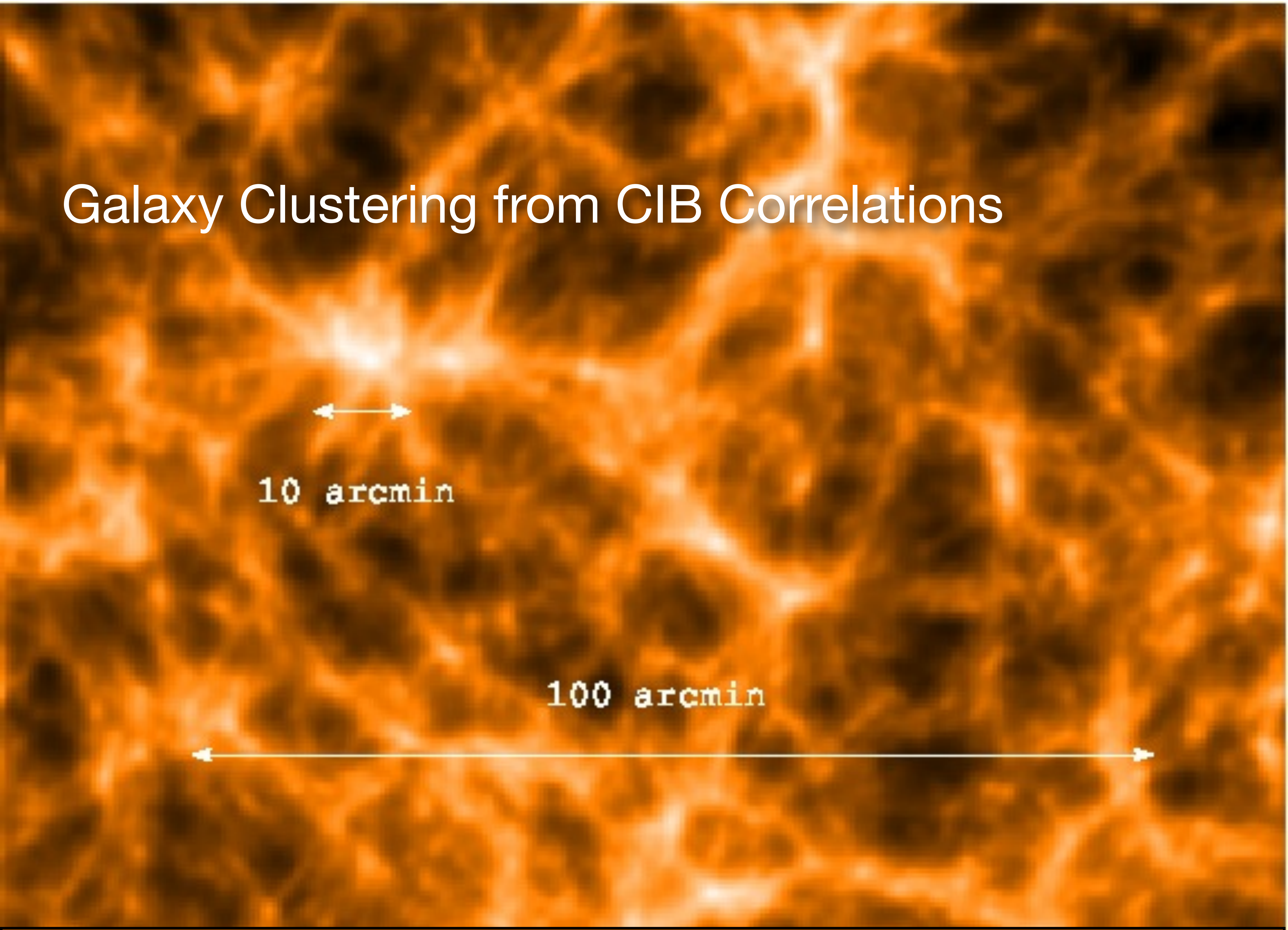
Galaxy Clustering from CIB Correlations



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Outline

- Motivation
  - Cosmic Radiation Budget
  - Far-Infrared Background
  - Correlations in the CIB
- Making the Measurement
  - The BLAST Experiment
  - Data Preparation and Map Making
  - Measuring the Power Spectrum
- Physical Interpretation
  - Halo Model
  - Interpreting the Fit
  - Cross-Band Spectrum
- Conclusion and Future Work

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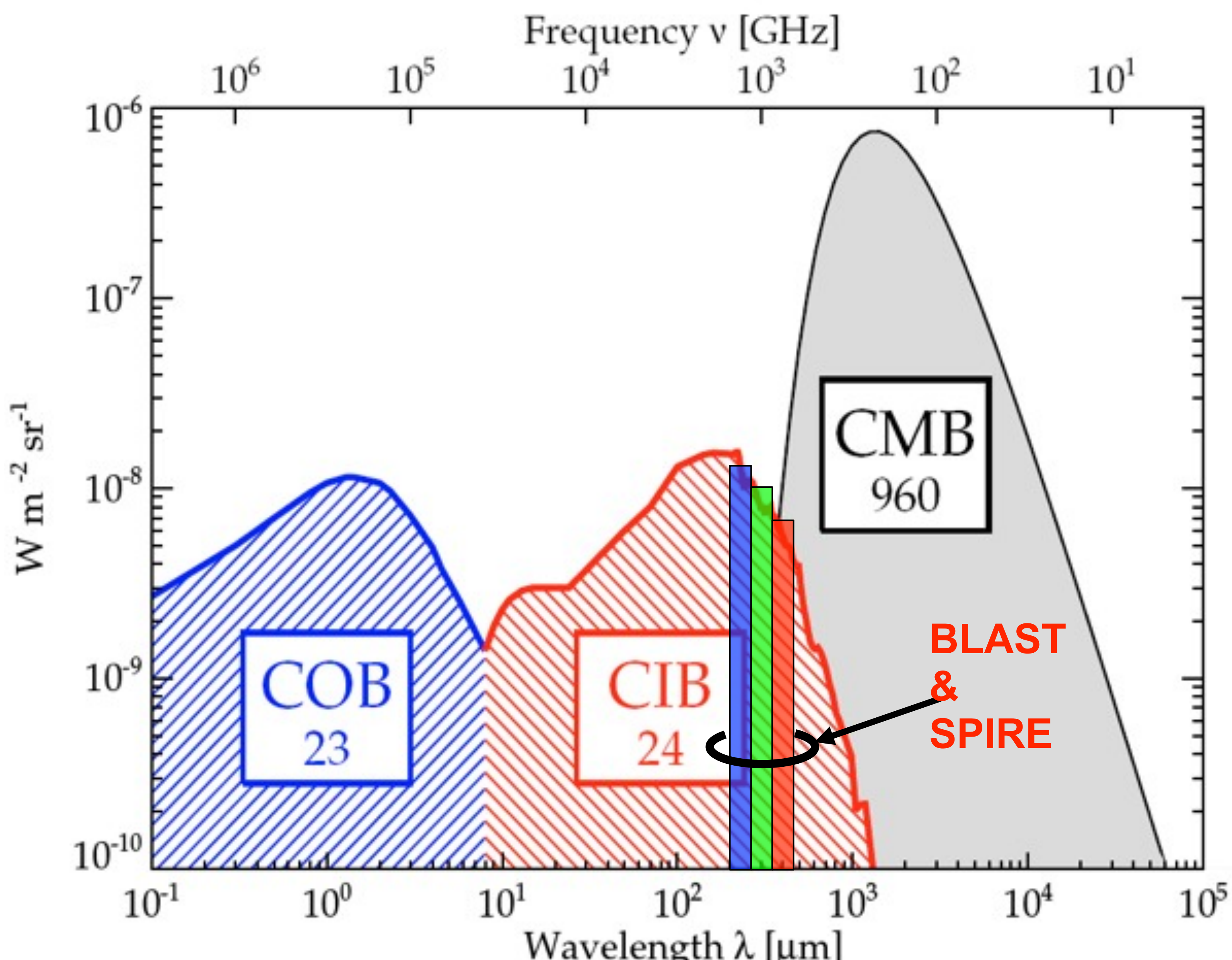
Cosmic Radiation Budget

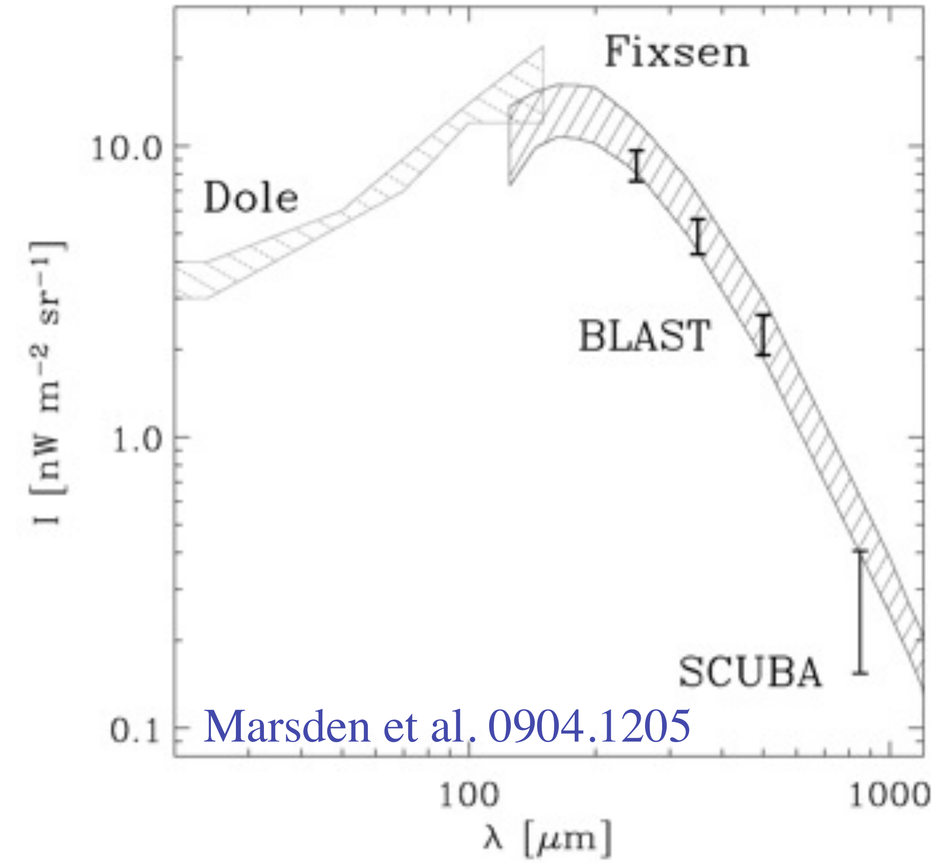
- After CMB, CIB makes up ~50% of the total radiation budget.
- Historically, optical background has attracted the most effort.
- The focus is shifting towards other wavelengths. Eg., in the infrared:
  - Spitzer
  - BLAST
  - Herschel
  - Planck
  - SCUBA II
  - ALMA

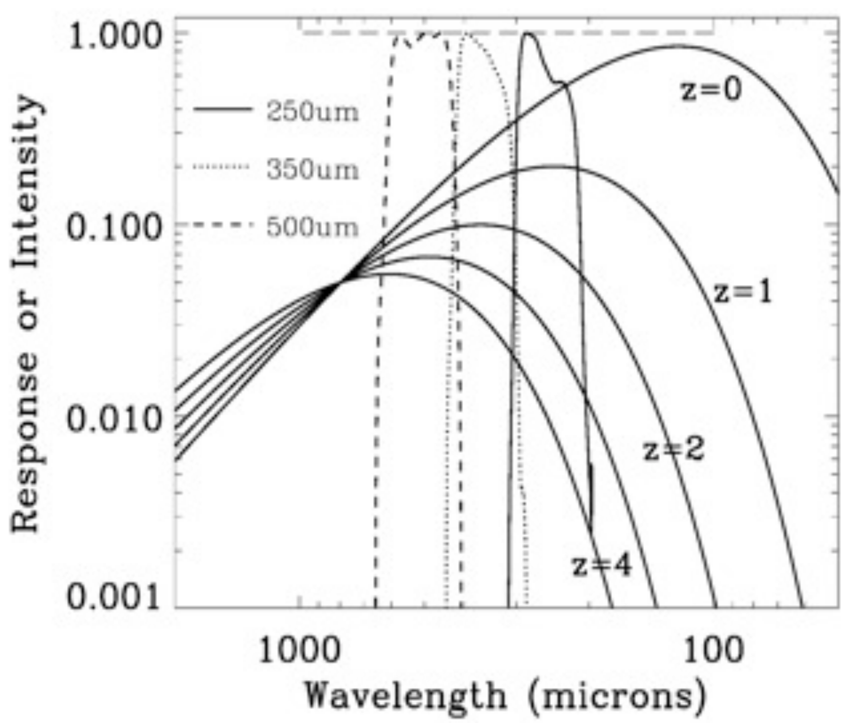


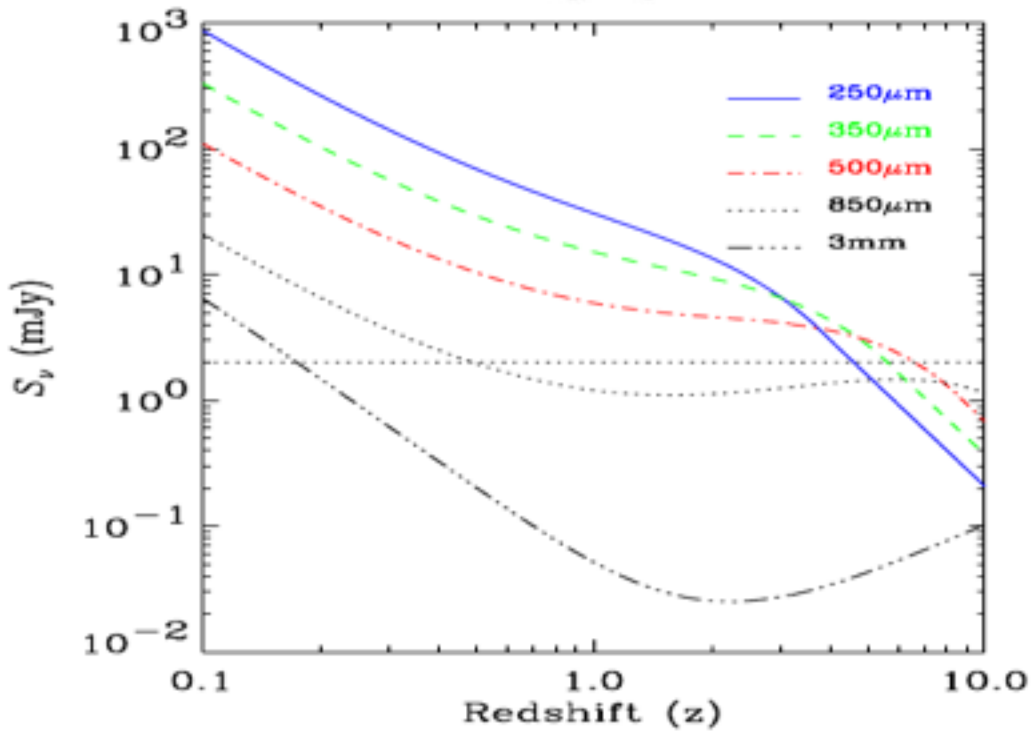
Dole et al. 2006

Source of the Background

- The CIB originates entirely from Dusty Galaxies (Devlin et al. 2009, Marsden et al. 2009)
- 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.



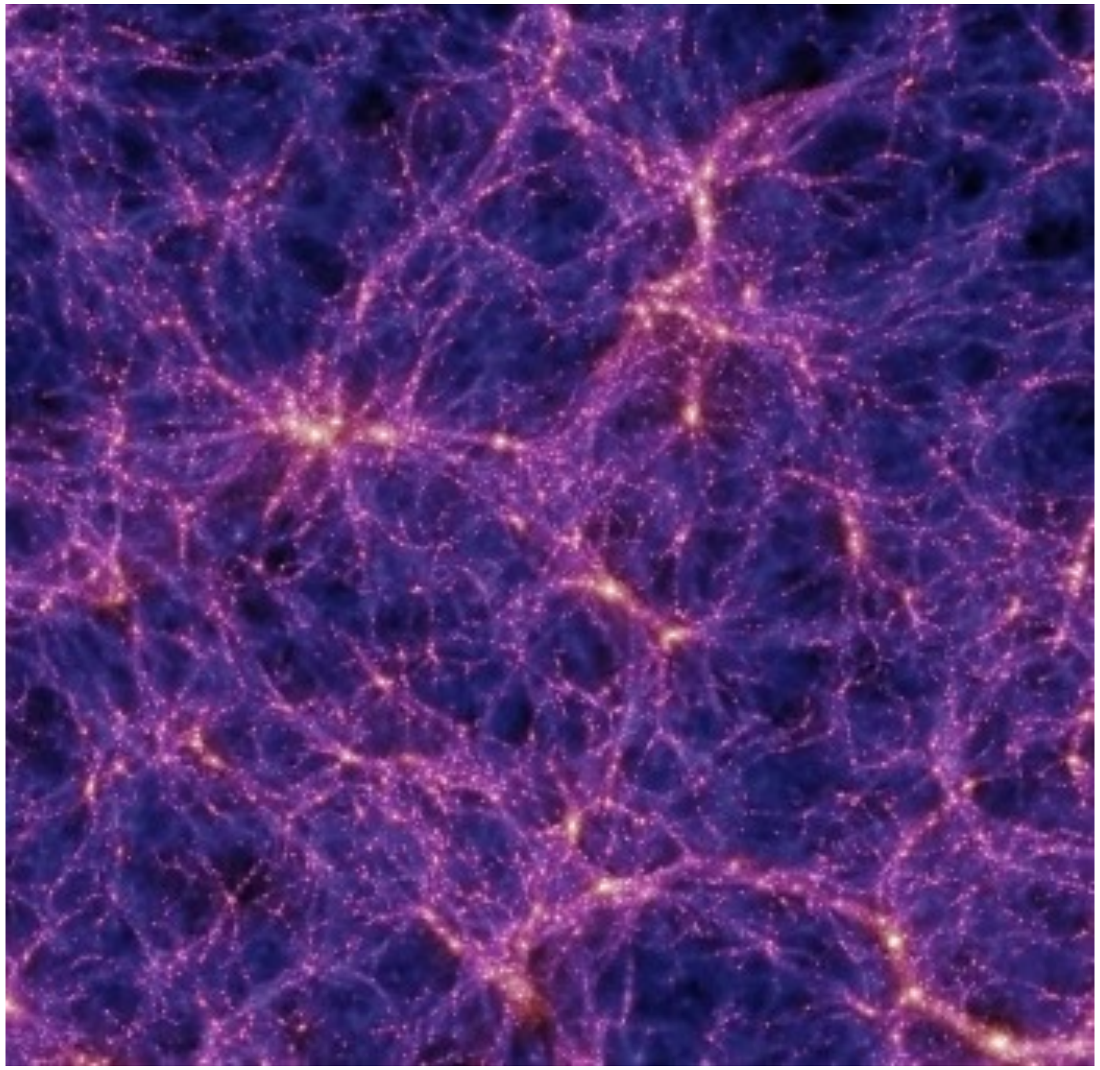




Clustering of Galaxies

- Galaxies are not randomly located, their locations are correlated.
- Correlations of star-forming galaxies give a picture of what environmental conditions favour star-formation, or alternatively, shut star-formation down.
- 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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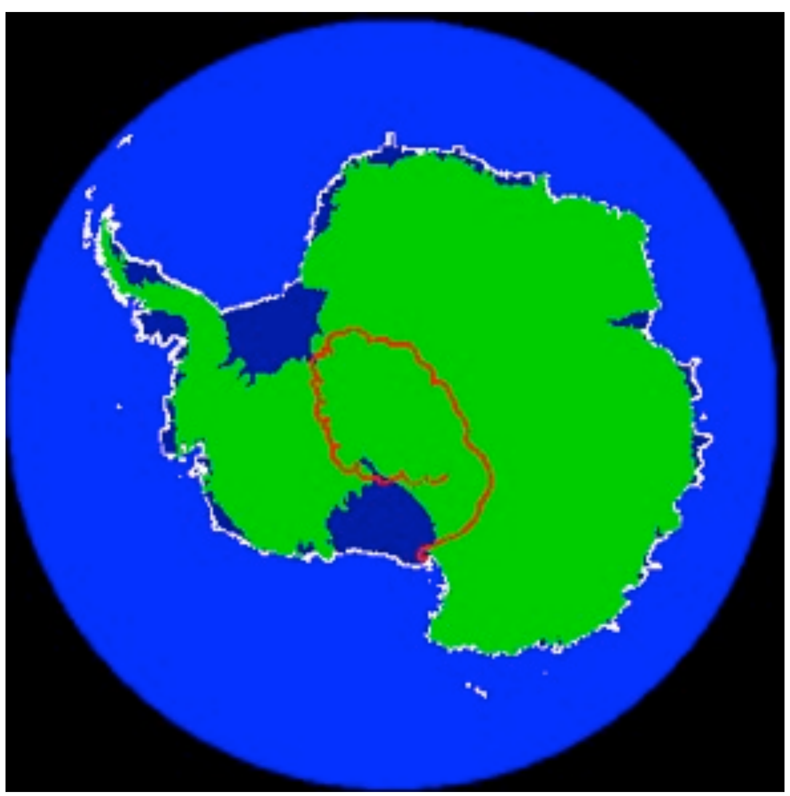
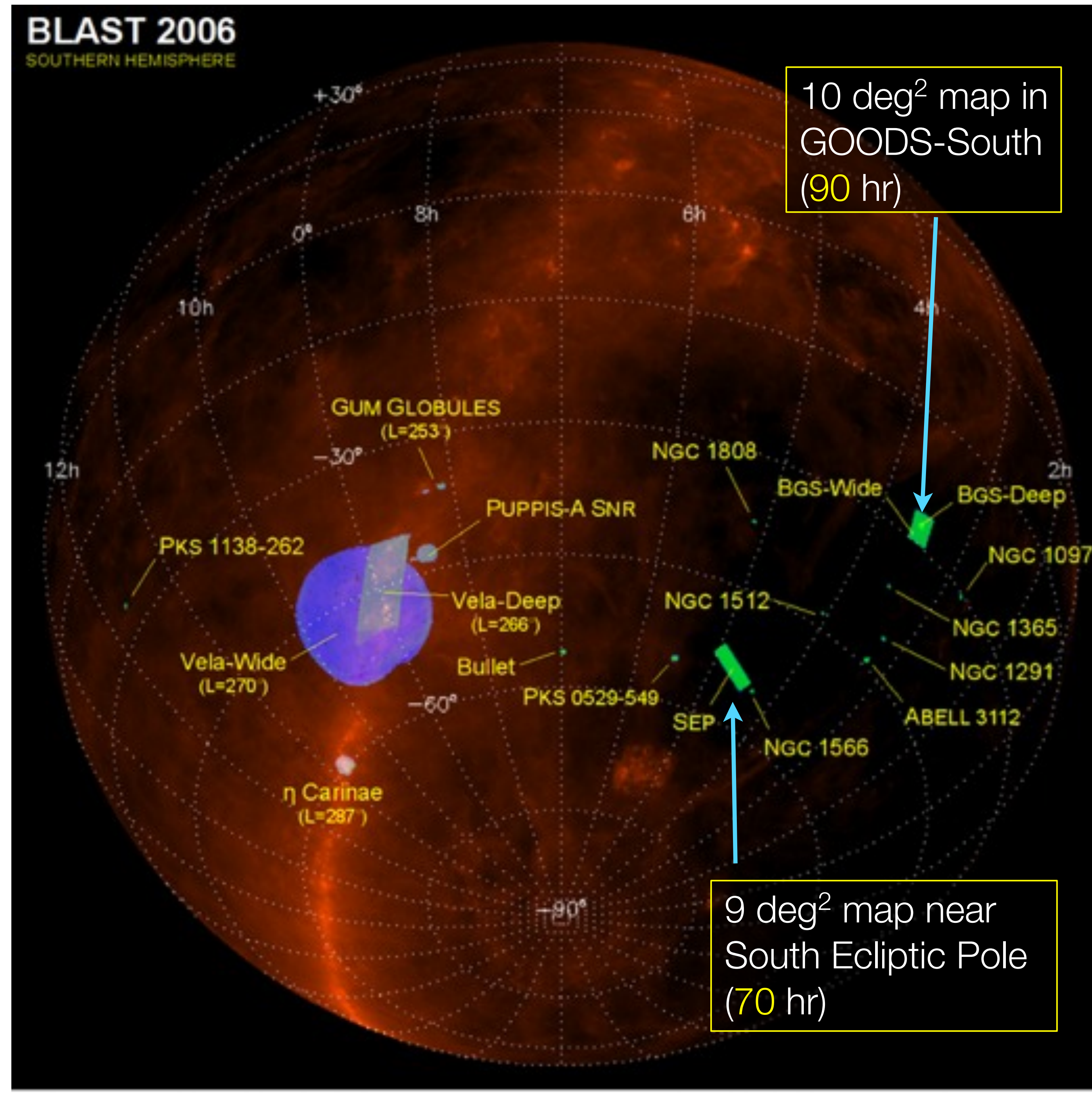
BLAST

- 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)

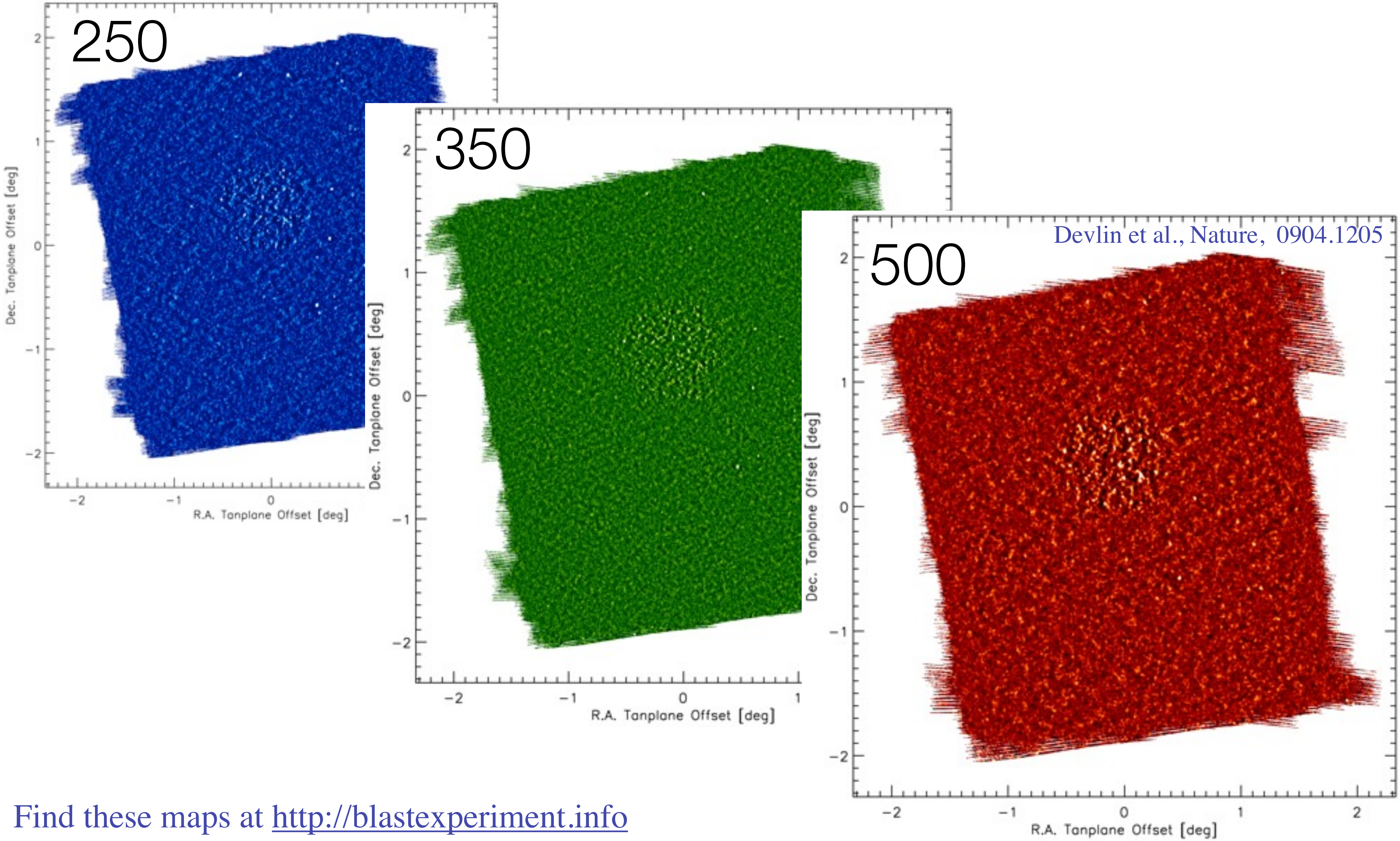
Fields

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





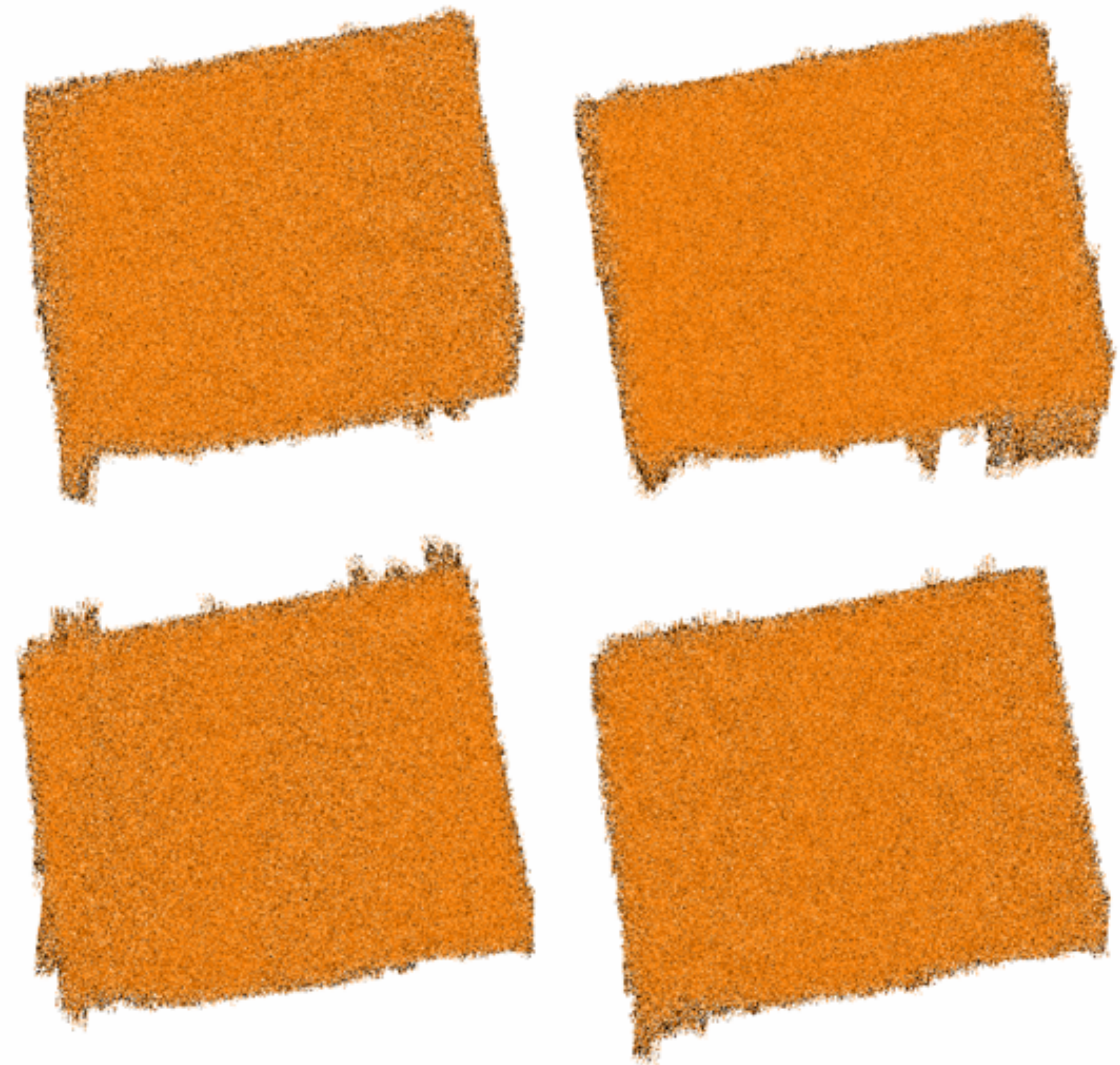
Public BLAST Maps



Find these maps at http://blastexperiment.info

Sub-Maps for Correlation Analysis

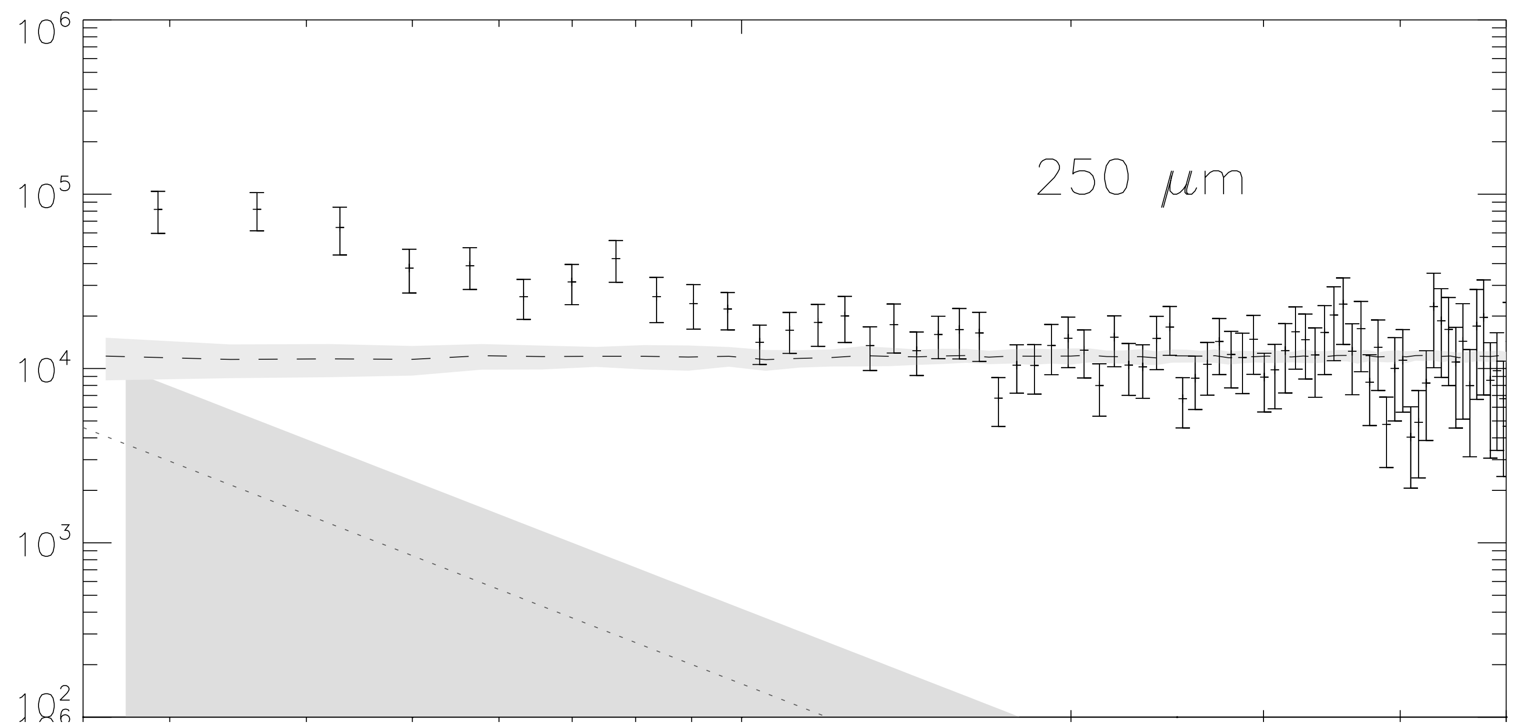
- Wide-only timestreams selected.
- Common-mode is NOT removed.
- Timestreams filtered at 0.2 Hz.
- Timestreams divided into four equal parts and made into 4 unique maps.
- Extract most uniform 6 deg^2



Power Spectrum Components

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

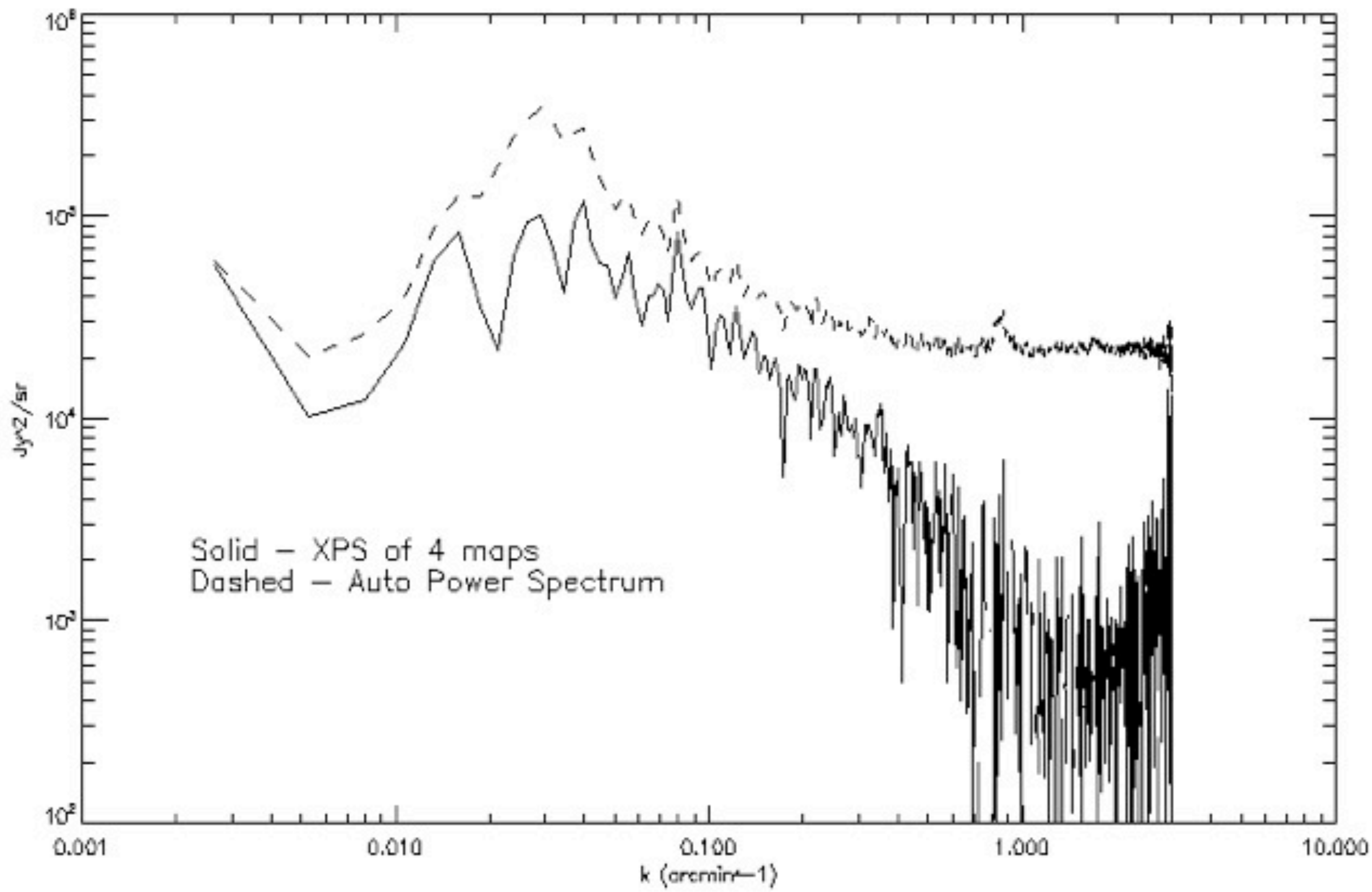
- Galactic Cirrus field dependent.
  - Generally dominates on scales $k < 0.01$ arcmin^{-1}
- Poisson (shot) Noise dominates on small scales, i.e., $k > 0.1$ arcmin^{-1}
- Clustering seen as an excess over Poisson noise on scales $k < 0.1$ arcmin^{-1}



Removing Noise: Auto vs. Cross Power Spectrum

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

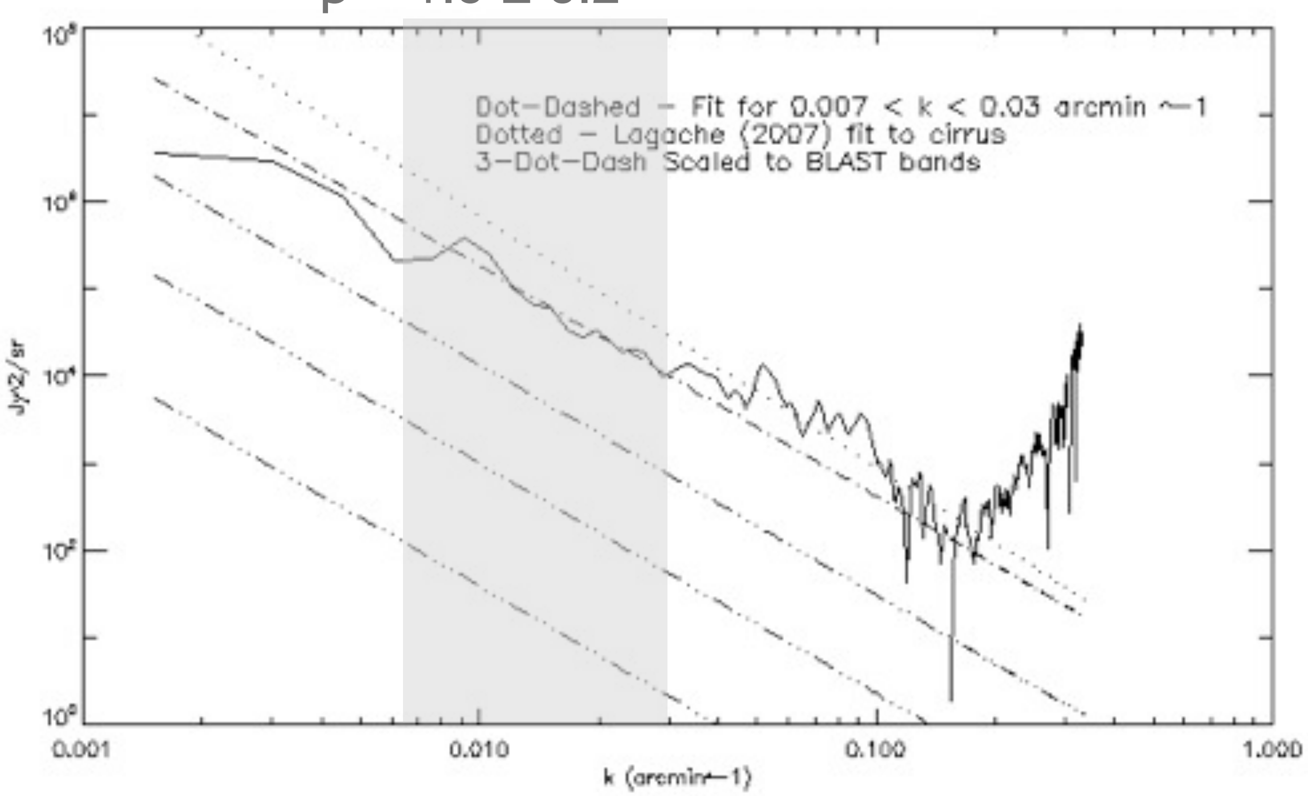
- Noise can be measured with *jackknife* maps and removed.
- Alternatively, noise which is uncorrelated between unique sub-maps will average to zero in the cross-correlation.



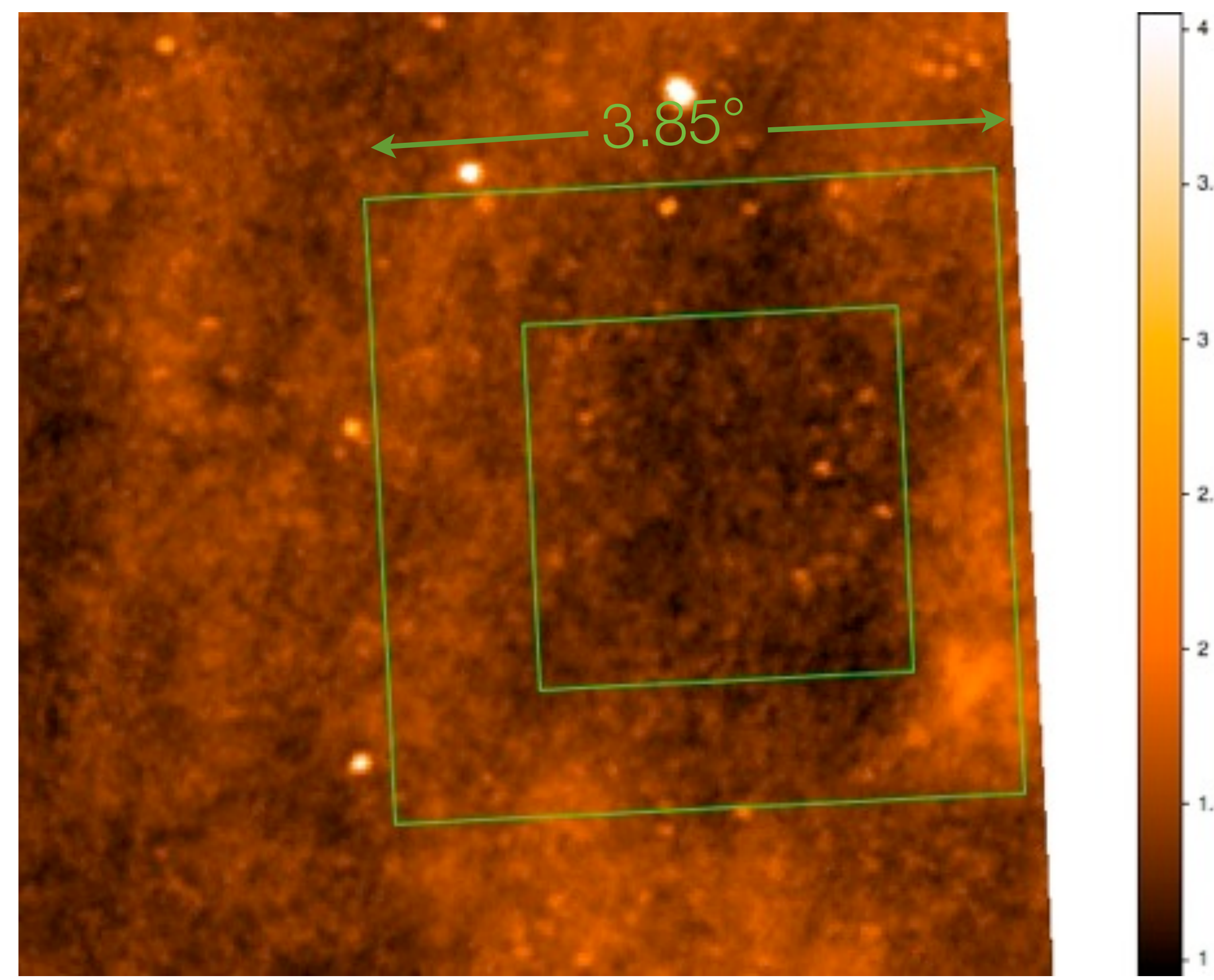
Galactic Cirrus

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

- Power spectrum of Galactic Cirrus
  - $P(k) = P_0(k/k_0)^{\alpha}$
    - $\alpha = 2.64$
    - $P_0 = 0.36x106\ Jy^2/sr$
- Scale to BLAST bands, $(I_{BLAST}/I_{100})^2$ assuming:
  - $T = 17.5 \pm 1.5$ K
  - $\beta = 1.9 \pm 0.2$



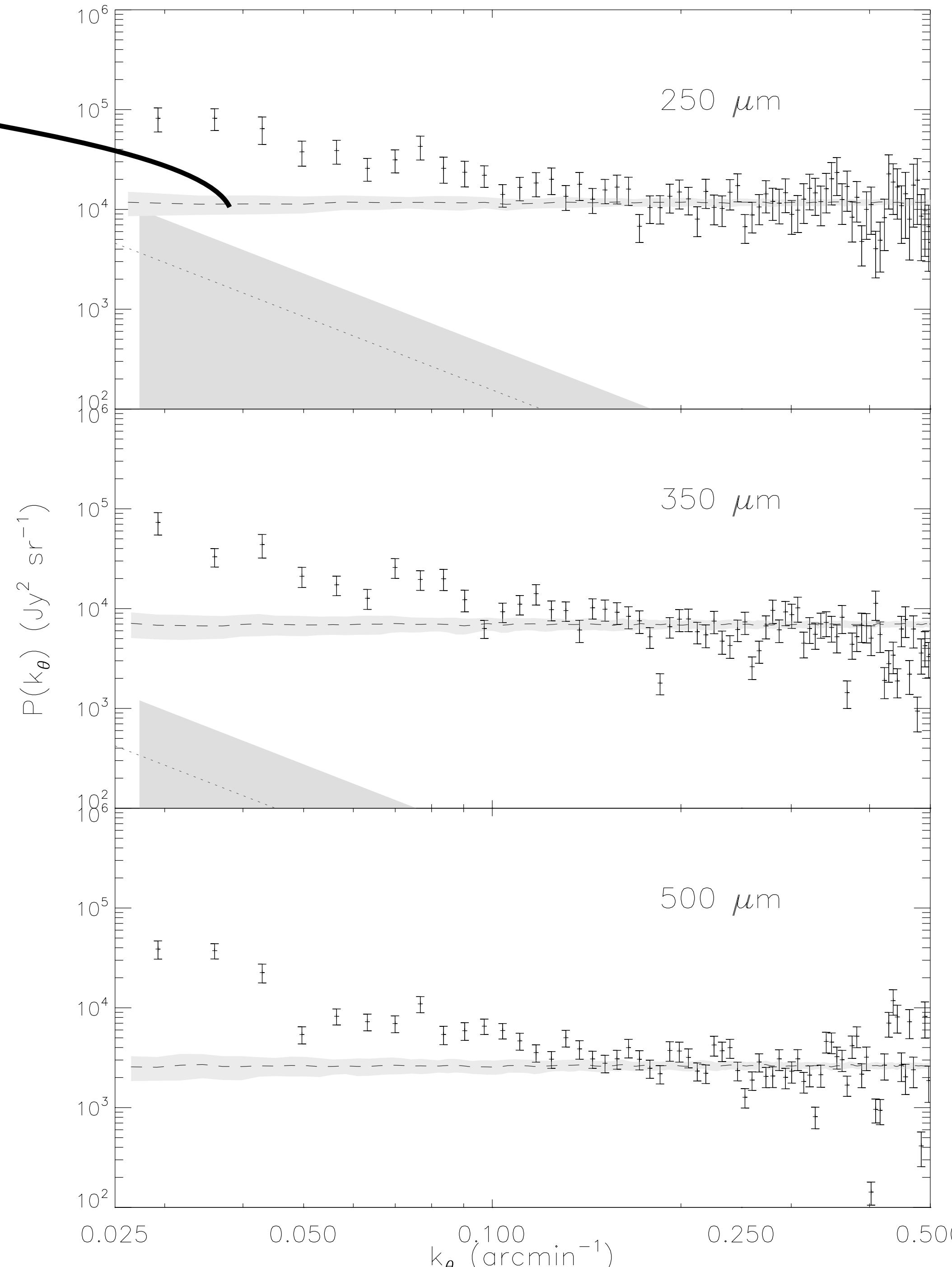
- Measure from IRIS 100 um map
  - Select ~ 15 deg^2 region
  - Mean ~ 1.4 MJy/sr



Poisson Noise

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

- Can be determined two ways:
  - Fit
  - From Counts
    - $P_{shot} = \int S^2 \, dN/dS \, dS$
- Counts are so steep (i.e., number of sources rises quickly as for fainter fluxes) that the faint source population dominates, therefore:
  - Removing only brightest sources is necessary.

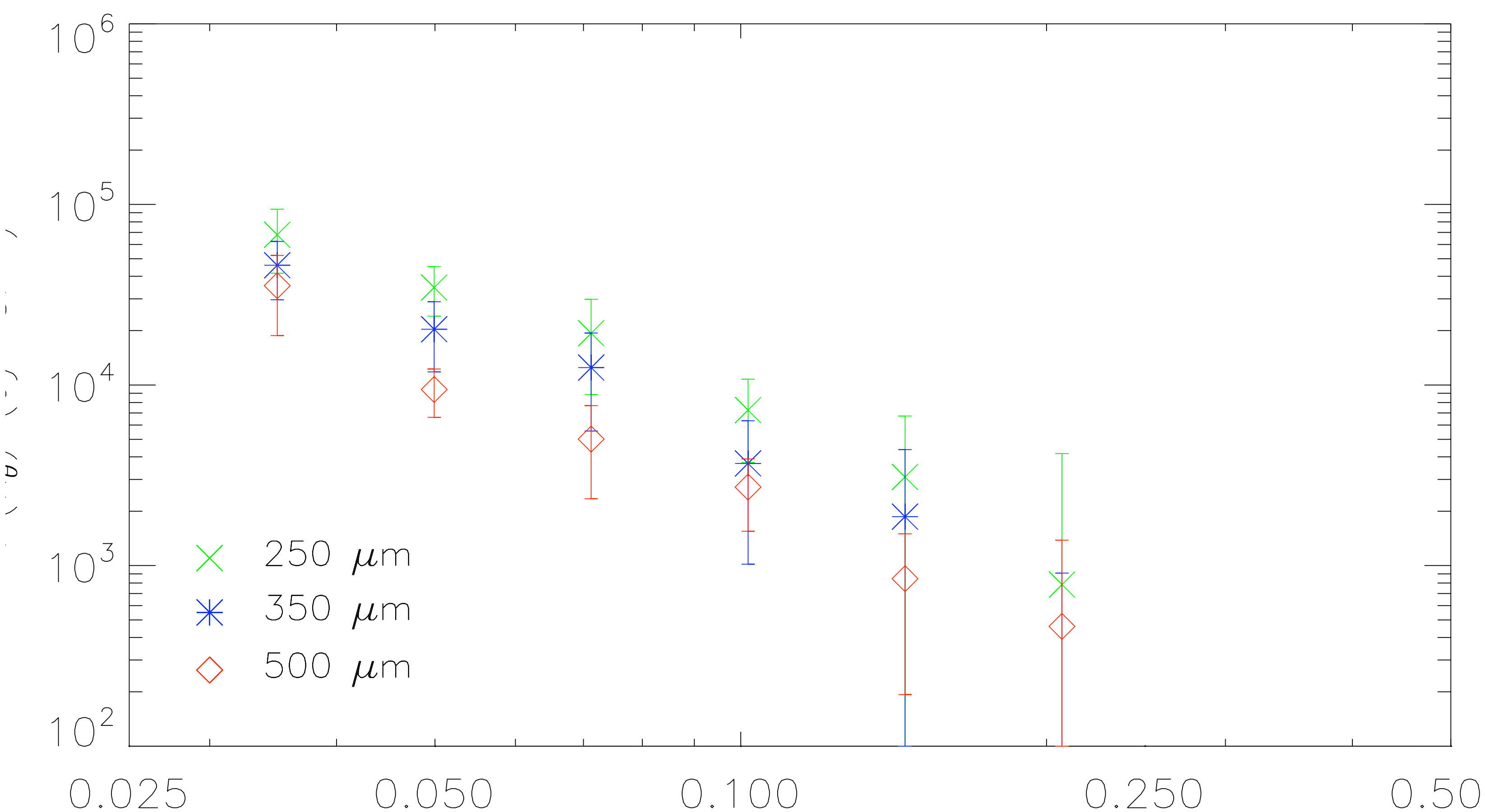


Wednesday, June 8, 2011

Clustering Component

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

- Clustering of star-forming galaxies detected at angular scales 0.03 - 0.2 arcmin^{-1}
- $\Delta I/I \approx 10\%$



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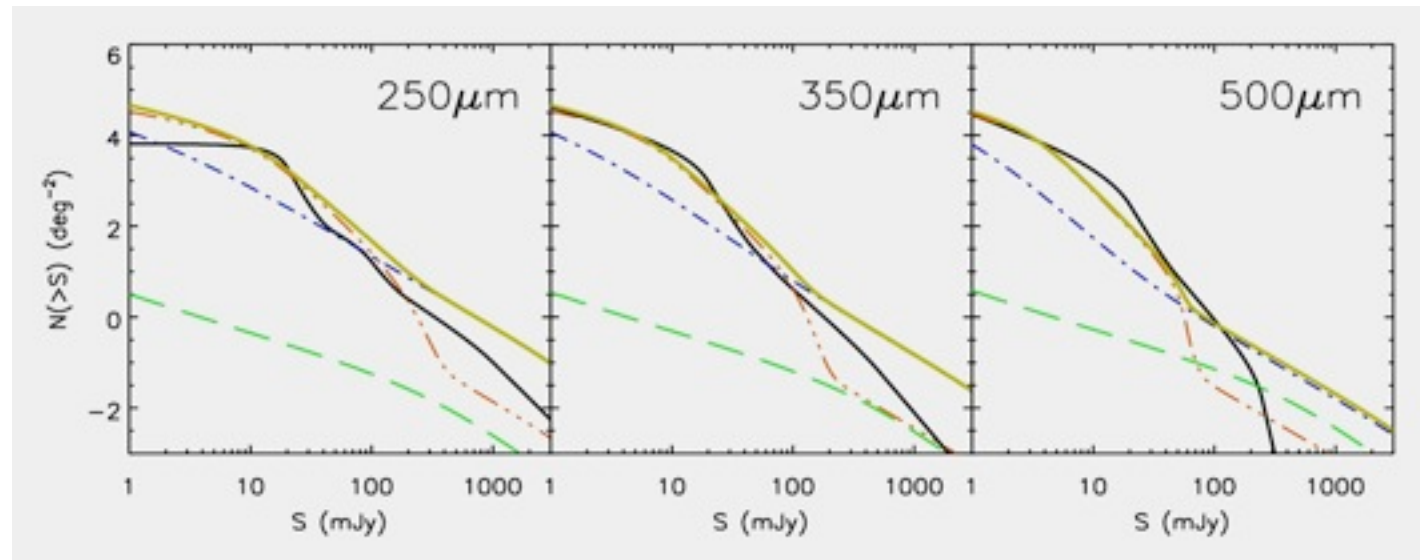
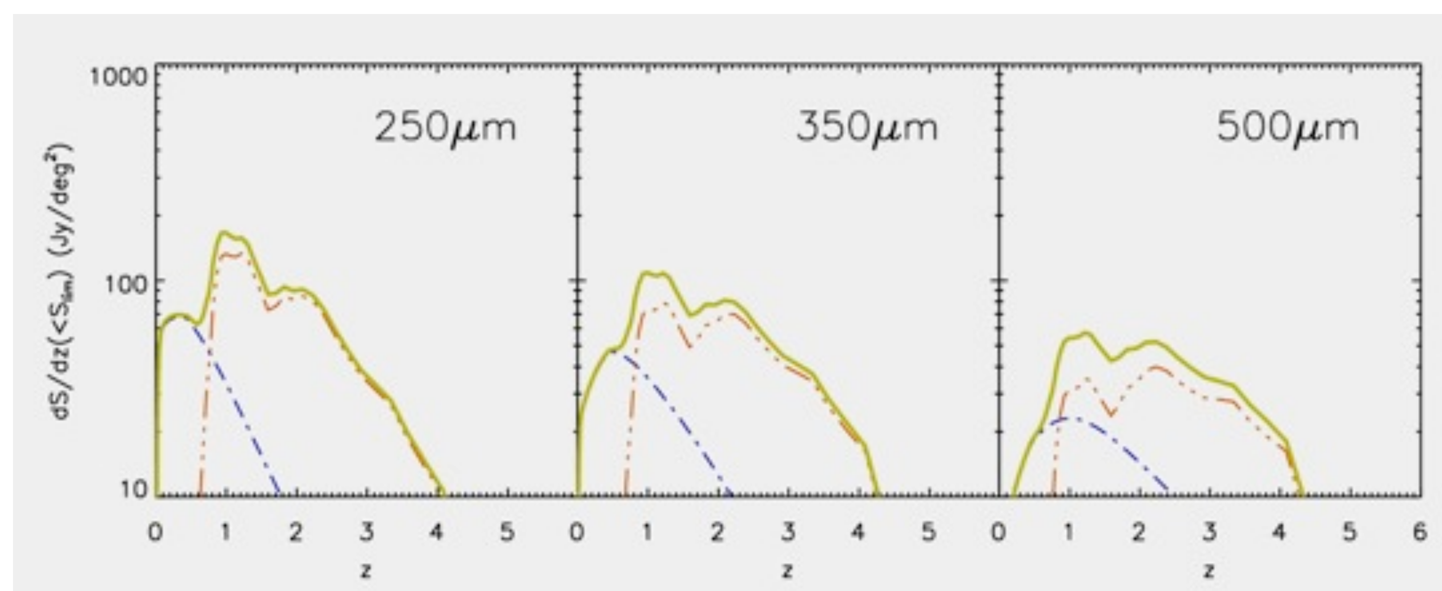
Source Population Model

- Lagache Source Model (2003, 2004)
  - IRAS galaxies: "regular" & "starforming"
  - Evolution of the local 60um counts
  - Provides counts and redshift distributions

Number Counts



Redshift Distribution



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

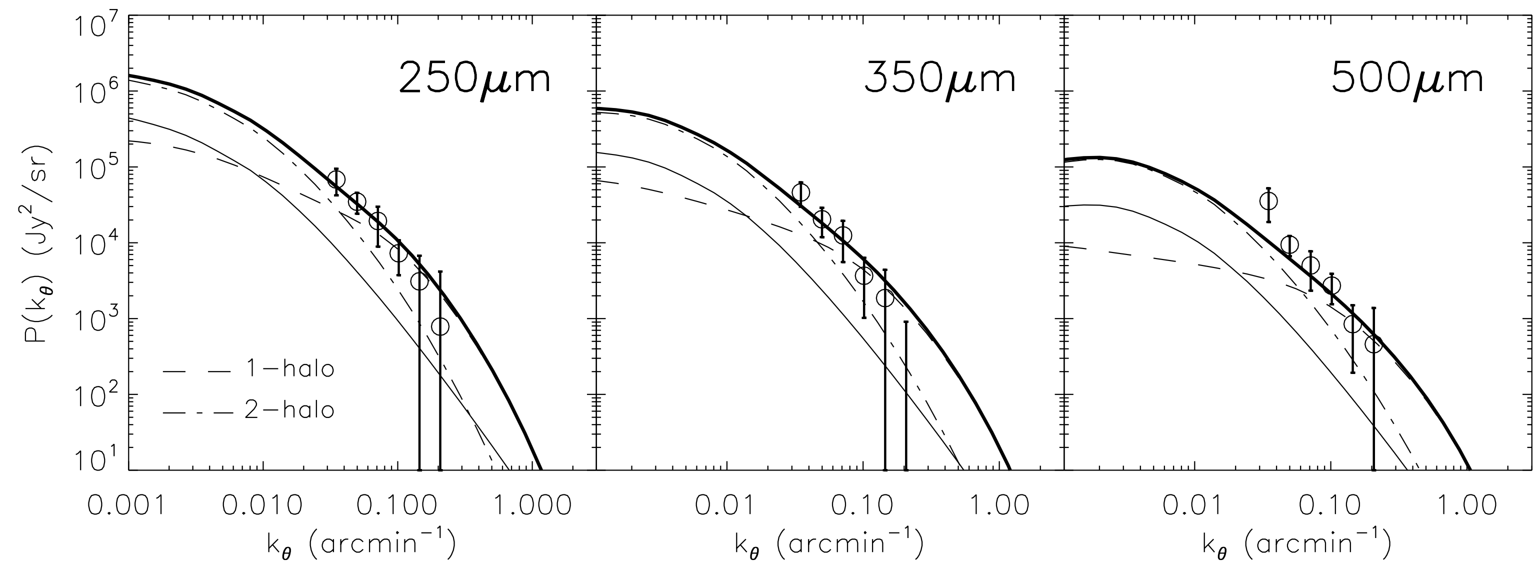
$$N_{gal}(M,z) = \begin{cases} N_0(z)\left(\frac{M}{M_{\min}(z)}\right)^{\alpha(z)} & \text{for} \quad M \geq M_{\min} \\ 0 & \text{for} \quad M < M_{\min} \end{cases}$$

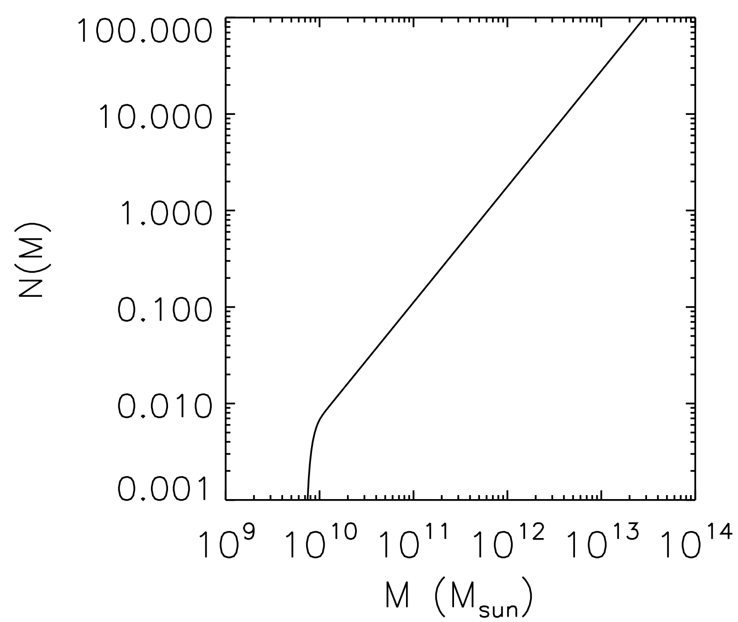
independent of redshift

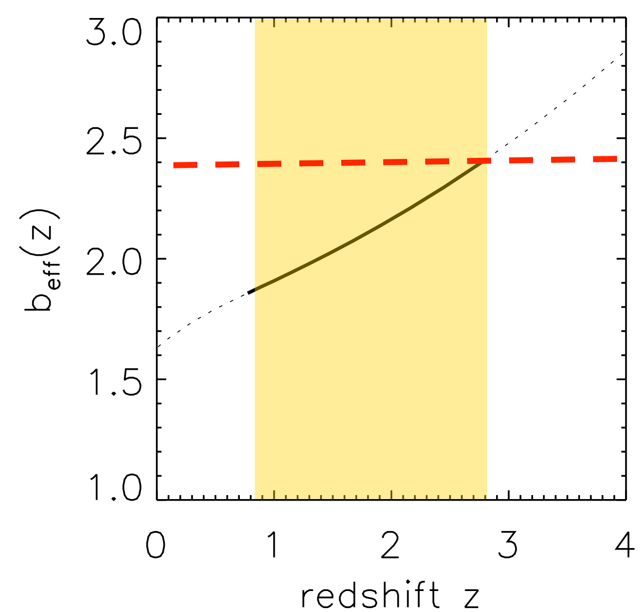
It is fixed by the source model, for any pair ($M_{\min}$ α)

Interpreting the FIt

- Best-fit parameters:
  - $M_{min} = 10^{9.9}\ M_{sun}$
  - $\alpha = 1.2 \pm 0.2$
  - $b = 2.2 \pm 0.2$
  - $M_{eff} = 10^{13.2}\ M_{sun}$
- 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

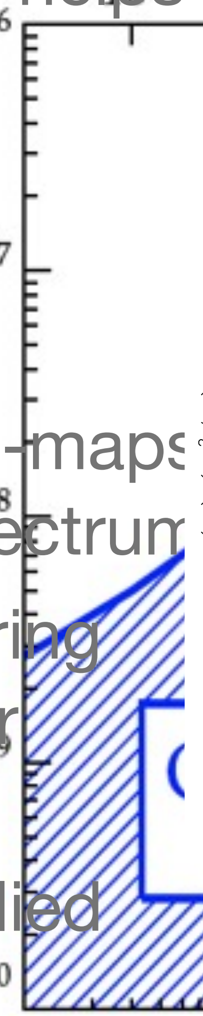


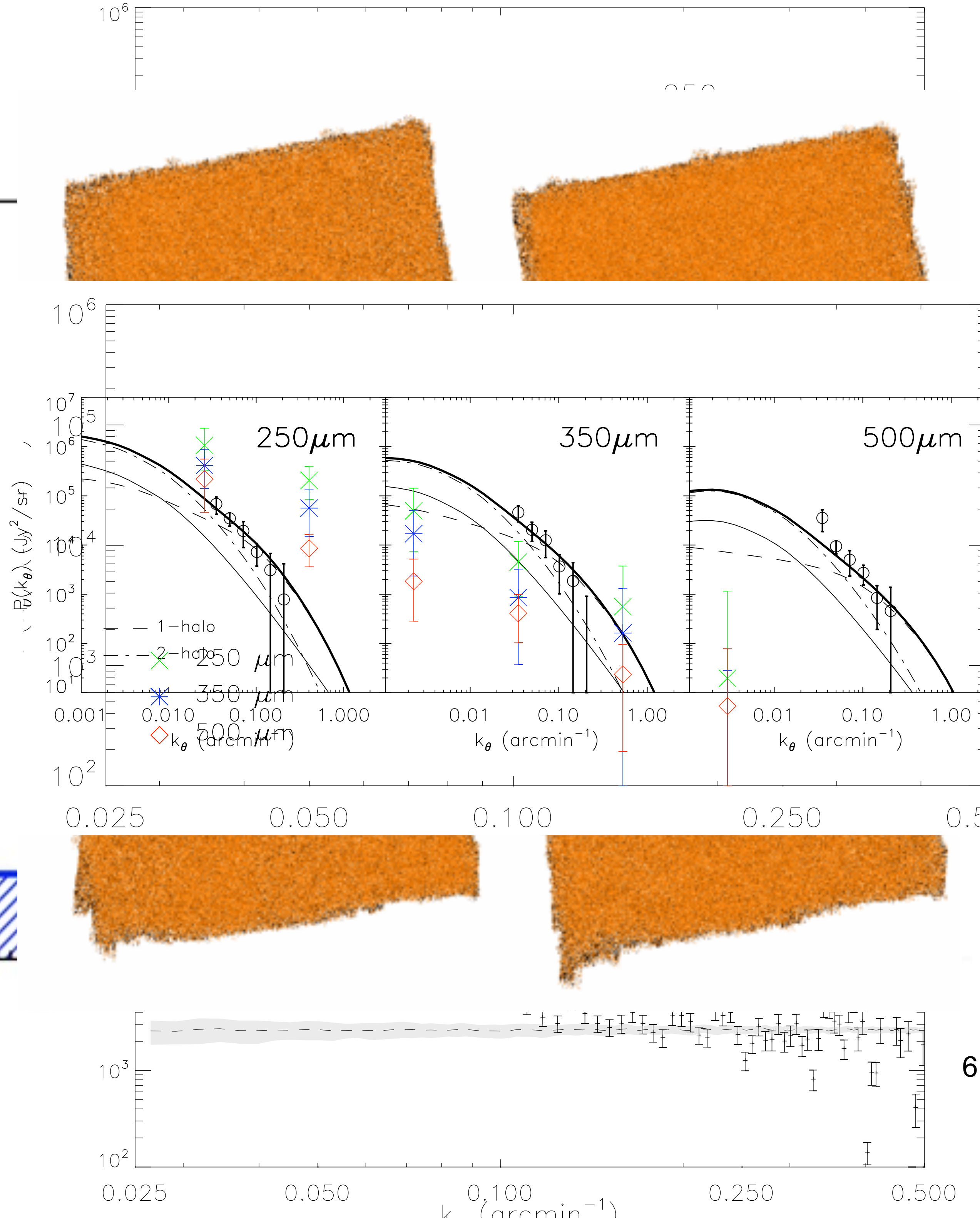




Conclusion

- Half of starlight absorbed and reradiated by dust.
- Clustering of star-forming galaxies helps in understanding of influence of environment on star formation.
- Clustering can by measured from *correlations* in the CIB.
- We prepared specially treated sub-maps in order to calculate the power spectrum
- We found correlations from clustering of star-forming galaxies on angular scales 0.03 - 0.2 arcmin^{-1}.
- We fit these to a Halo model supplied with the Lagache source model.
- We found that star-forming galaxies at high redshift are biased tracers of the underlying dark matter.





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BLAST

Balloon-borne Large-Aperture Sub-millimeter Telescope

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

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