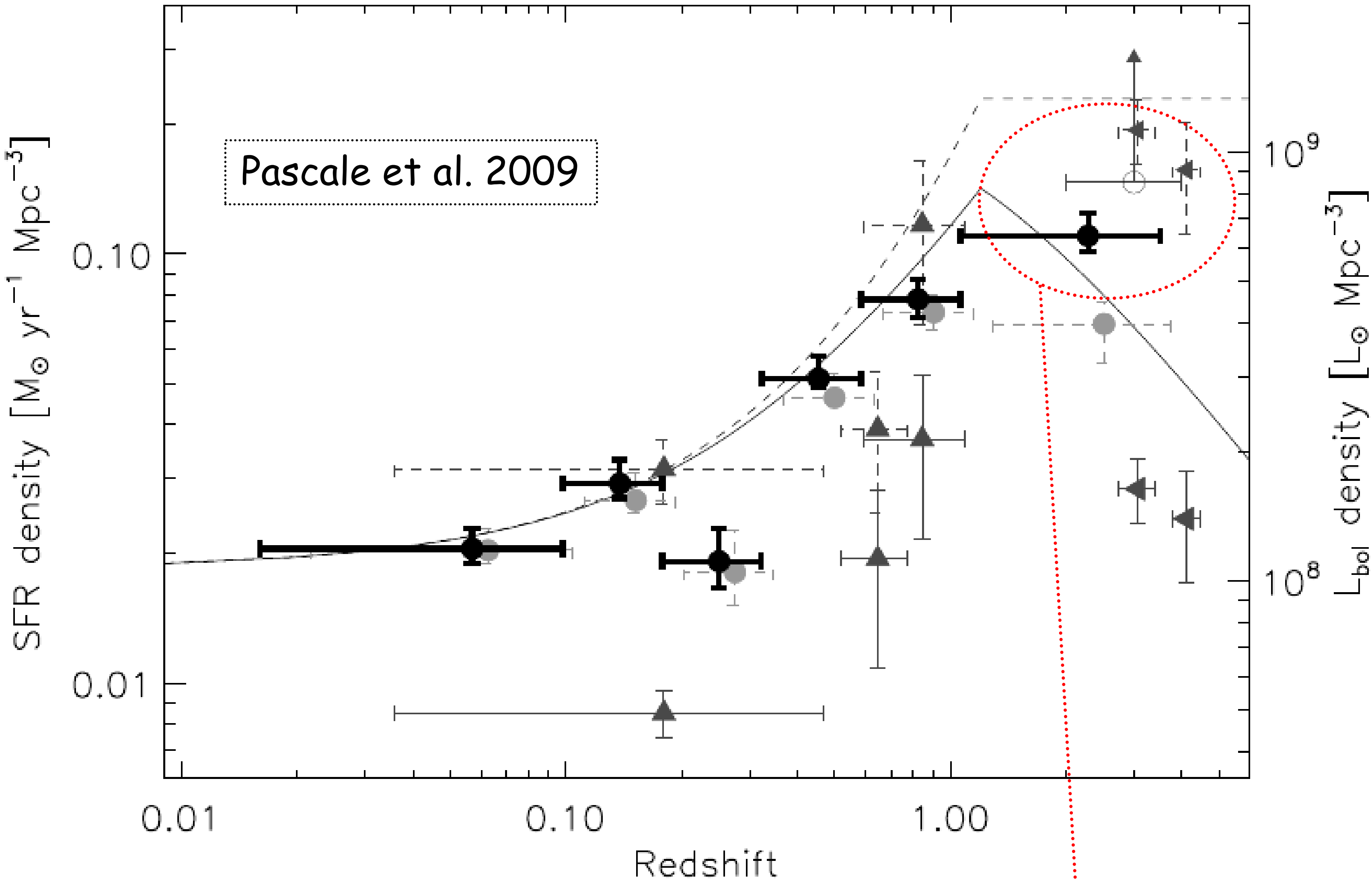
Model fitting allows calculation of rest-frame L_{FIR}, T, SFR, M_d







Star Formation History



Are we missing a fraction of SCUBA galaxies?

High redshift ⟶ faint at 24 μm

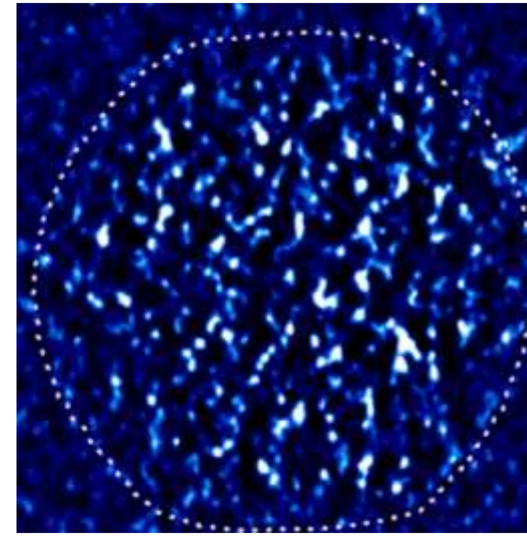
however, small contribution to the CIB…

HOW?

P(D) analysis

source counts

Counting submillimetre sources: P(D)

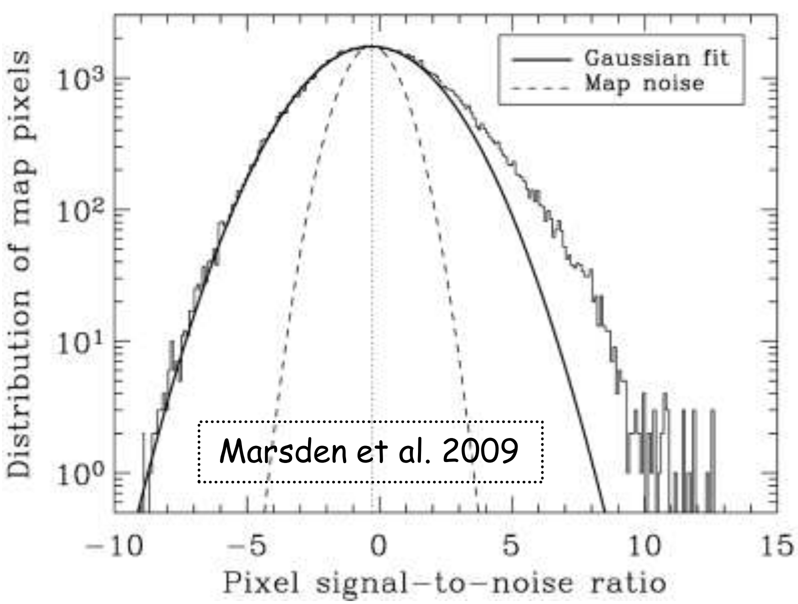


Maps are confused!! Do NOT count catalog members!

- there is more information than just counting individual sources (i.e. source lists)

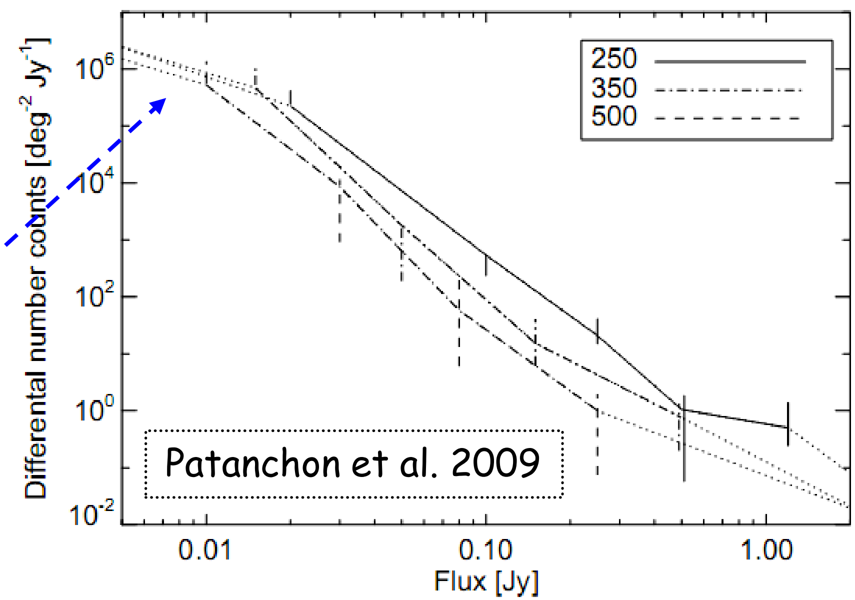
- Eddington bias, source blending and confusion… determining counts from a catalog is a poor and biased estimator unless it is a 10σ catalog!

- fit “counts” directly to the pixel histograms, bright end included! ➡P(D)



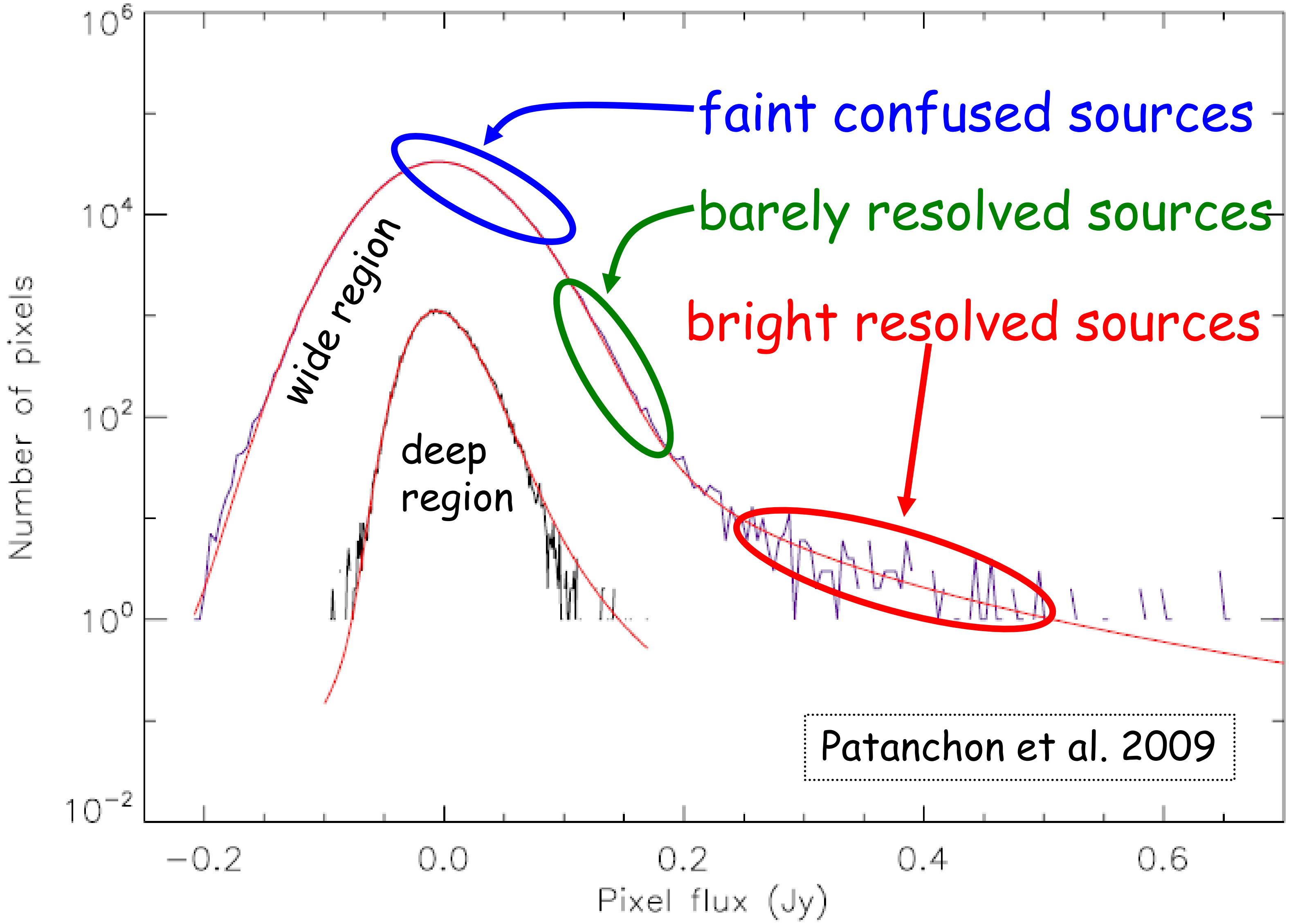
multi power-law model fit to data

break in the slope observed at the faint end

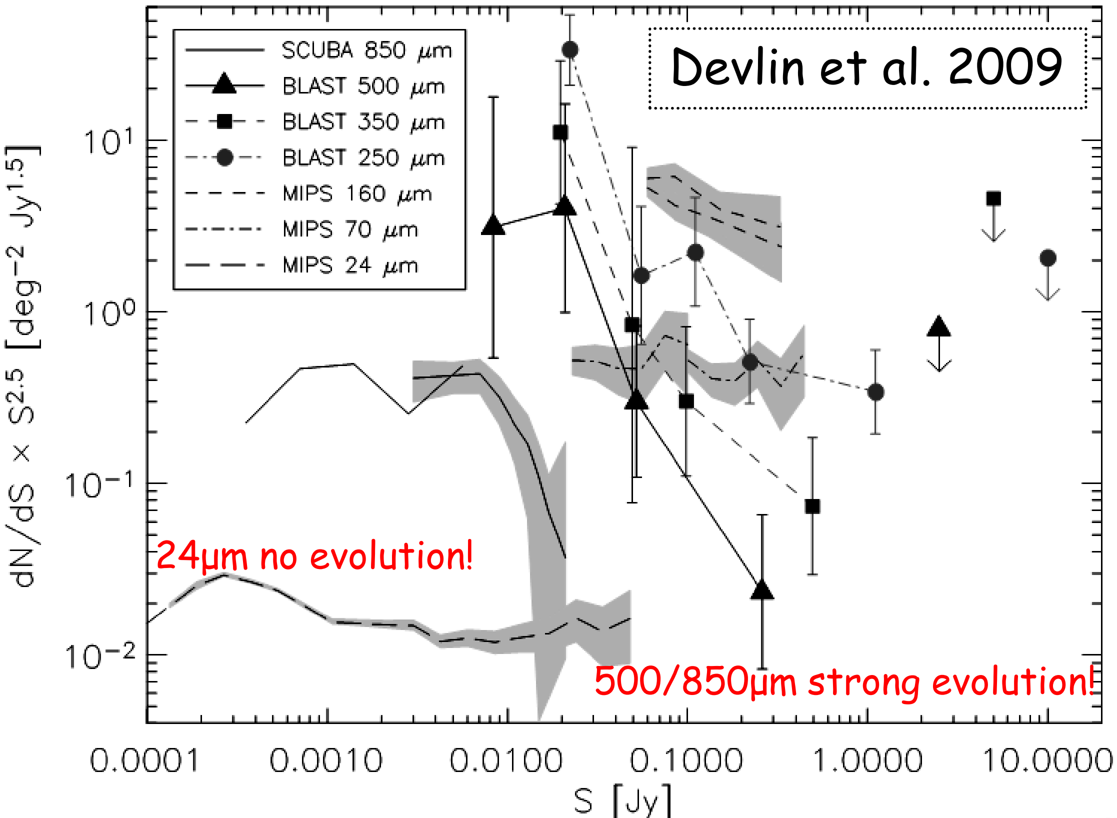


Counting submillimetre sources: P(d)

Map pixel histogram contains information from detected sources, and from confused sources



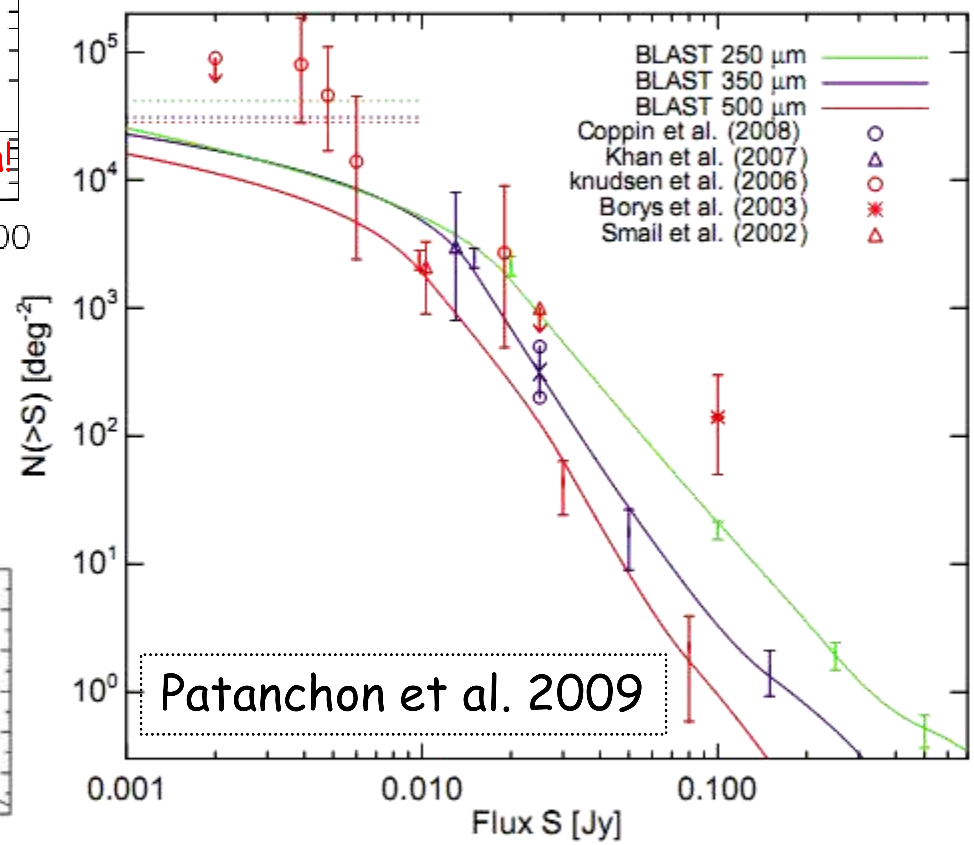
Counting submillimetre sources



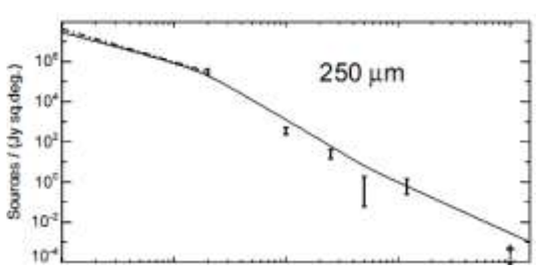
+ first counts estimate at 250 μm

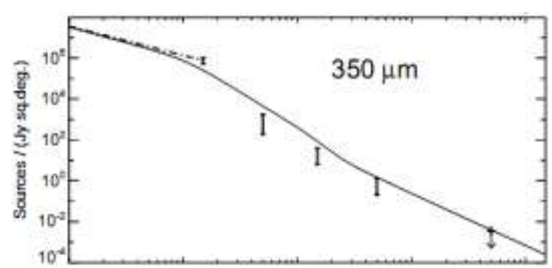
+ slopes steepen with increasing λ

+ at short-λ, FIRB dominated by local sources, at longer-λ by starburst galaxies



Counts are steeper than Lagache models, and at 250 and 350 μm there are fewer sources than predicted





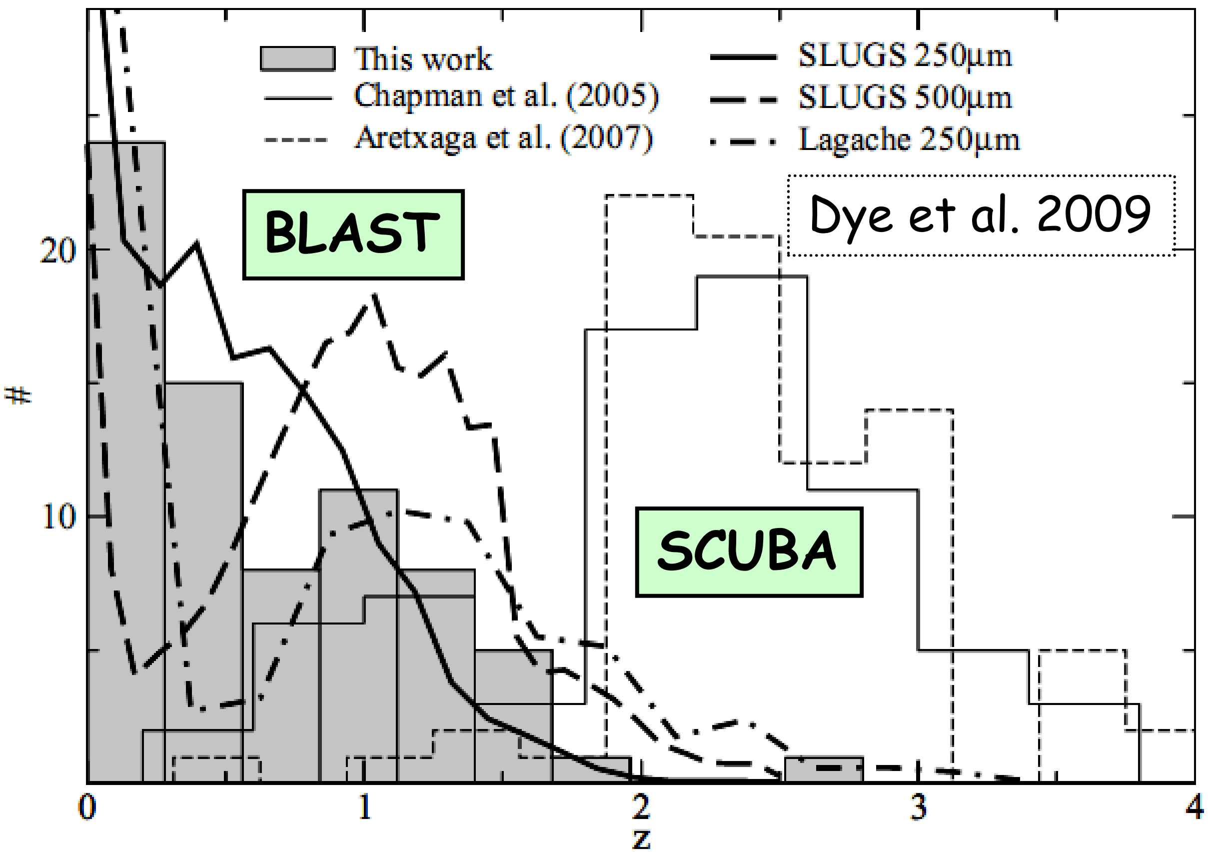
HOW?

ID analysis

counterparts

BLAST ID'd sources: redshift

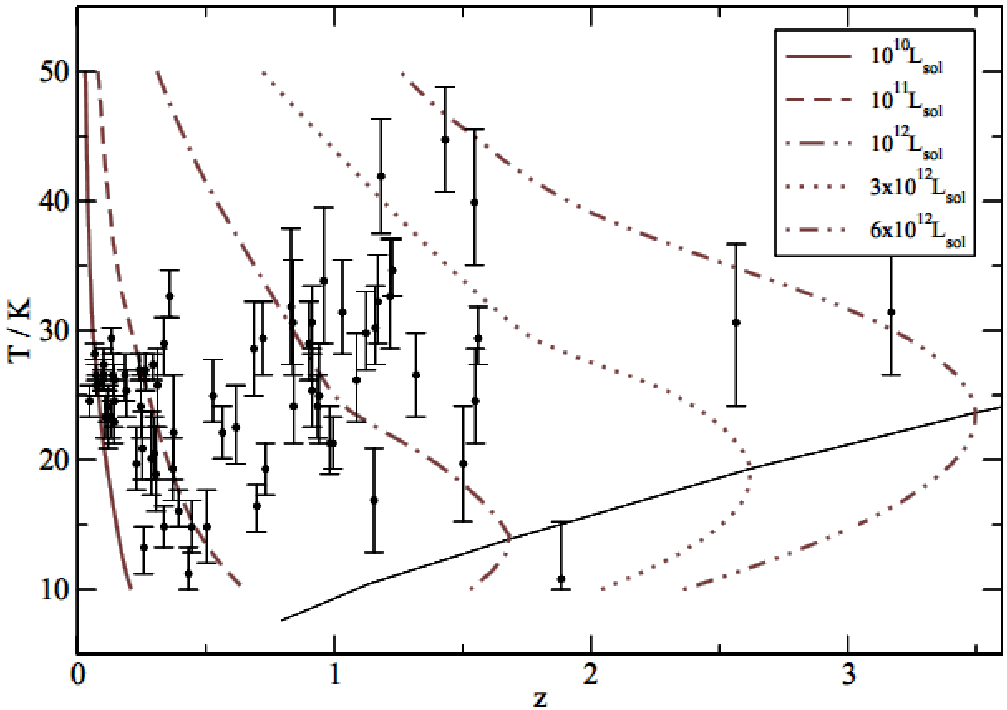
- Blast combined multi-wavelength catalogue list 351 sources detected at more than 5σ in any of the three bands
- Radio or 24μm counterparts are found for ~56% of the sources
- 58% of the IDs have photo-z from public catalogues
- ID success rate decreases with wavelength, and with source flux density



Redshift distribution of BLAST IDs

- robust sample of 74 sources
- median ~0.6, inter-quartile [0.2–1.0]
- SCUBA: median ~2.4 with [1.8-3.1]

BLAST ID'd sources: T and L_{FIR}



Dye et al. 2009

+ Dust temperatures:
  BLAST: ~ 26K
  SCUBA: ~ 36K

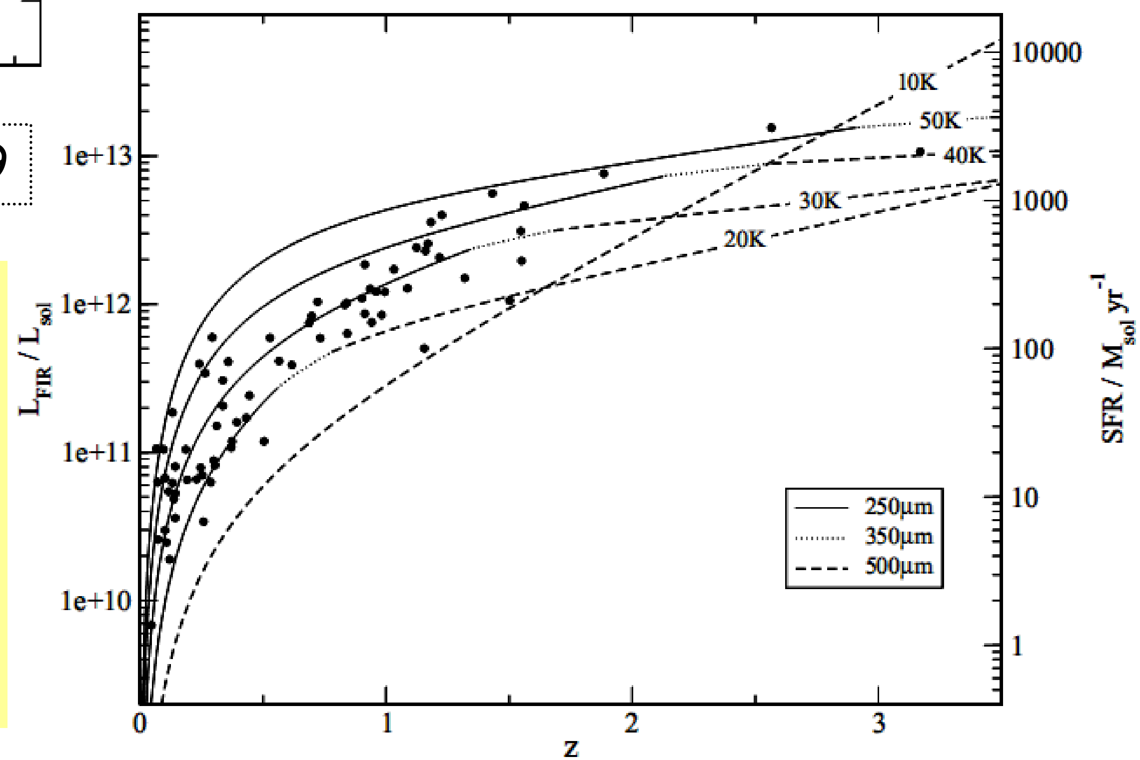
+ hotter sources lie at higher redshifts

+ selection effects

+ bolometric FIR/submm luminosity median ~ $4x10^{11}$ L_{sun}

+ compare with average values from stacking (Pascale et al. 2009)

+ again, selection effects

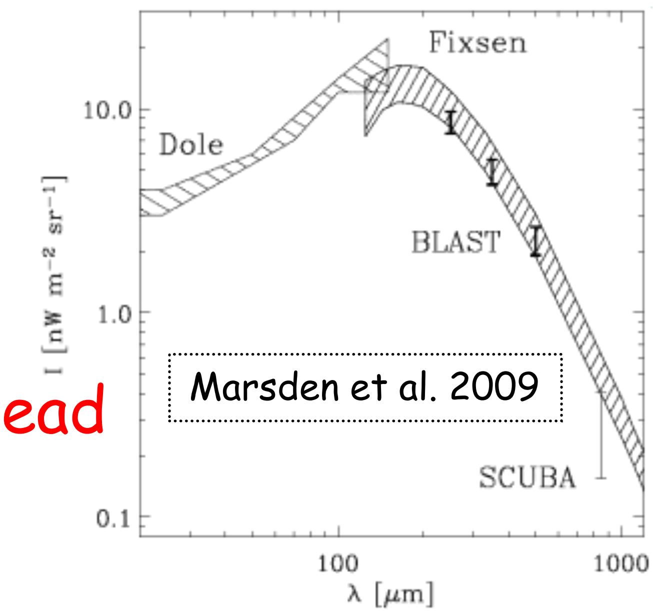


Lessons learned:

+ The CIB is composed of emission from identified galaxies

+ Source lists tell small part of the story

+ statistical approaches must be used instead
  - stacking
  - counts



+ We <u>might</u> still be missing a population of faint 24 μm sources

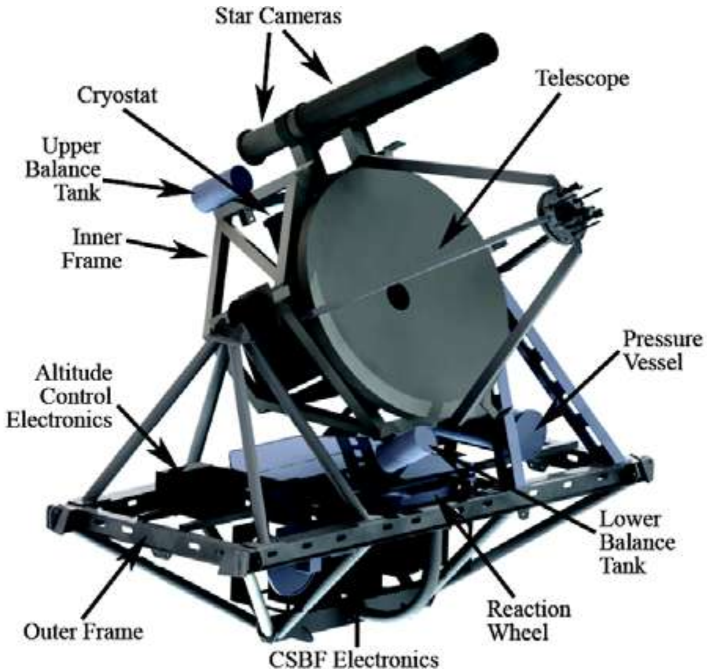
Next...BLAST-pol

- What drives star formation?
- What is the role of magnetic fields?

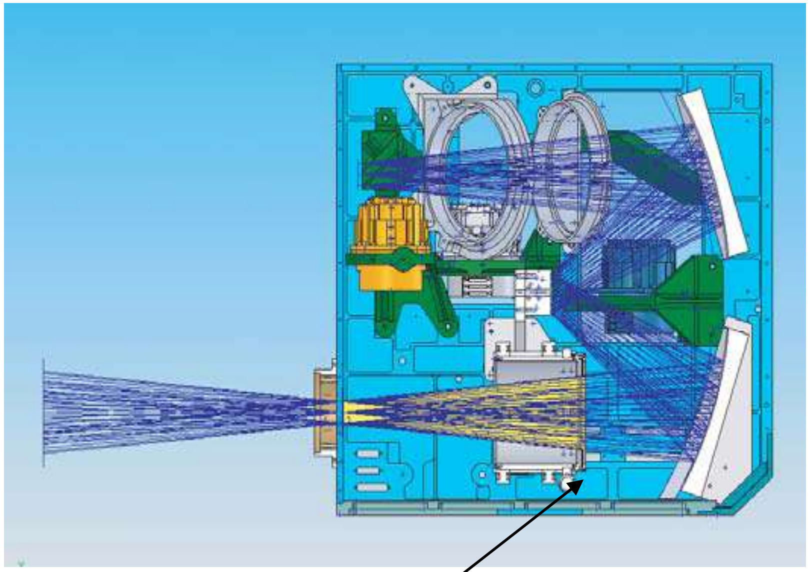
+ Study dust grain alignment with the magnetic fields

+ Submillimetric polarimetry is a promising technique to probes dense optically-obscured regions not accessible in the optical

+ Also, study properties of high latitude cirrus



Existing BLAST Optics



Half wave plate polarimetry

Flight: December 2010

Watch the movie: http://blastthemovie.com/

Source Stacking

Stacking is a powerful tool to estimate the contribution of one class of objects to the background

INGREDIENTS

- Catalog of source positions: N_{ij}
- A zero-mean map: $Dij = S_0 (N_{ij} - \mu)$
- $\mu = \langle Nij \rangle$

RECIPE

The zero-leg cross-correlation of the map with the catalog is an estimator of the total flux contributed by these sources

$$D * N = S_0 \sum_{ij} N_{ij} (N_{ij} - \mu) = S_0 N_{pix} \mu$$

1) Poisson statistics is assumed: no clustering
2) This statistical method works even if the map is confused, or the surface density of the catalog is large compared to the scale of the beam