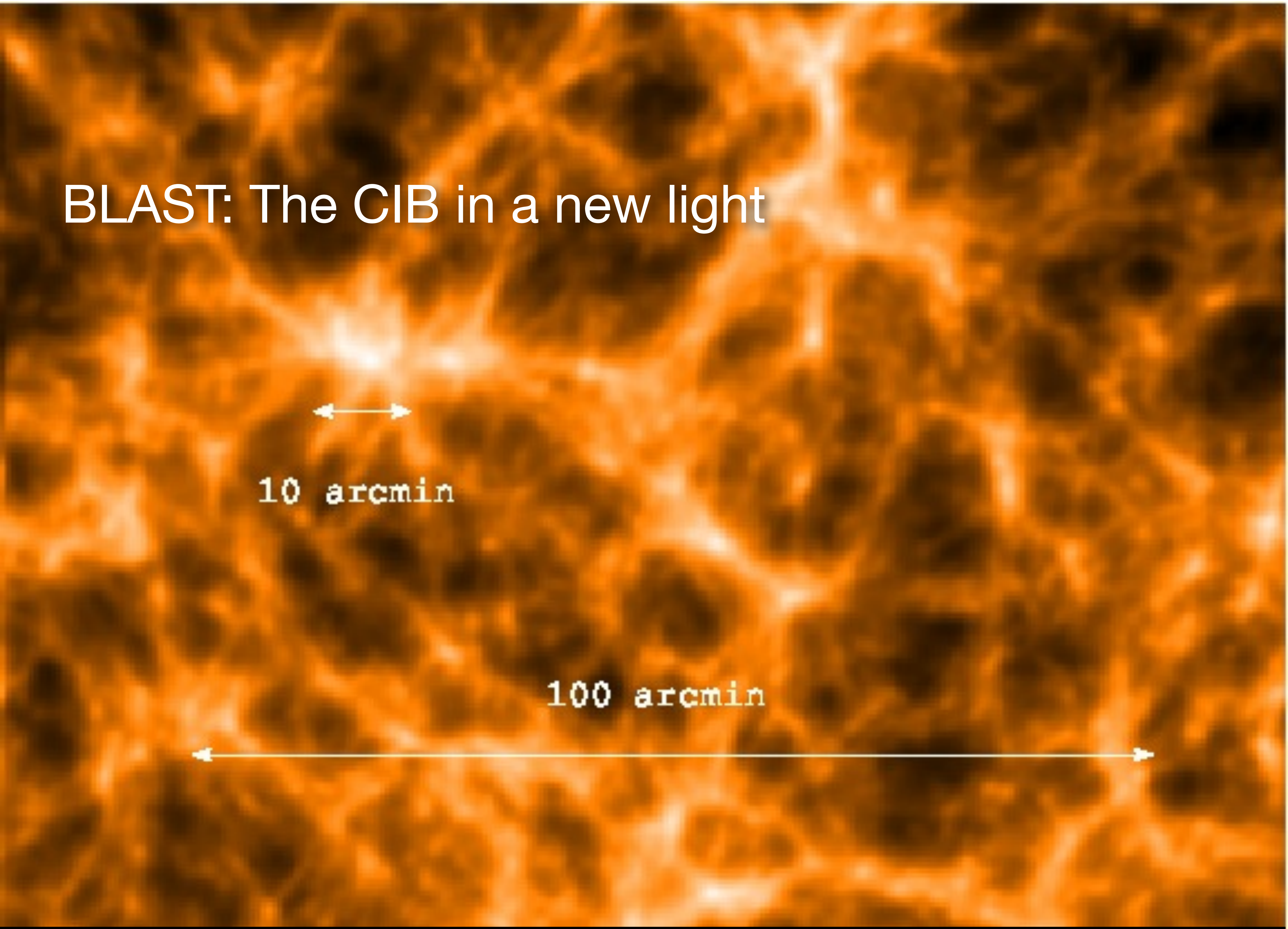
BLAST: The CIB in a new light



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Outline

- Motivation
  - ◉ Cosmic Radiation Budget
  - ◉ Cosmic Far-Infrared Background (CIB)
  - ◉ Correlations in the CIB
- Making the Measurement
  - ◉ The BLAST Experiment
  - ◉ Data Preparation and Map Making
  - ◉ Measuring the Power Spectrum
- Results
  - ◉ Resolving the Background
  - ◉ Source Counts
  - ◉ Clustering of Star-forming Galaxies

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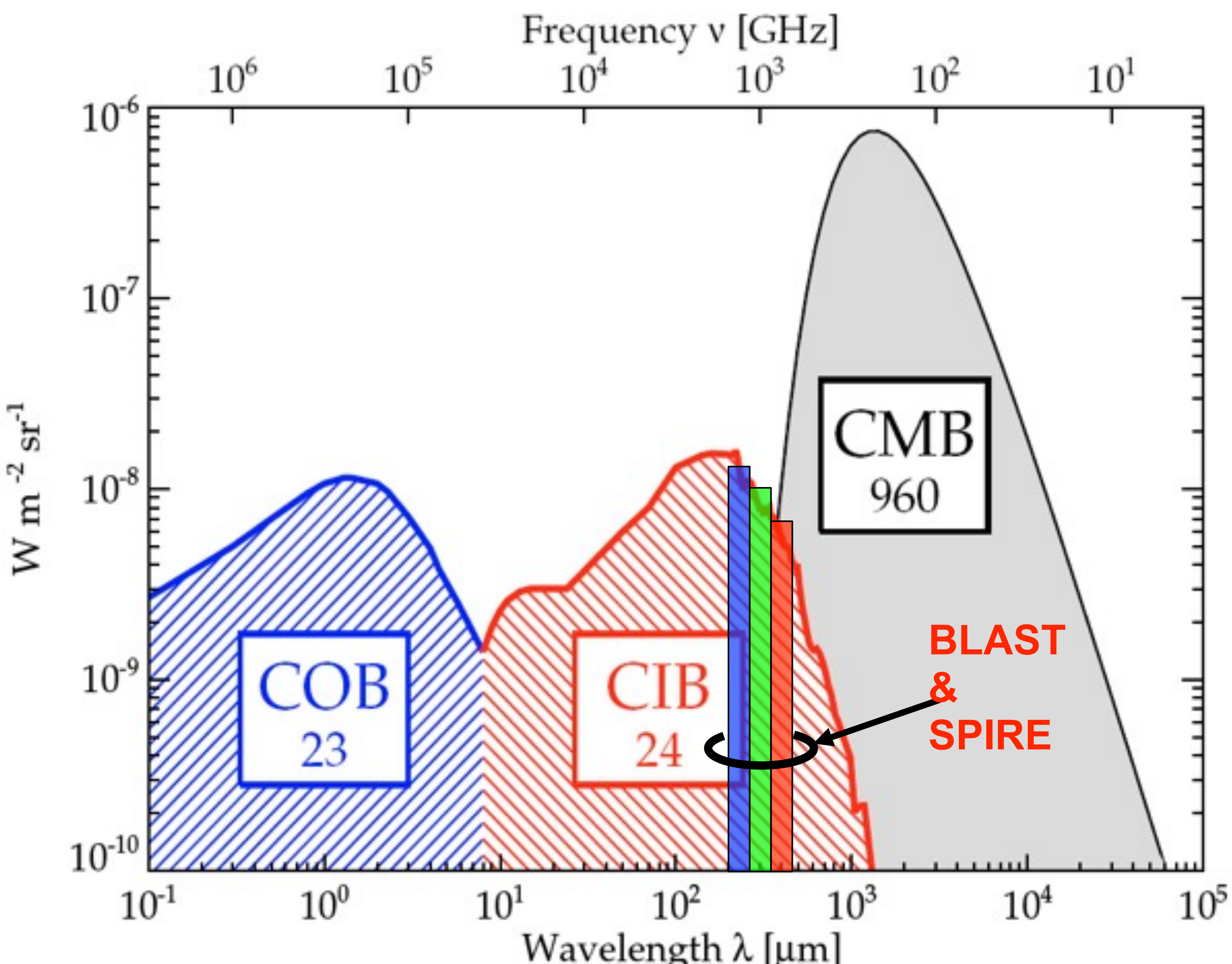
Cosmic Radiation Budget

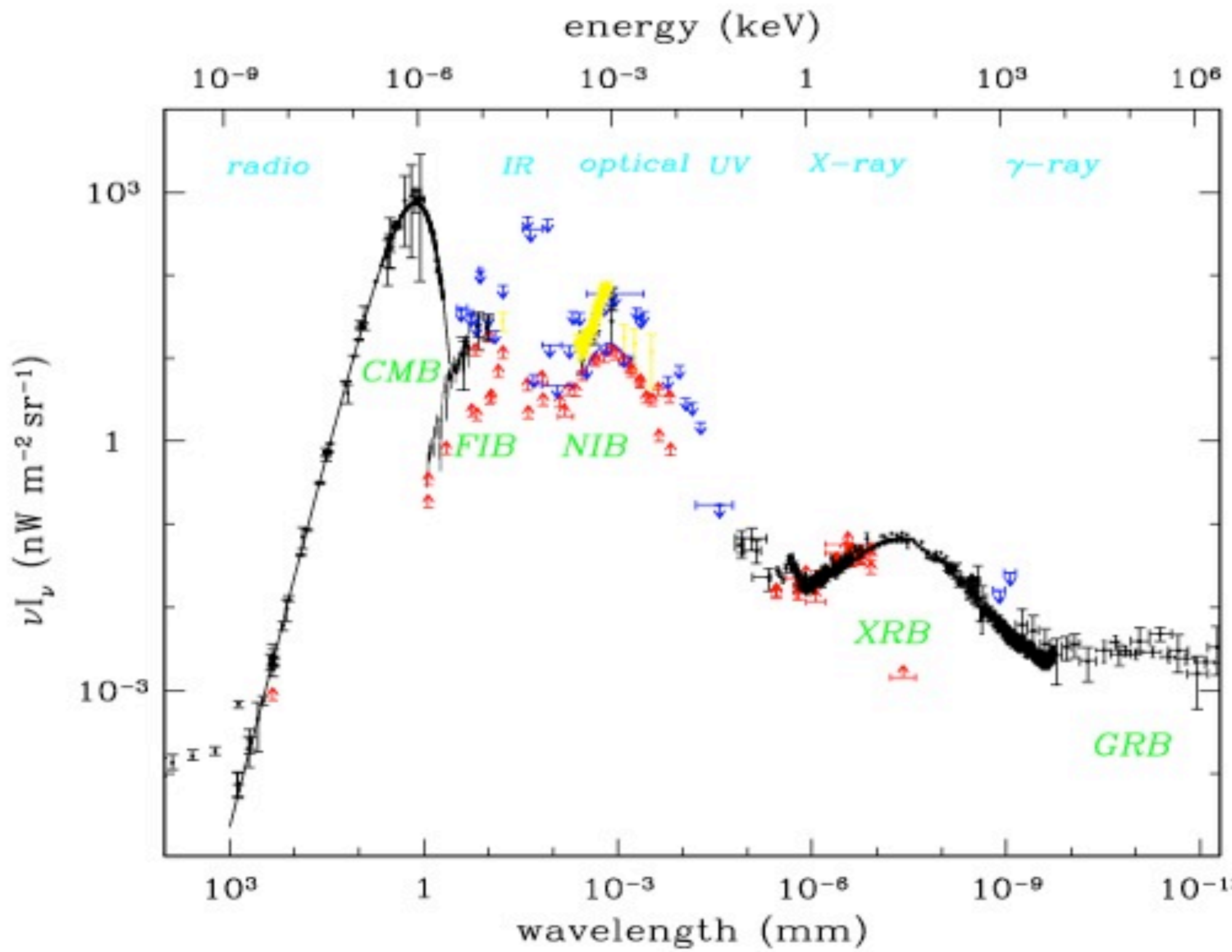
- After CMB, CIB makes up ~50% of the total radiation budget.
- Historically, optical background has attracted the most effort.
- The focus is shifting towards other wavelengths. Eg., in the infrared:
  - Spitzer
  - BLAST
  - Herschel
  - Planck
  - SCUBA II
  - ALMA



Dole et al. 2006

Understanding the CIB

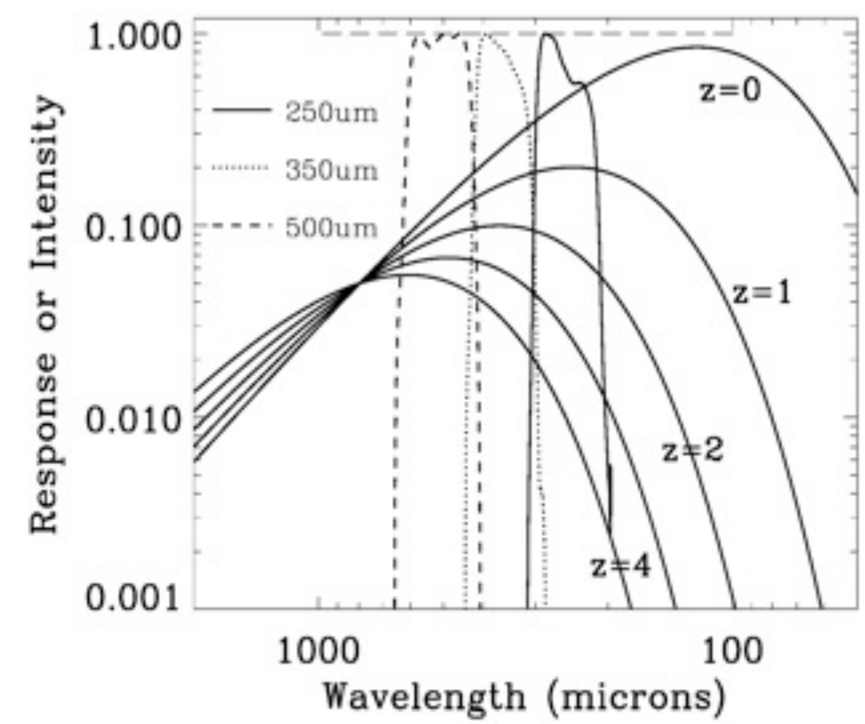
- What makes up the background?
- Dusty galaxies make up a large fraction of the total CIB, but it is all of it?
- How many galaxies for a given flux are there?
- Are they randomly distributed in space or are their locations correlated?

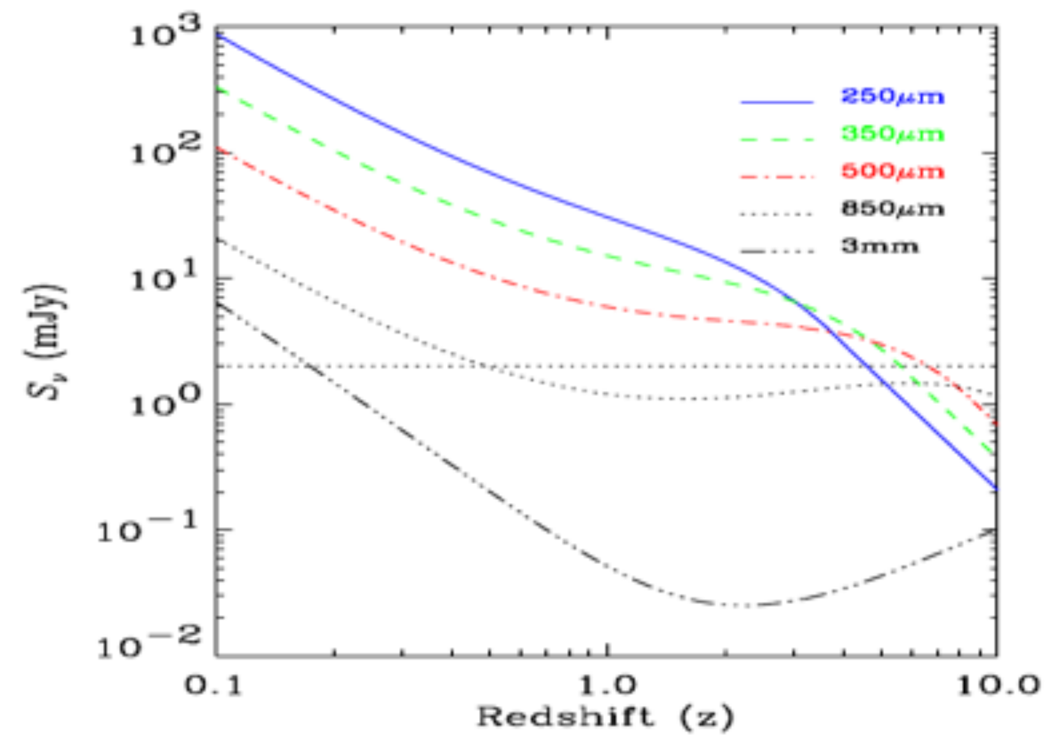


From D. Scott

Observing Dusty Galaxies

- Dust is heated by absorption of UV photons, and emits as a modified blackbody.
- Dust is heated to ~30 K, with emission peaking at ~160um.
- For high-z galaxies, this peak shifts to redder bands.
- Negative k-correction makes high-redshift galaxies easier to observe.

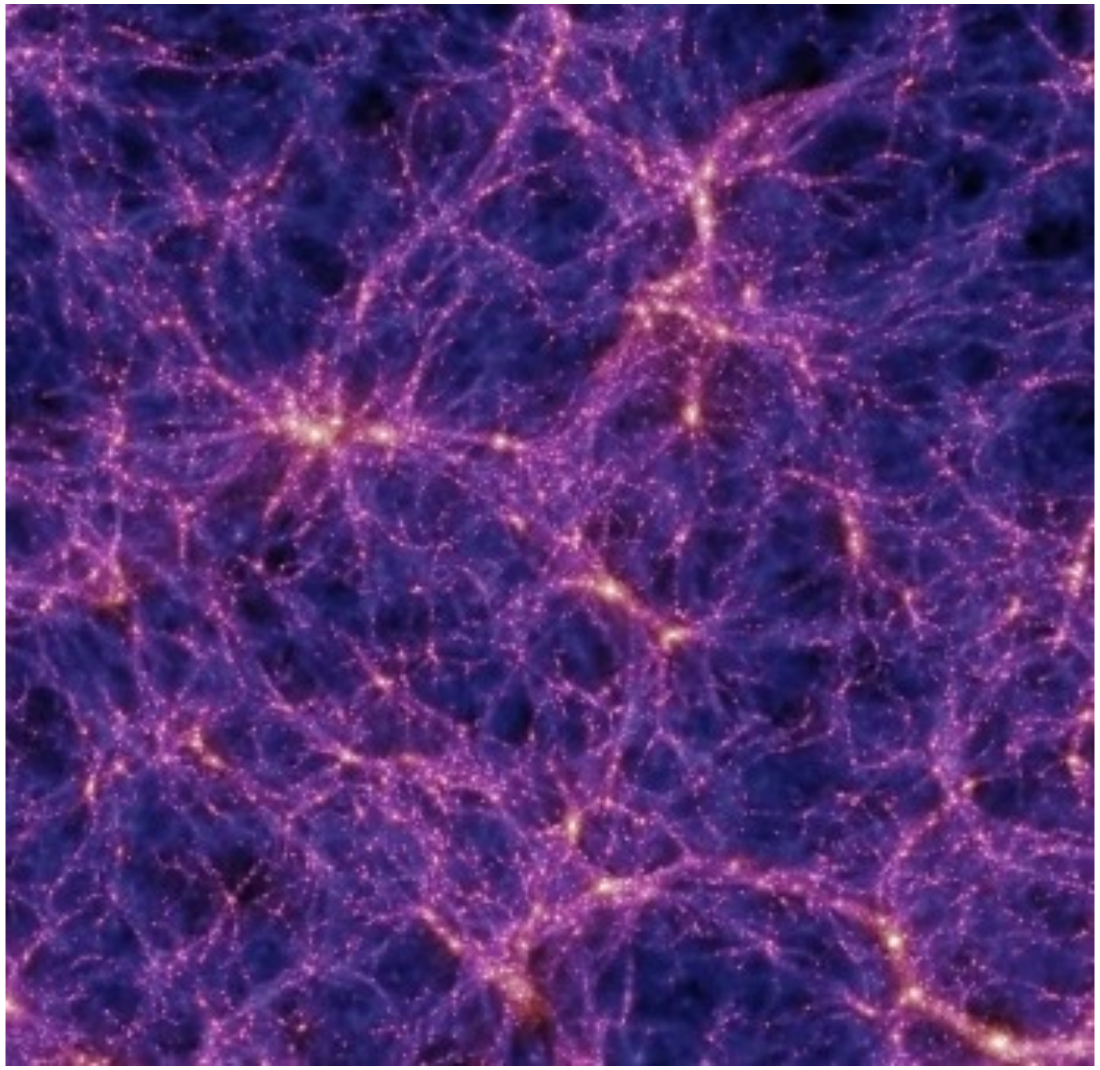




Clustering of Galaxies from Background Correlations

- Galaxies are not randomly located; in general, they trace the high density peaks of the dark matter distribution.
- Correlations of star-forming galaxies describe how strongly they trace the dark matter, which in turn gives a picture of what environmental conditions favour star formation, or alternatively, shut-down star formation.
- We can measure the correlations in the CIB and identify the signal from clustering of galaxies.
- We can relate the correlations of star-forming galaxies to those of the underlying dark matter through the bias.

Millenium Simulation @ z ~ 1.5



65 Mpc

Springel et al. (2005)

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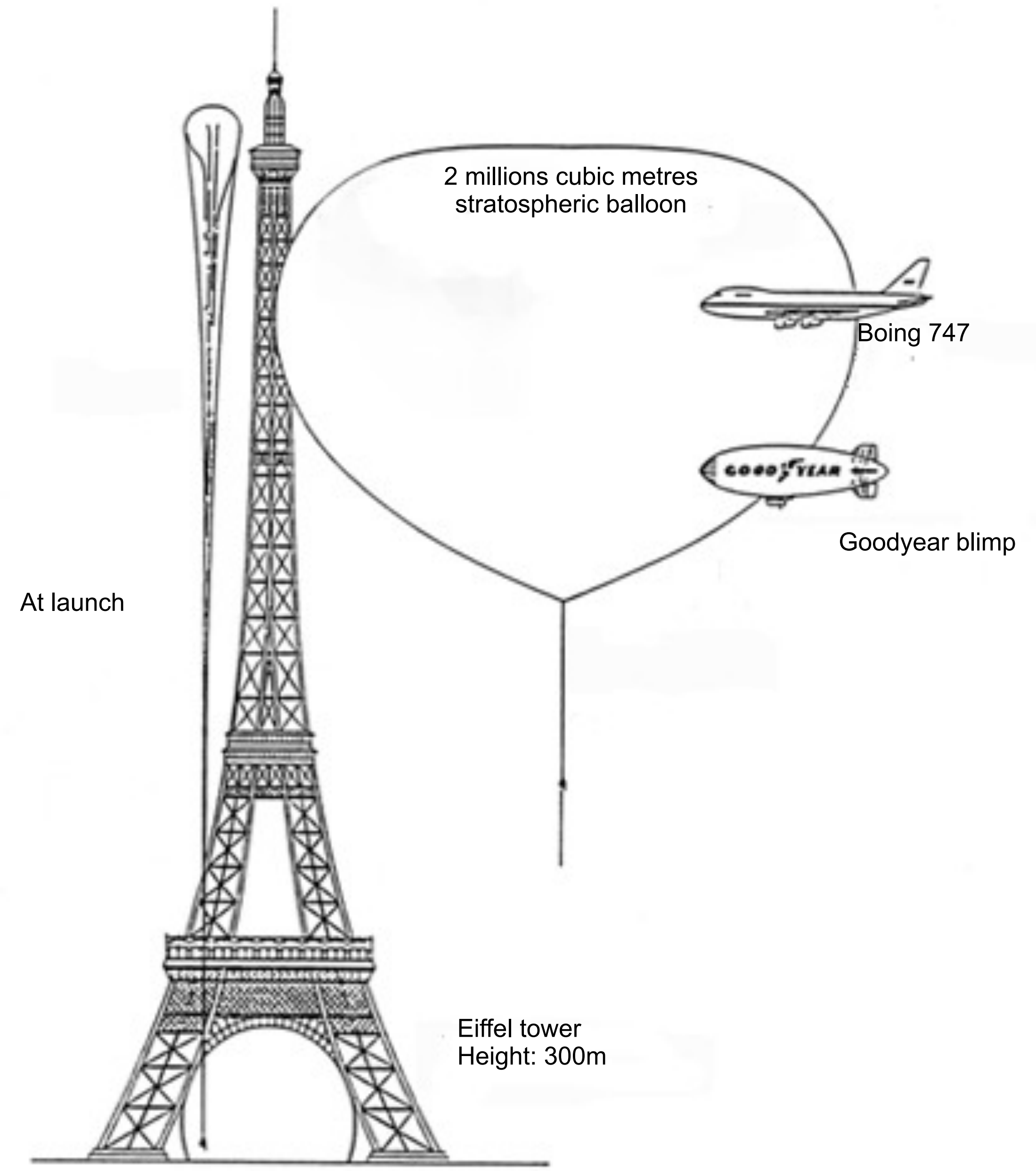
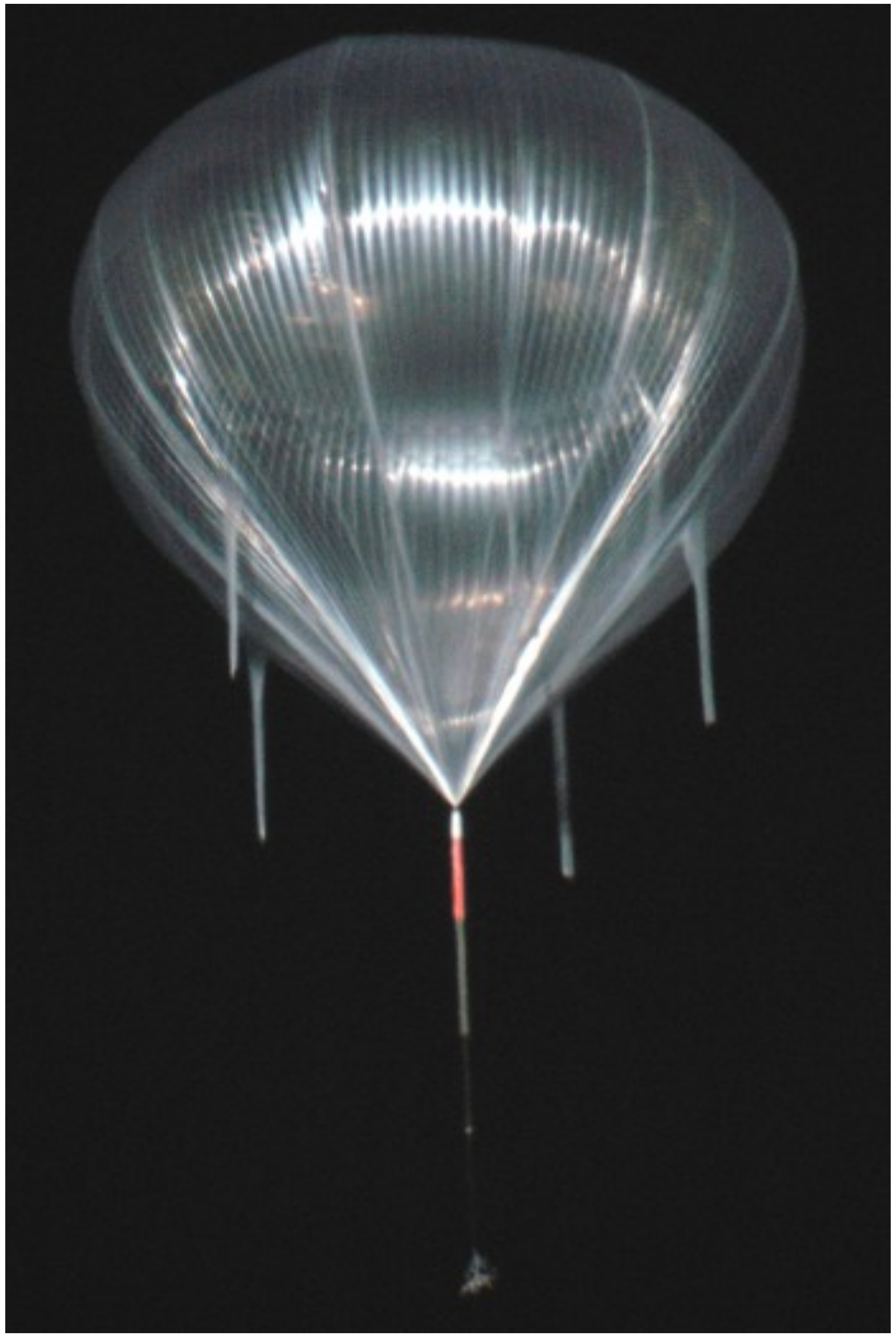
BLAST

- Telescope
  - 2m Primary
  - 35-40 km altitude (>99% atmospheric emission)
  - alt-az pointing system
  - autonomous / satellite commanding
  - diagnostic data via satellite
- Camera (SPIRE prototype)
  - 250, 350, 500 µm (244 bolometers)
  - 30, 41, 60 arcsec FWHM beams
  - NEFD ~ 250 mJy sqrt(s)

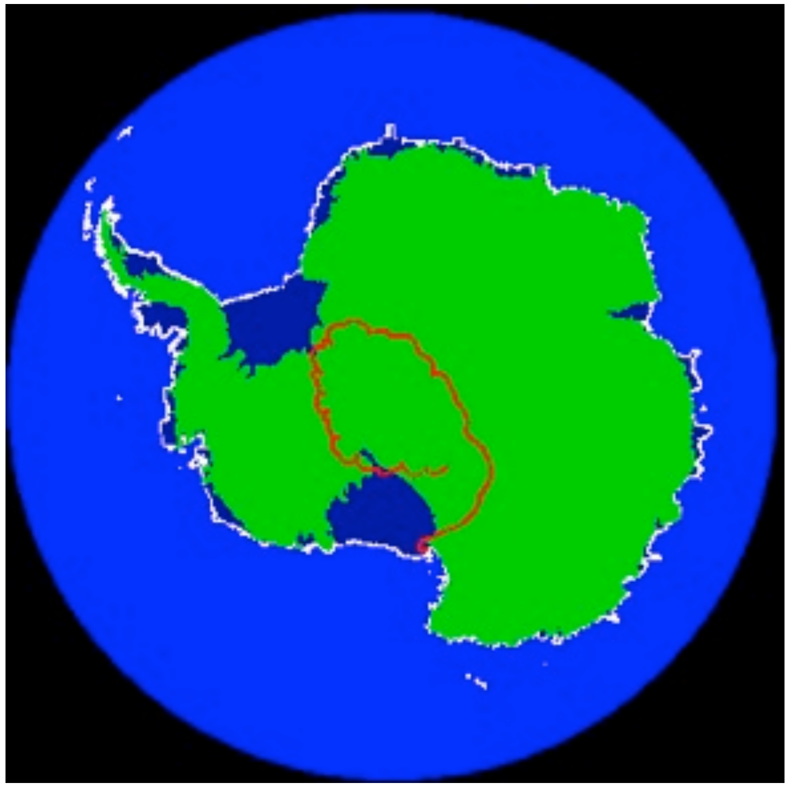
Balloon into ~space (above 99.5% atmosphere)

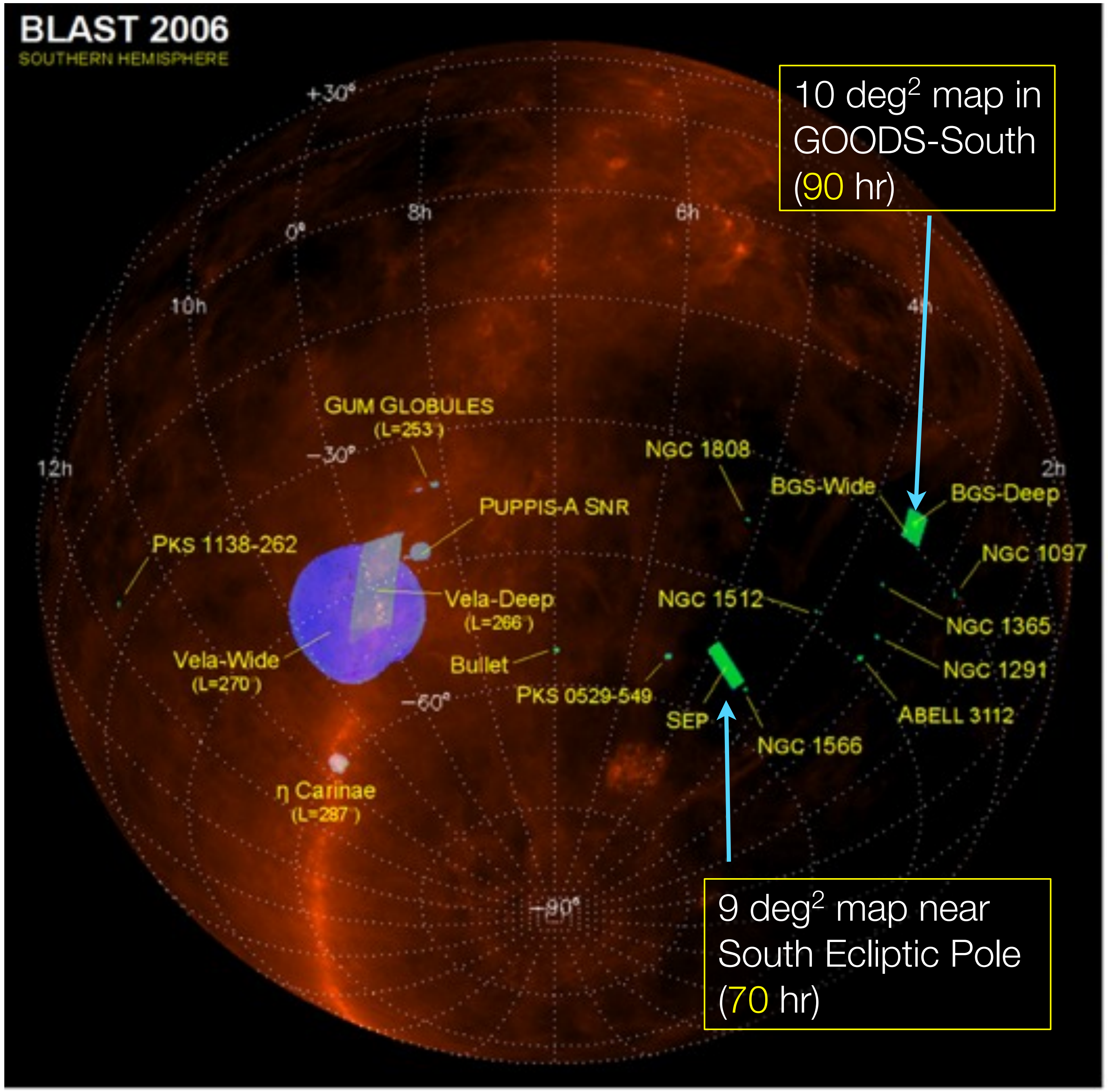




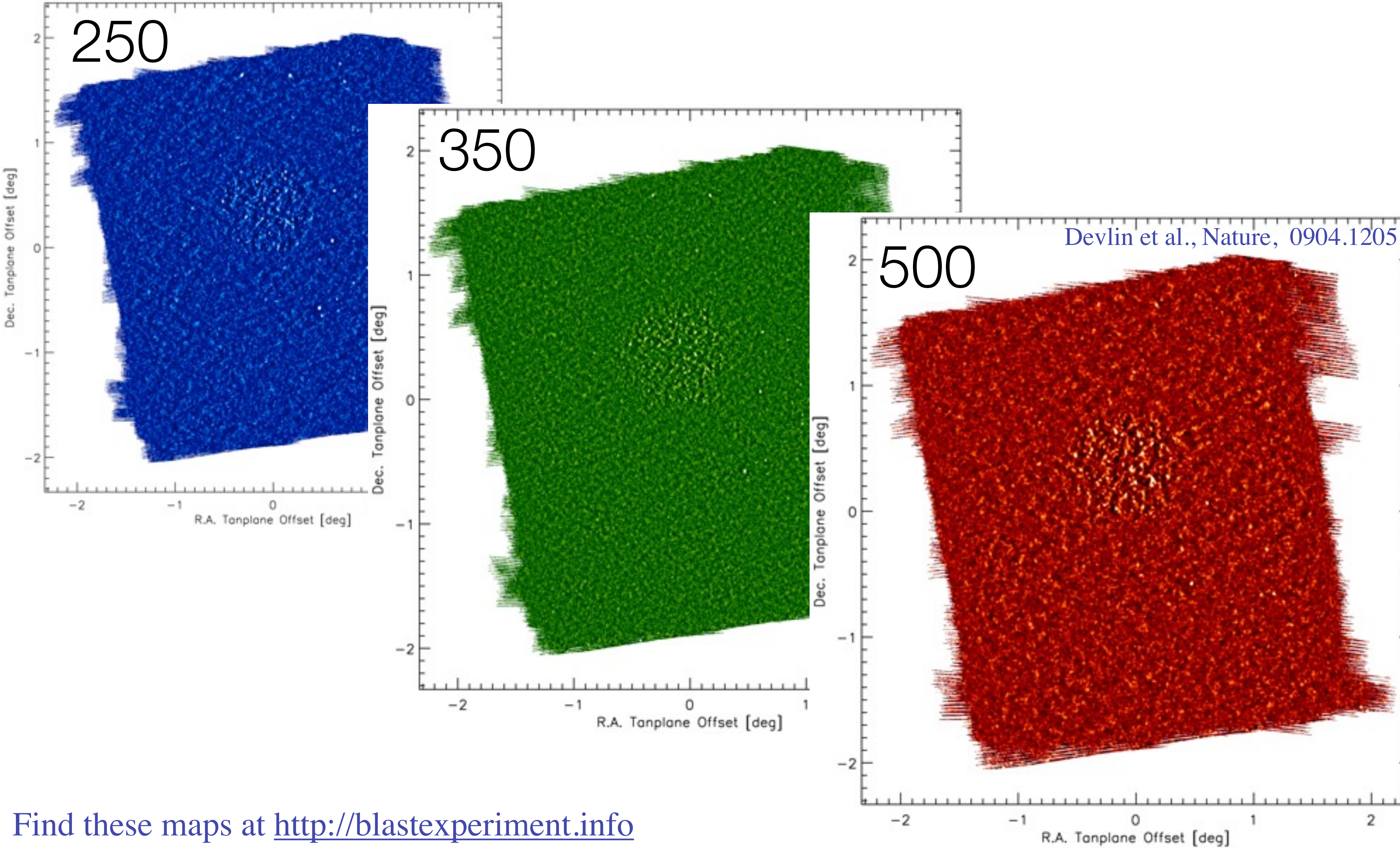
Fields

- BLAST 2006:
  - 11 day circumpolar flight from McMurdo Station, Antarctica
- Extra-Galactic Surveys: 175 hours
- Galactic Surveys: 45 hours





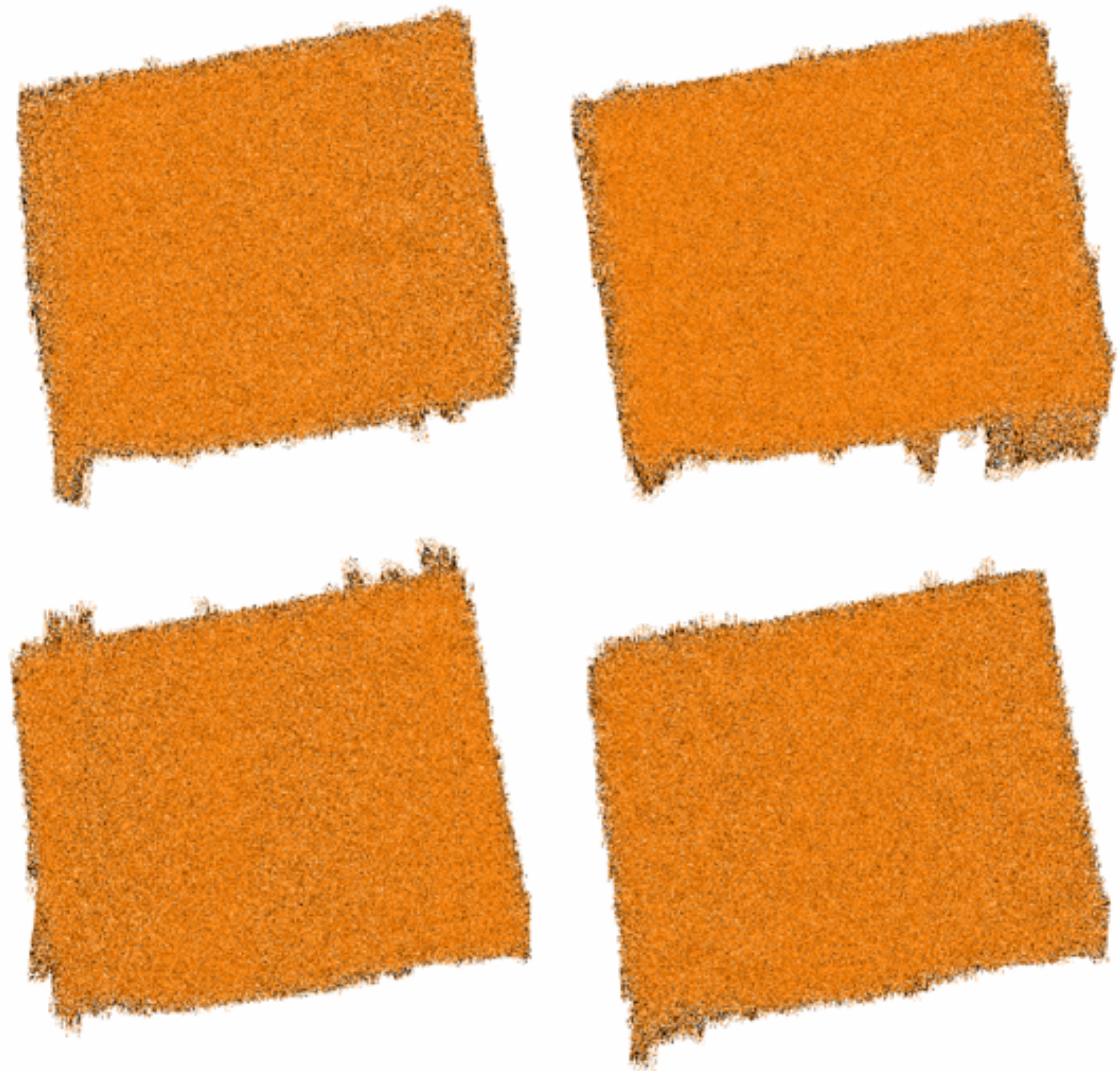
Public BLAST Maps



Find these maps at http://blastexperiment.info

Sub-Maps for Correlation Analysis

- Wide-only timestreams selected.
- Common-mode is NOT removed.
- Timestreams filtered at 0.2 Hz.
- Timestreams divided into four equal parts and made into 4 unique maps.
- Extract most uniform 6 deg^2



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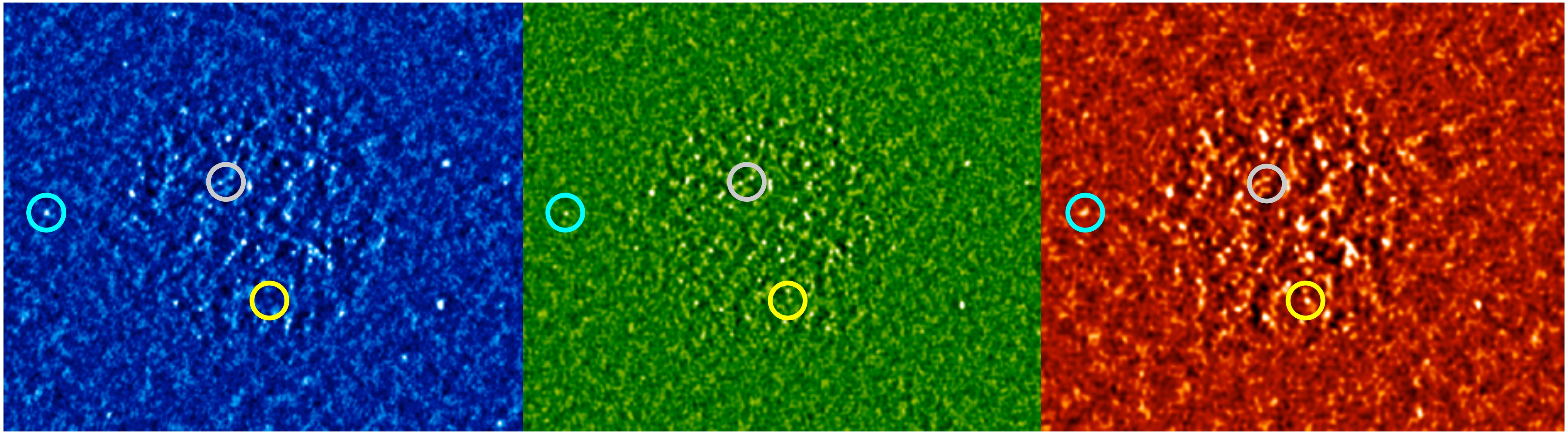
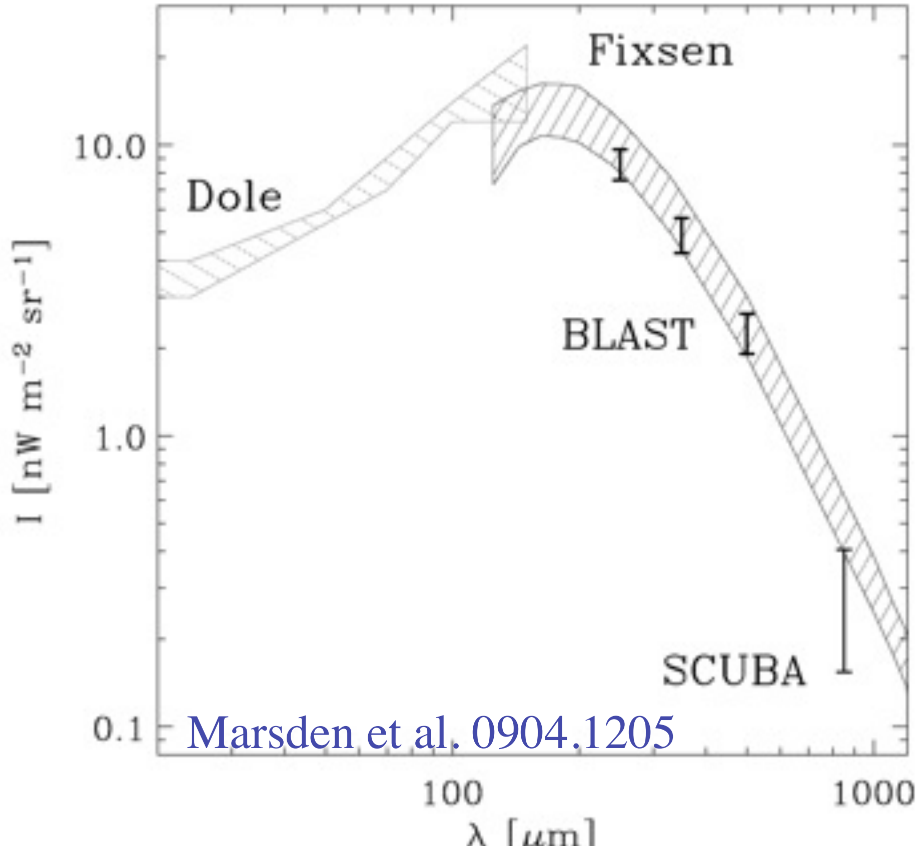
Color Selected Sources

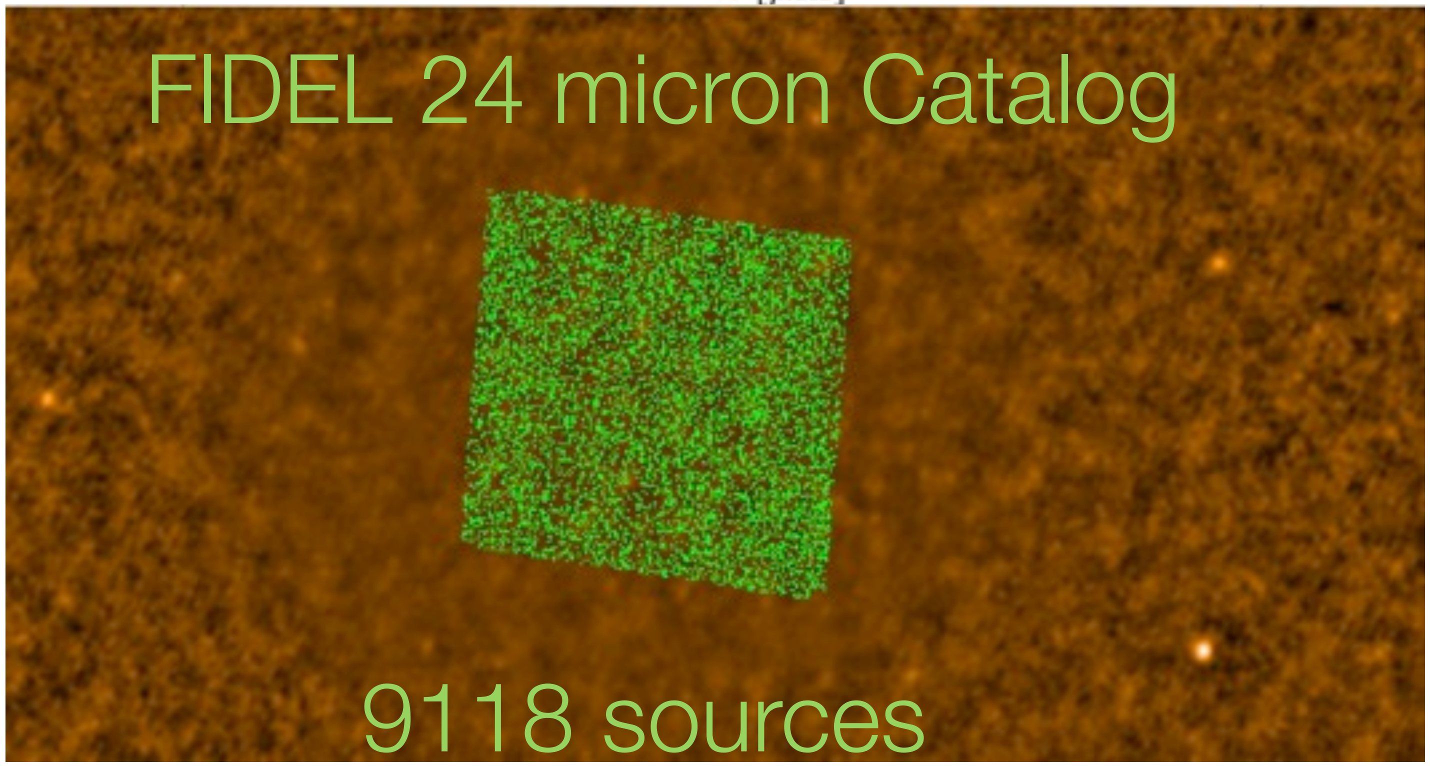


z=0.169 IRAS galaxy
z=1.1 Spitzer/SWIRE selected Galaxy
z~3 Strong BLAST 500μm emitter

Stacking : Resolving the Background

- Determine the contribution of a population of sources - too dim to be individually detected - to the background.
- Use ancillary data to go beyond noise properties of BLAST map.
  - Find that *all* of the CIB is composed of emission from identified galaxies.
  - BLAST 3σ catalog is only 15% of the total intensity.



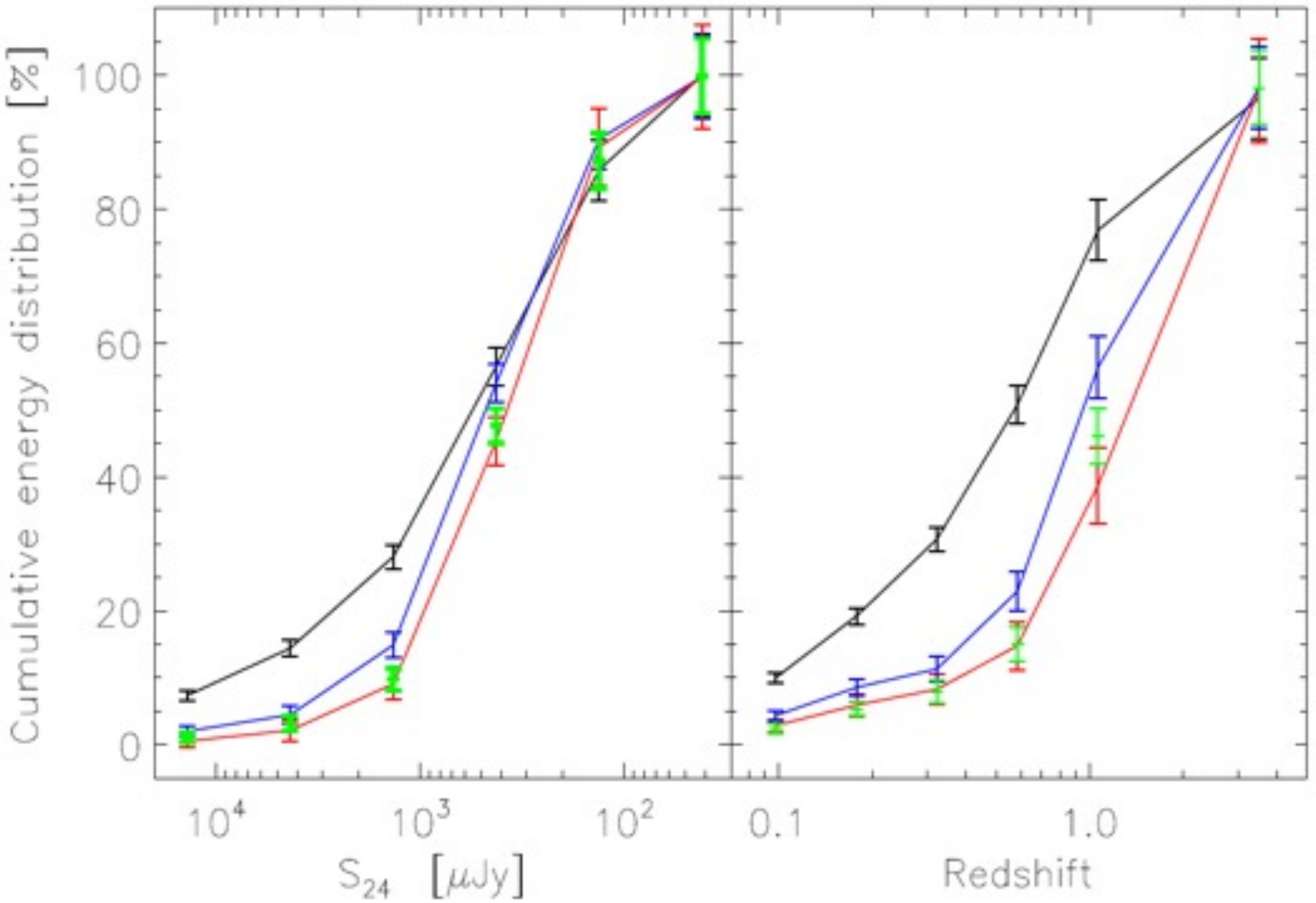


Stacking: Redshift Distribution of the CIB

- 95% of 24 μm sources have redshift information (72%photo-z)

-Different wavelengths probe different ranges of redshift.

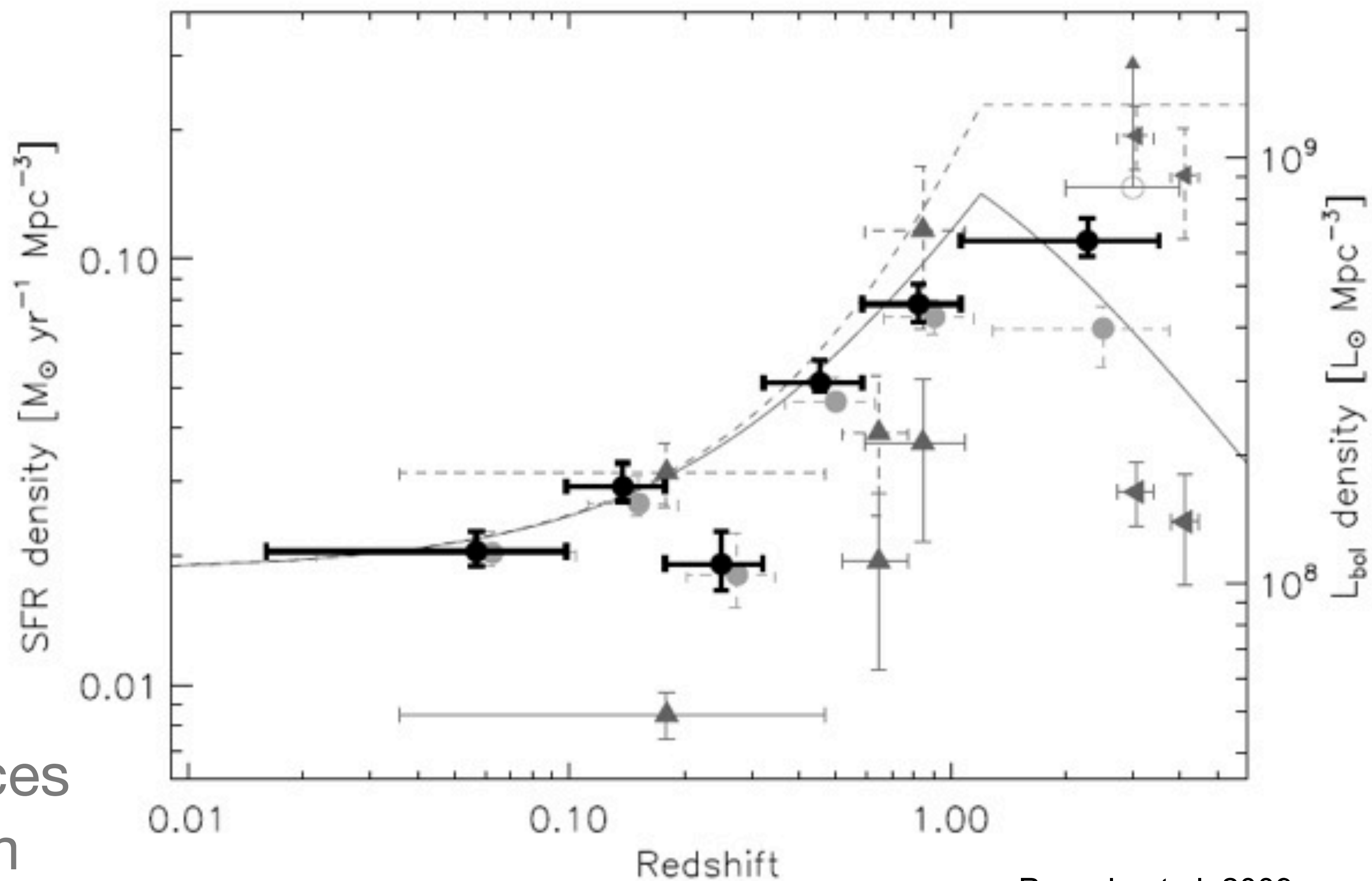
- Percent CIB generated between $0 < z < 1.1$:
  75% @ 70 μm
  55% @ 250 μm
  45% @ 350 μm
  40% @ 500 μm



Pascale et al. 2009

Stacking : Star Formation Density History

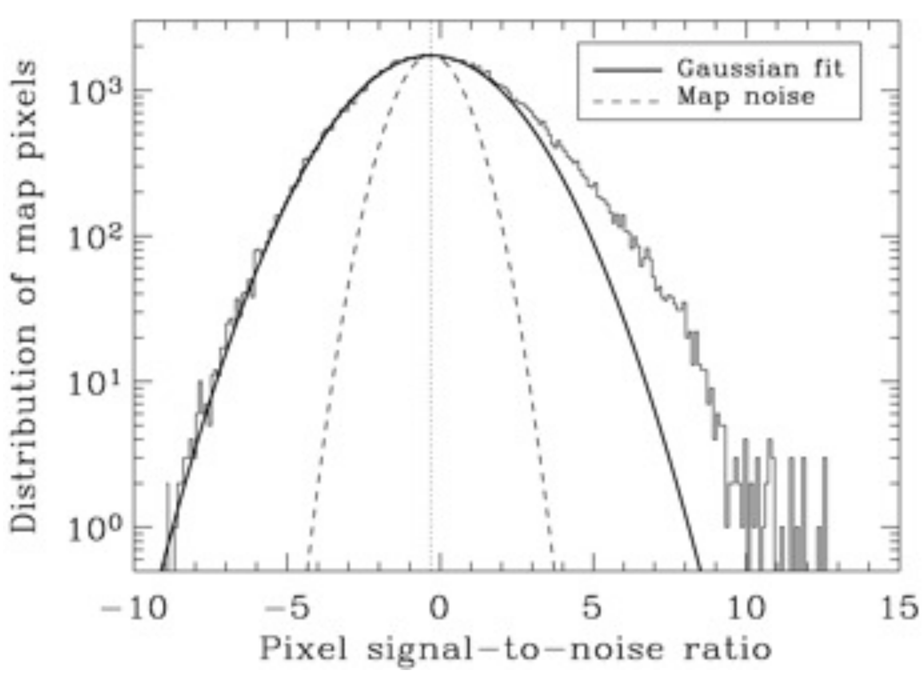
- Calculate L_{IR} and convert those into Star Formation Rate Densities.
- Compare to other observations:
  - ▲ Lilly (1996), optical-UV
  - ◀ Steidel (1996), optical-UV
  - ○ Hughes (1998), 850 μm
- Missing information for highest redshift?
  - Expect those to be most massive SCUBA galaxies.
  - Indeed, stacking 24um sources does not resolve all of 850um SCUBA maps.



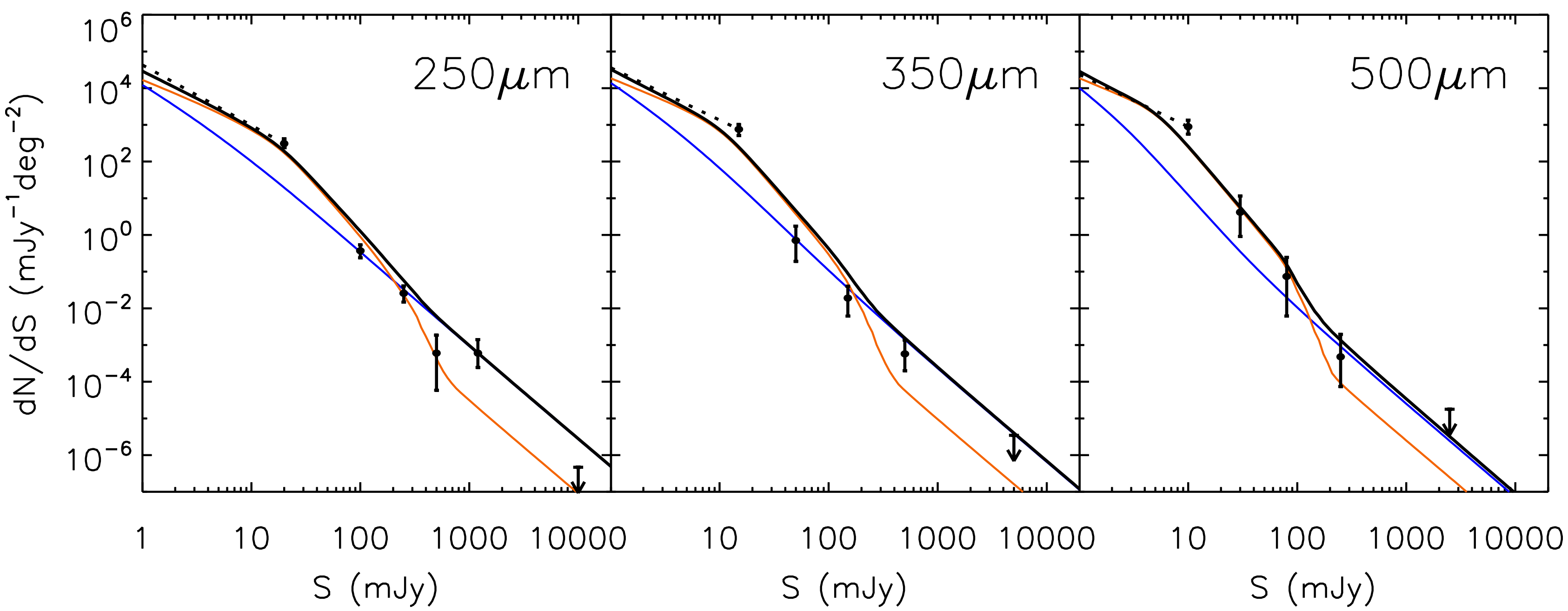
Pascale et al. 2009

Source Counts - P(d)

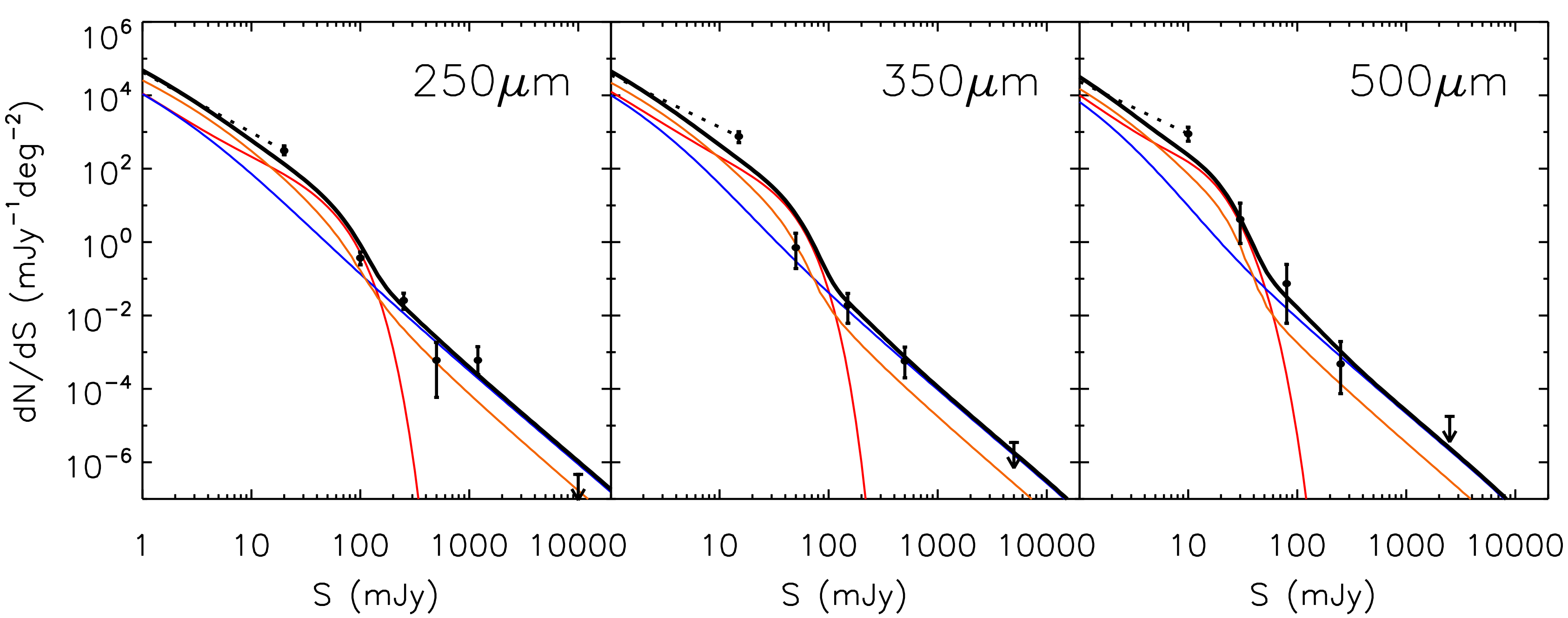
- Large beams and steep counts make identifying sources and their fluxes complicated.
- Sources need to be "de-boosted", which introduces bias.
- To estimate the counts, it is better to fit the map histogram; a so called "P (d)" analysis.



Lagache Model (2003)



Granato Model (2004)

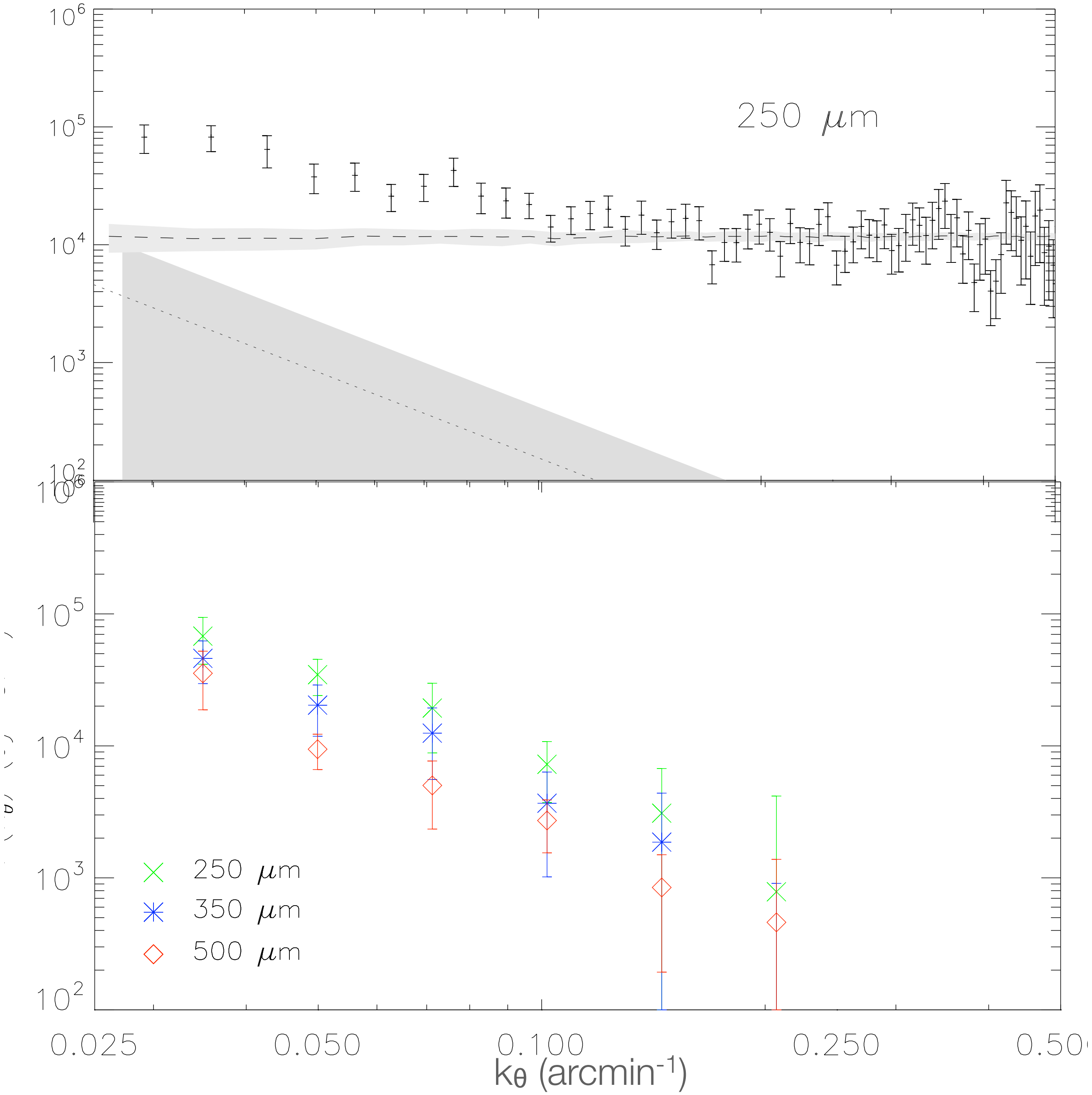


Points from Patanchon et al., 2009

Power Spectrum Components

$$P_{tot} = P_{cirrus} + P_{shot} + P_{clustering} + \text{Noise}$$

- Galactic Cirrus field dependent.
  - Generally dominates on scales $k < 0.01$ arcmin^{-1}
- Poisson (shot) Noise dominates on small scales, i.e., $k > 0.1$ arcmin^{-1}
- Clustering seen as an excess over Poisson noise on scales $k < 0.1$ arcmin^{-1}



Clustering Model

- Clustering Signal has contributions from galaxies:

  -on small scales within a halo (1-halo term, nonlinear)

  -on large scales in two different halos (2-halo term, linear)

- Galaxies occupy halos according to the halo-occupation distribution (HOD), which constrains

  -$N_0(z)$

  -M_{min}

  -α

$$P(k,z) = P_{1h}(k,z) + P_{2h}(k,z)$$

- 1-halo term (small scales)

$$P_{1h}(k,z) = \int_{\mathcal{M}} n_{halo}(M,z)\sigma^2(M,z)|u_{DM}(k,z|M)|^p dM / n_{gal}^2(z)$$

- 2-halo term (large scales)

$$P_{2h}(k,z) = P_{DM}(k,z) \times \left[\int_{\mathcal{M}} n_{halo}(M,z)N_{gal}(M)b(M,z)u_{DM}(k,z|M)dM\right]^2 / n_{gal}^2(z)$$

- Halo Occupation Distribution

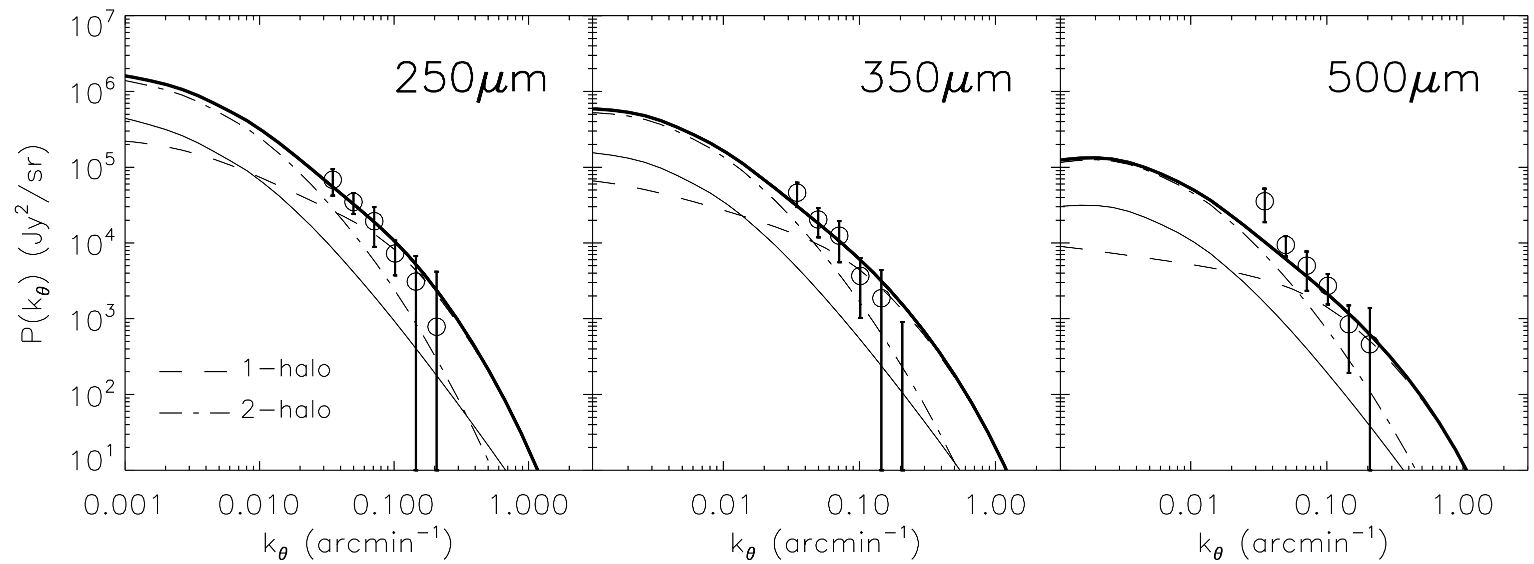
$$N_{gal}(M,z) = \begin{cases} N_0(z)\left(\frac{M}{M_{\min}(z)}\right)^{\alpha(z)} & \text{for} \quad M \geq M_{\min} \\ 0 & \text{for} \quad M < M_{\min} \end{cases}$$

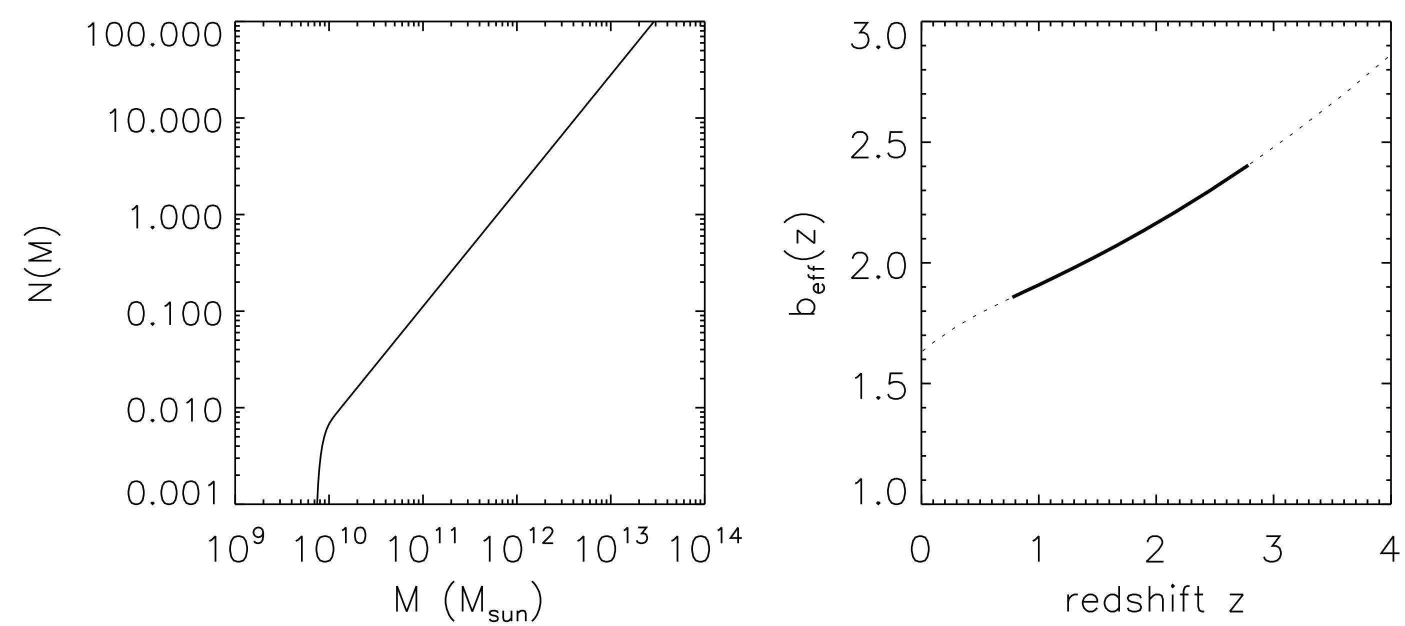
independent of redshift

It is fixed by the source model, for any pair ($M_{\min}$ α)

Fit to Halo Model

- Best-fit parameters:
  - $M_{min} = 10^{9.9}\ M_{sun}$
  - $\alpha = 1.2 \pm 0.2$
  - $b = 2.2 \pm 0.2$
  - $M_{eff} = 10^{13.2}\ M_{sun}$
- Our sources are strongly biased tracers of the underlying dark matter, sampling the highest peaks of the density field.
- Strong evolution of bias consistent with downsizing scenario, where:
  - Massive objects observed in the Local Universe (i.e. cluster elliptical galaxies) formed at high redshifts - possibly though merger events - and then evolve passively
  - Star-formation shifted to lower mass environments as the Universe evolved





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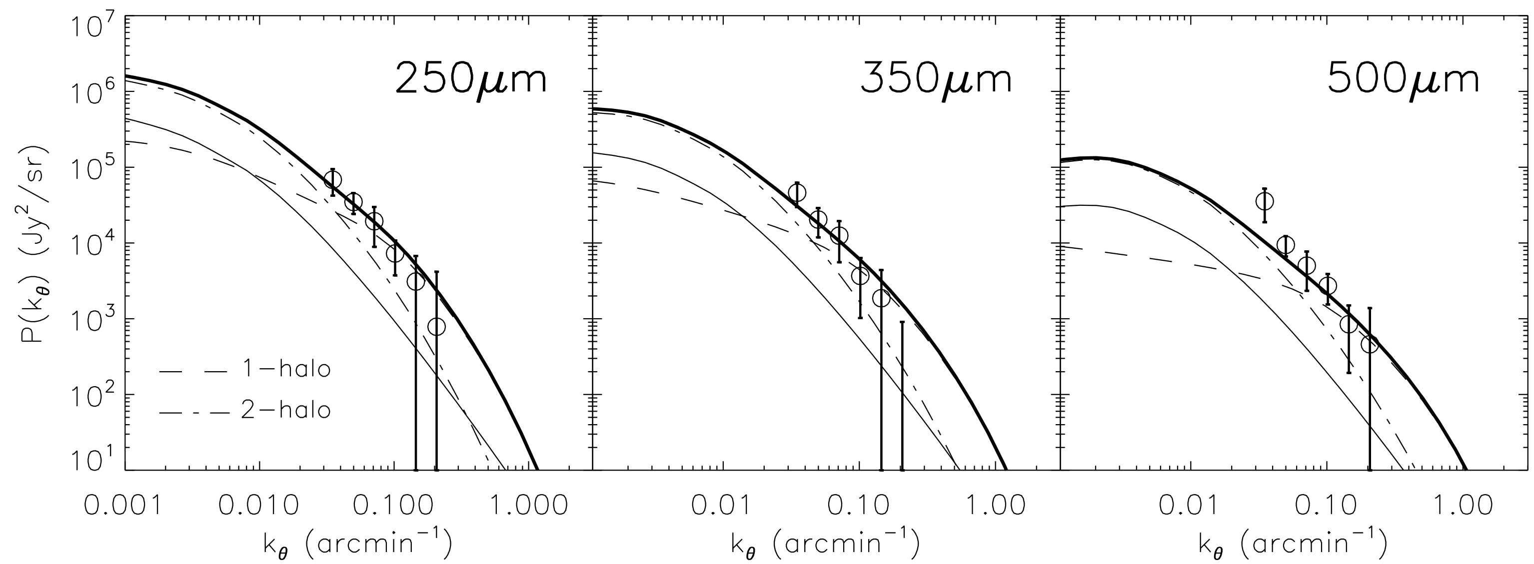

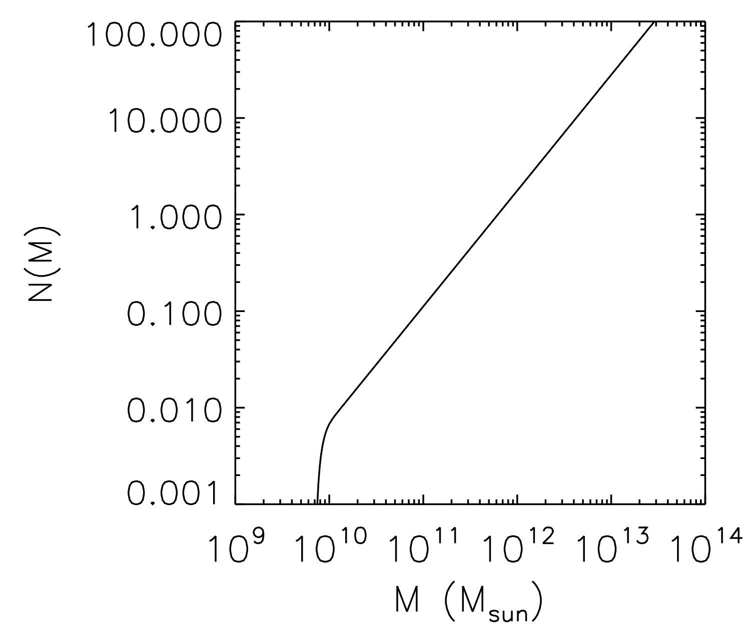

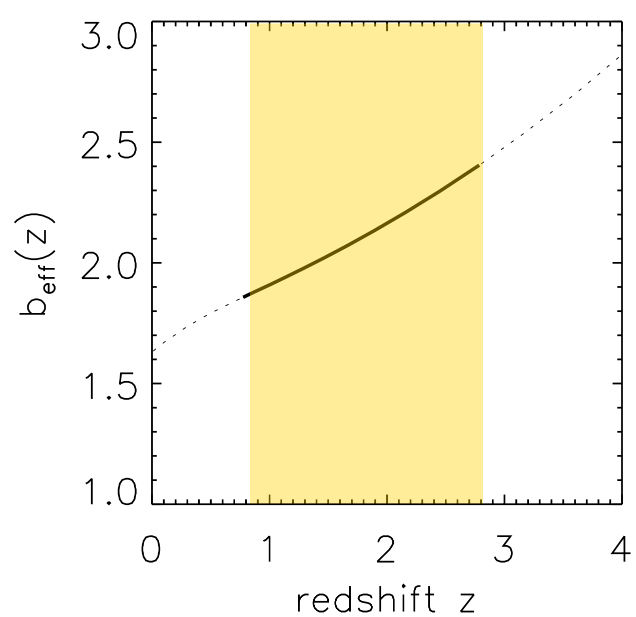

Conclusion

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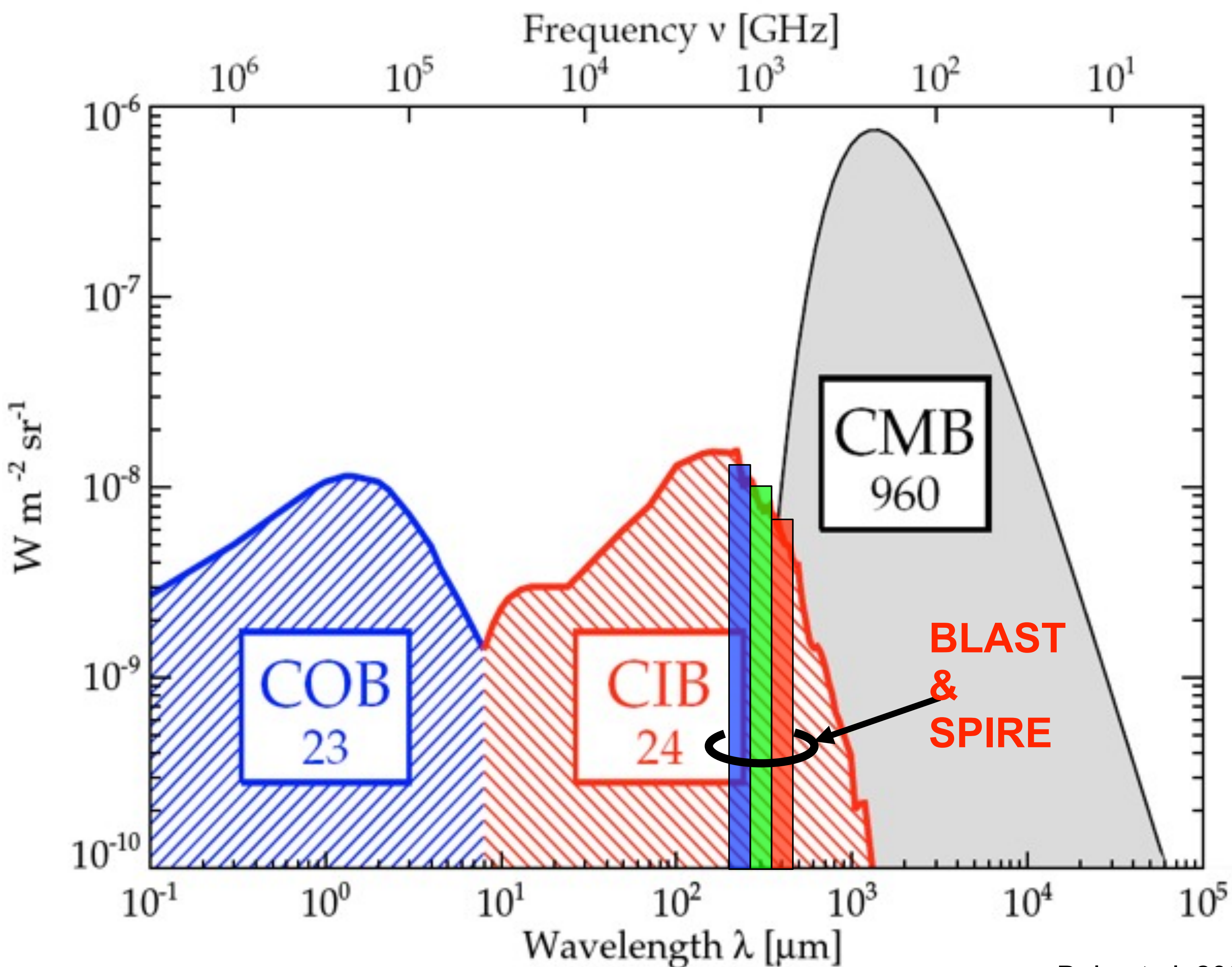

Dole et al. 2006

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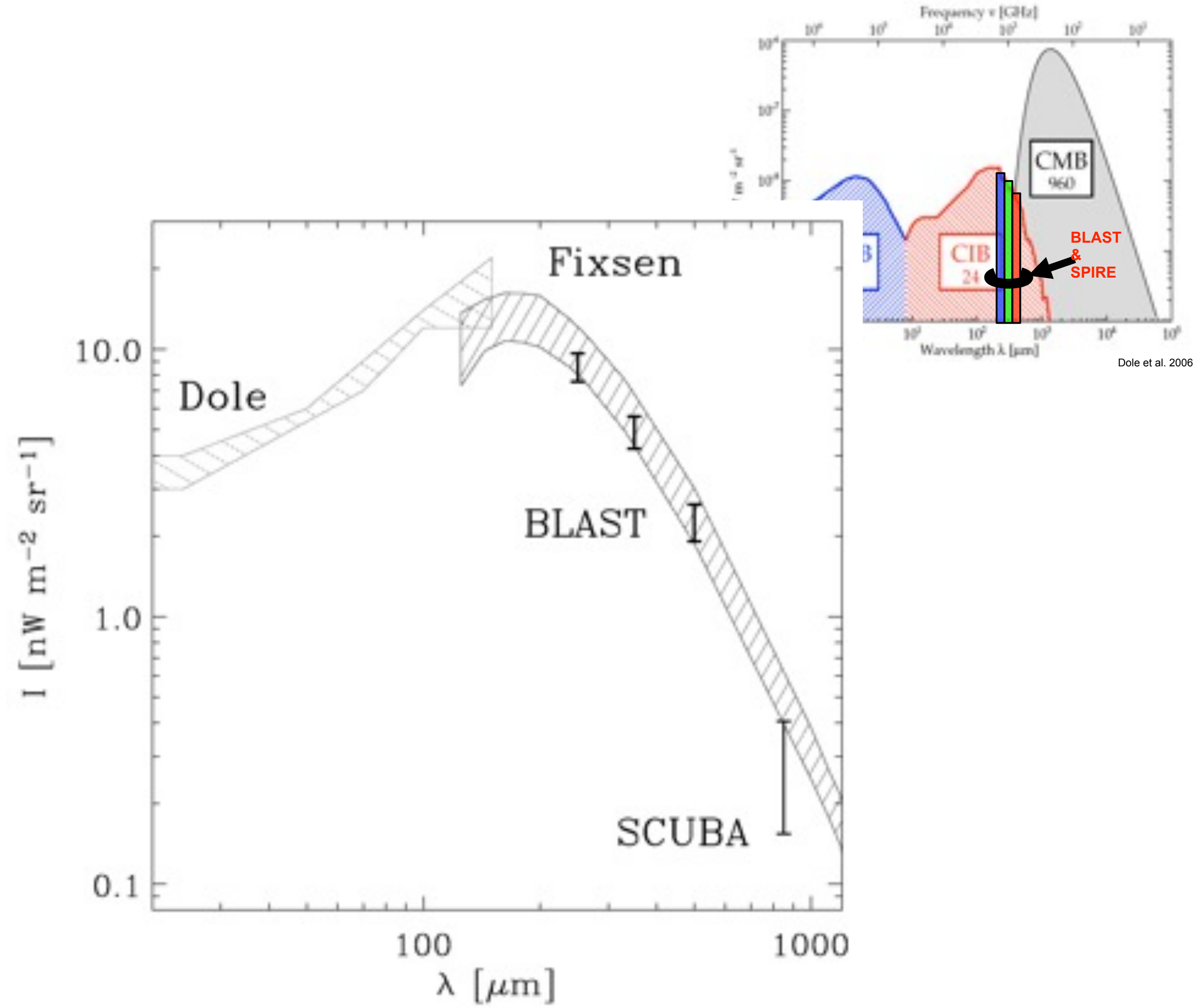

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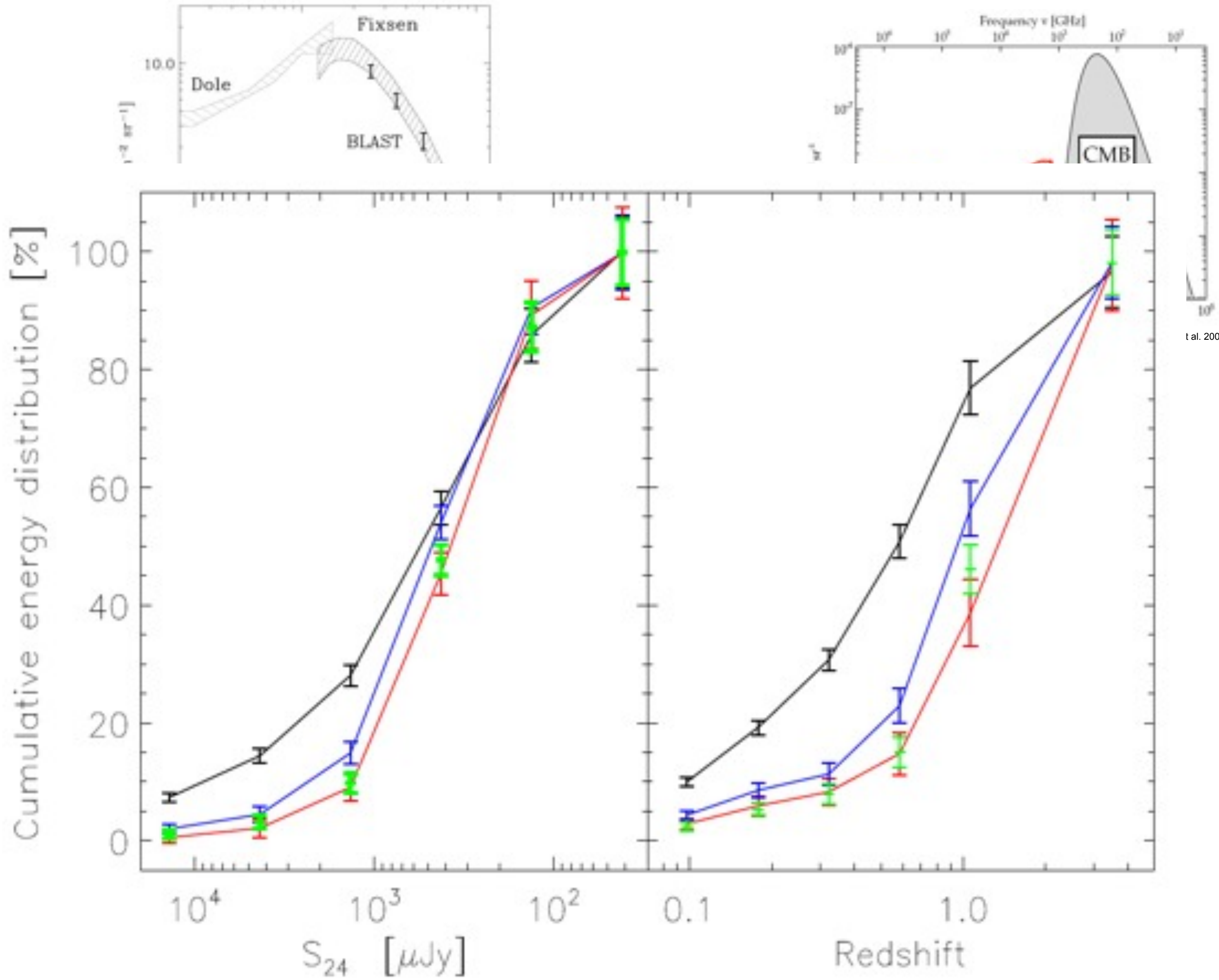

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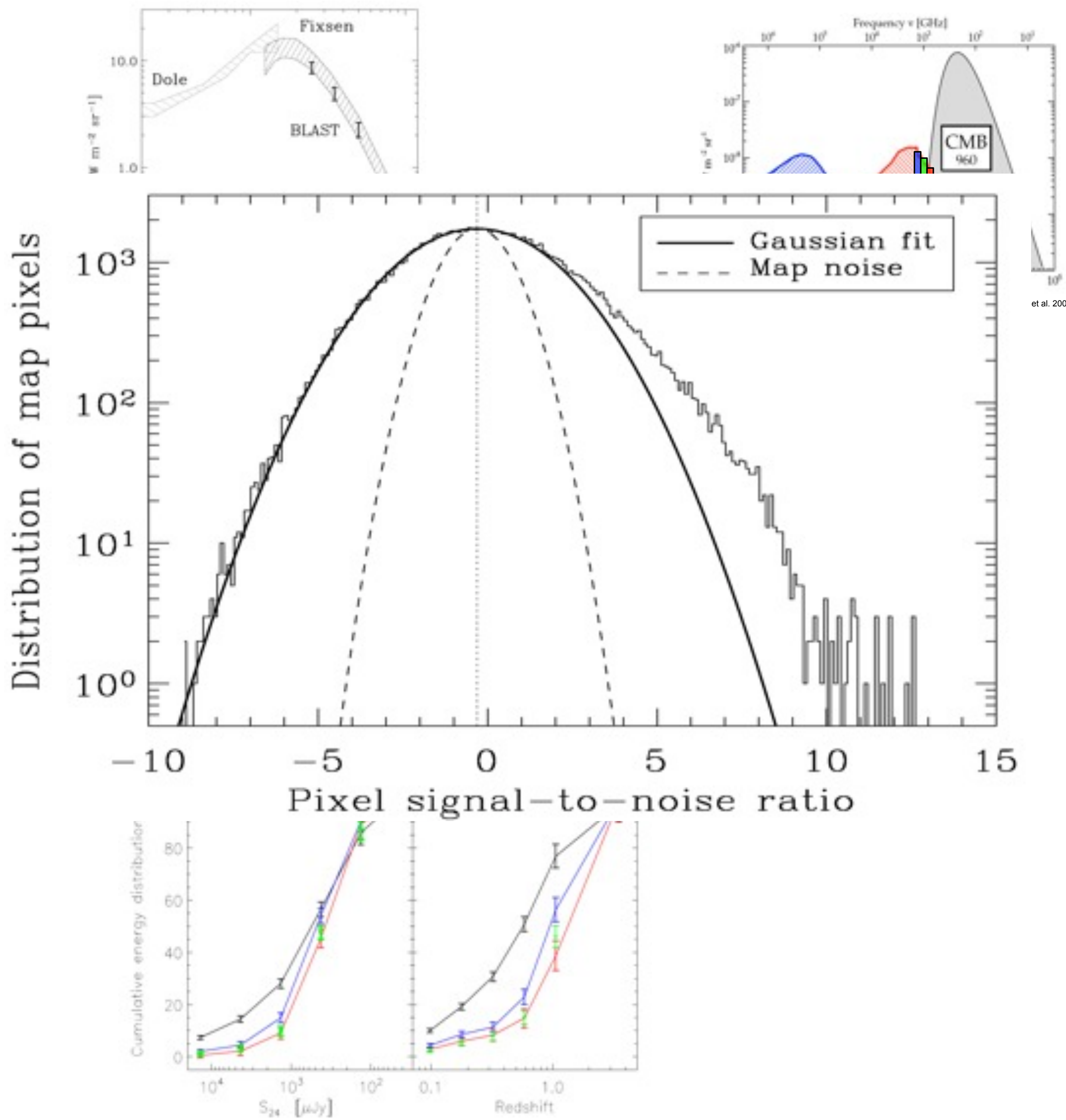

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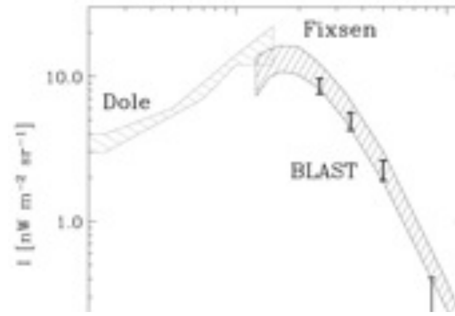

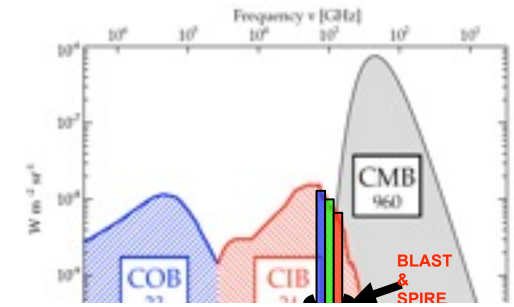

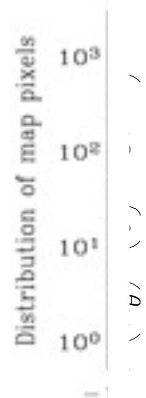

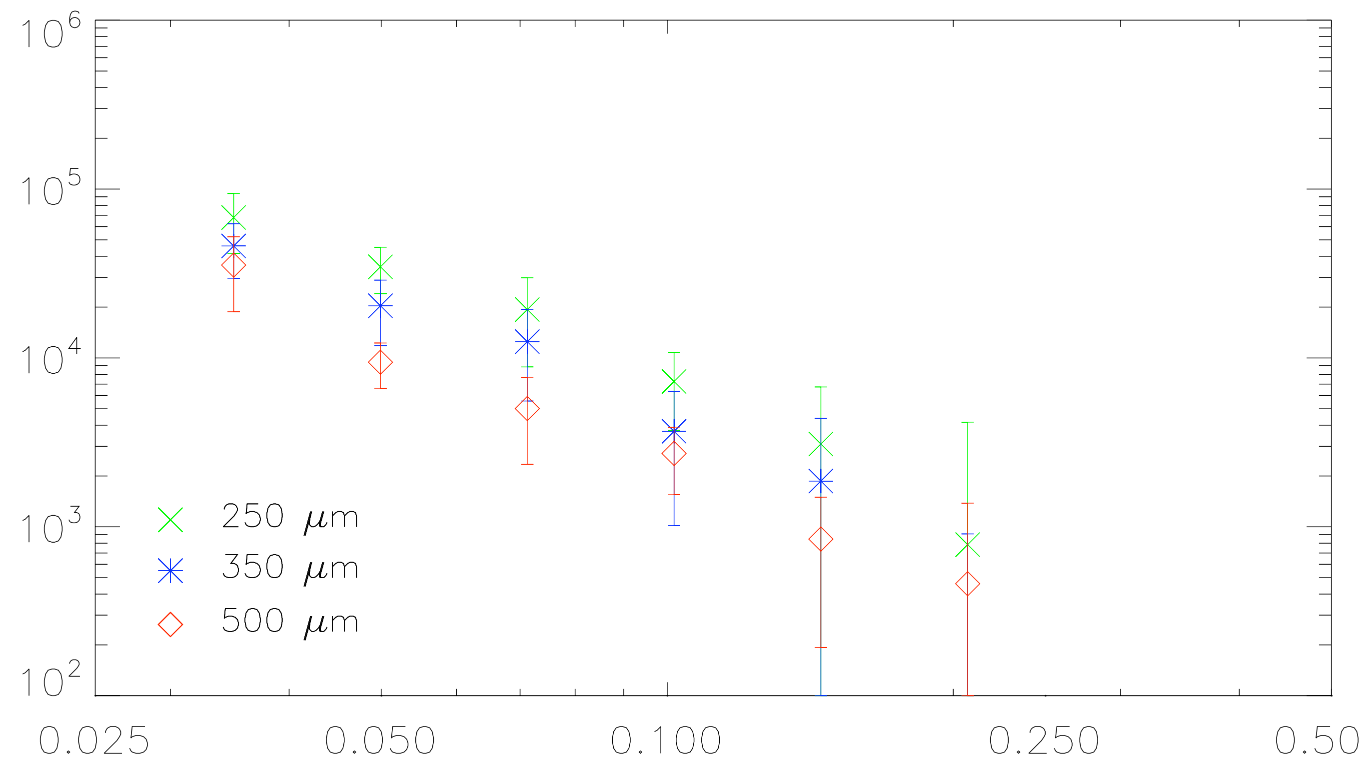

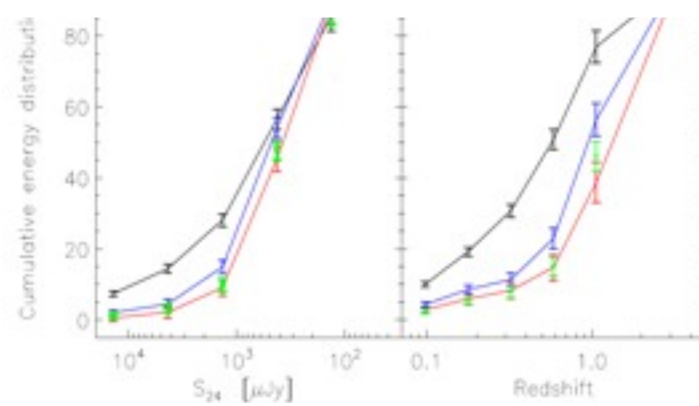

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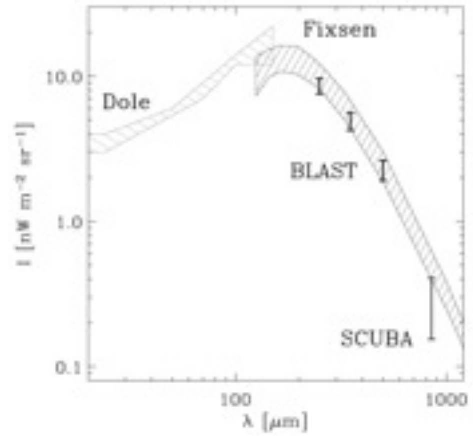

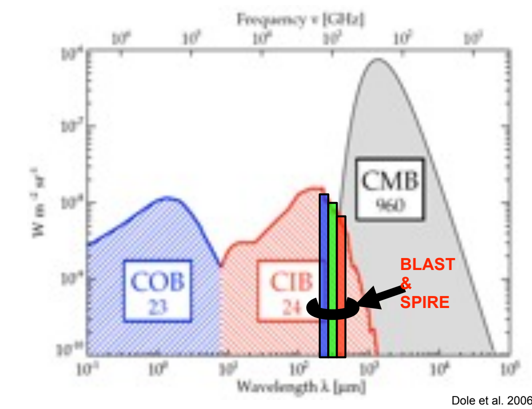

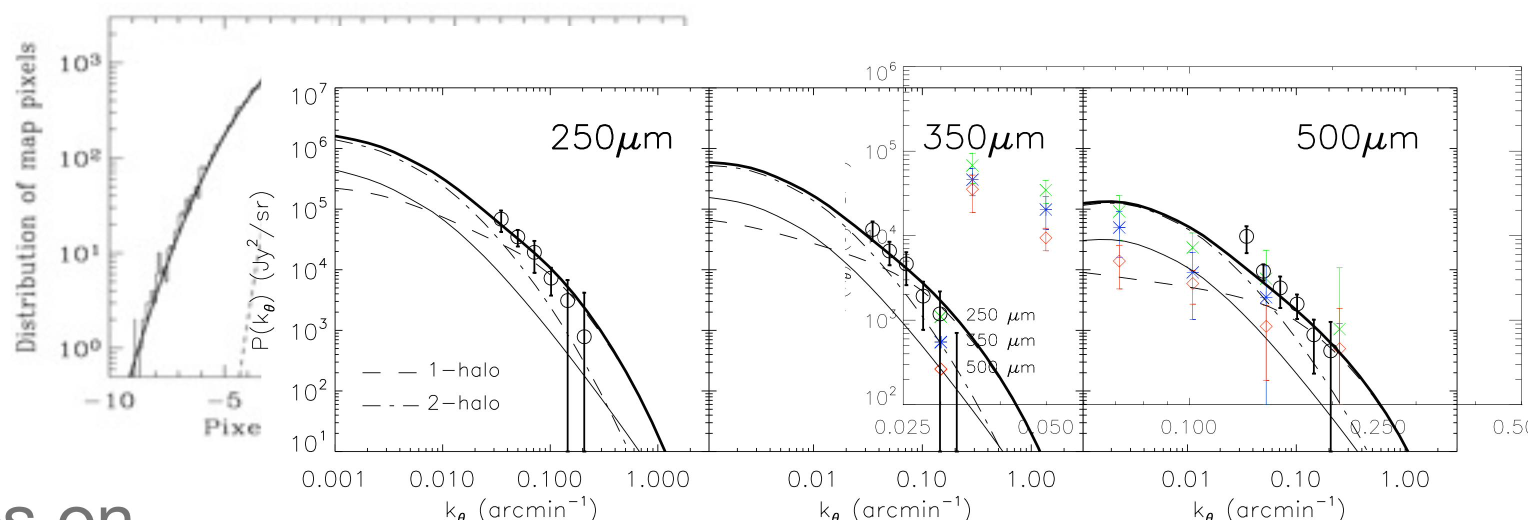

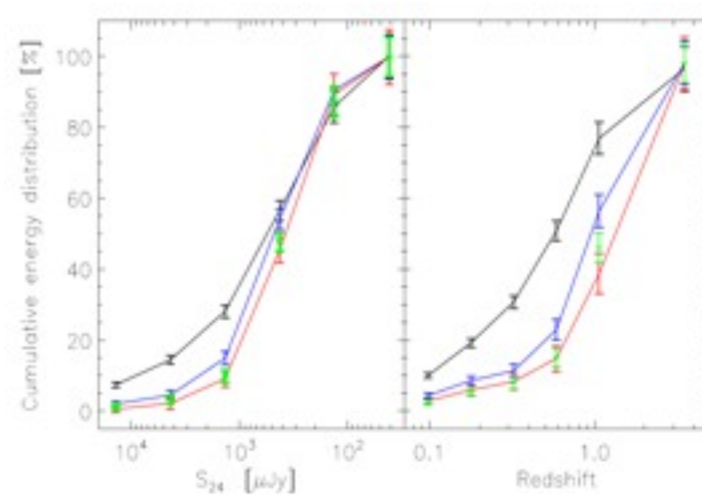

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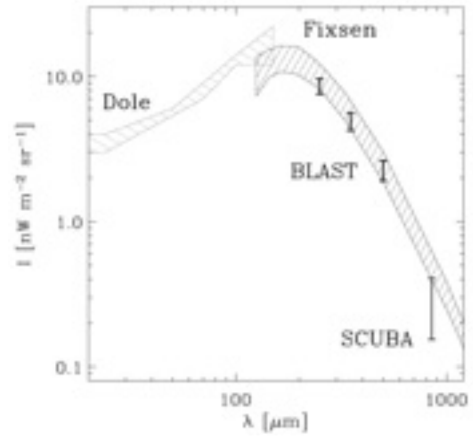

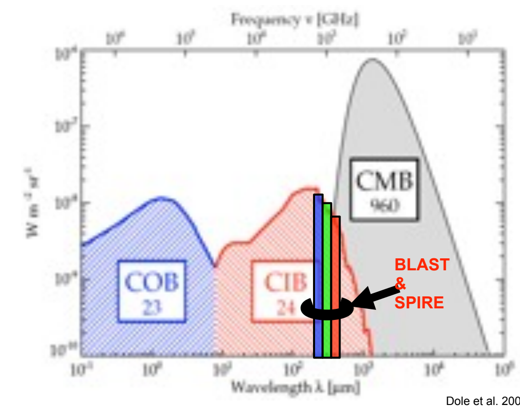

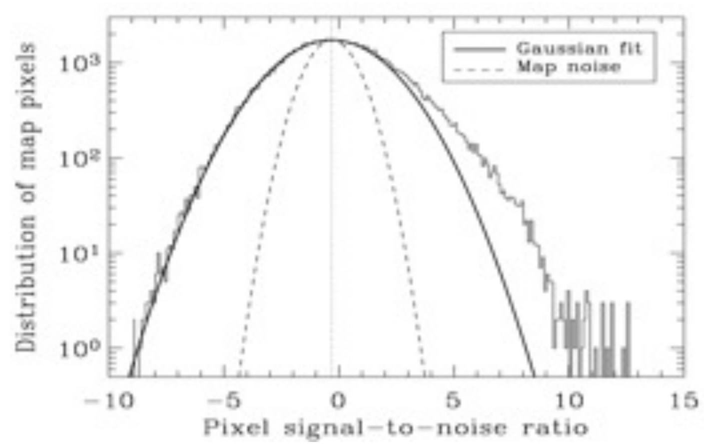

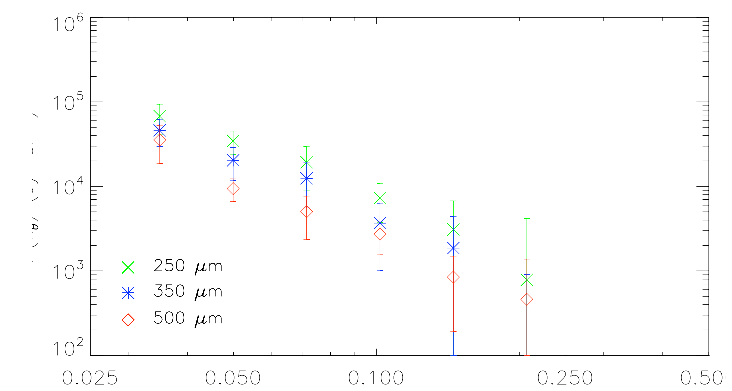

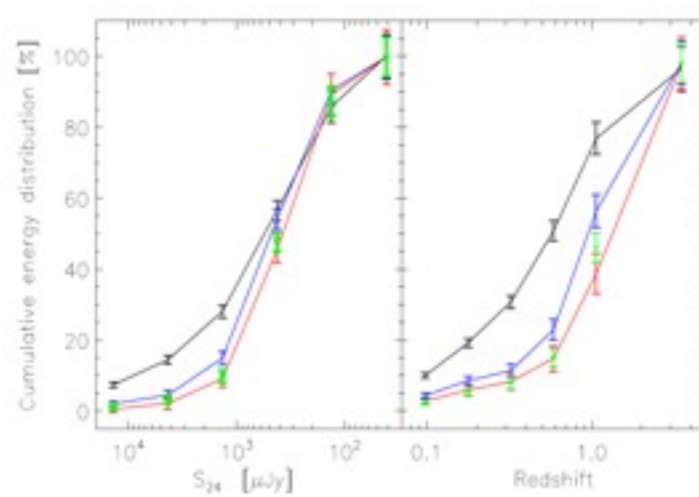

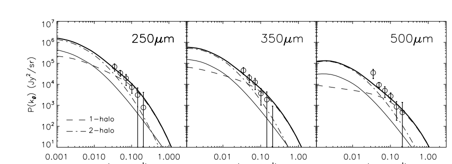

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BLAST

Balloon-borne Large-Aperture Sub-millimeter Telescope

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Maps, Papers and more at http://blastexperiment.info

END