Cosmic Infrared Background

Jean-Loup Puget

on the behalf of the Planck collaboration

with slides and work on this topic from Guilaine Lagache, Olivier Doré, Hervé Dole, Matthieu Bethermin, …

but also a lot of work from those who designed, built, tested and operated in flight the instruments and developed the data processing

Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

The Planck Collaboration is composed of
- a core: the PI. Sc. Off., the two instruments Core Teams and the telescope team. They are in charge of producing the scientific products distributed to the scientific community and the first set of papers on CMB cosmology.
- it also includes associates from more than 50 scientific institutes in Europe, the USA and Canada who are contributing to the scientific program outside CMB cosmology.

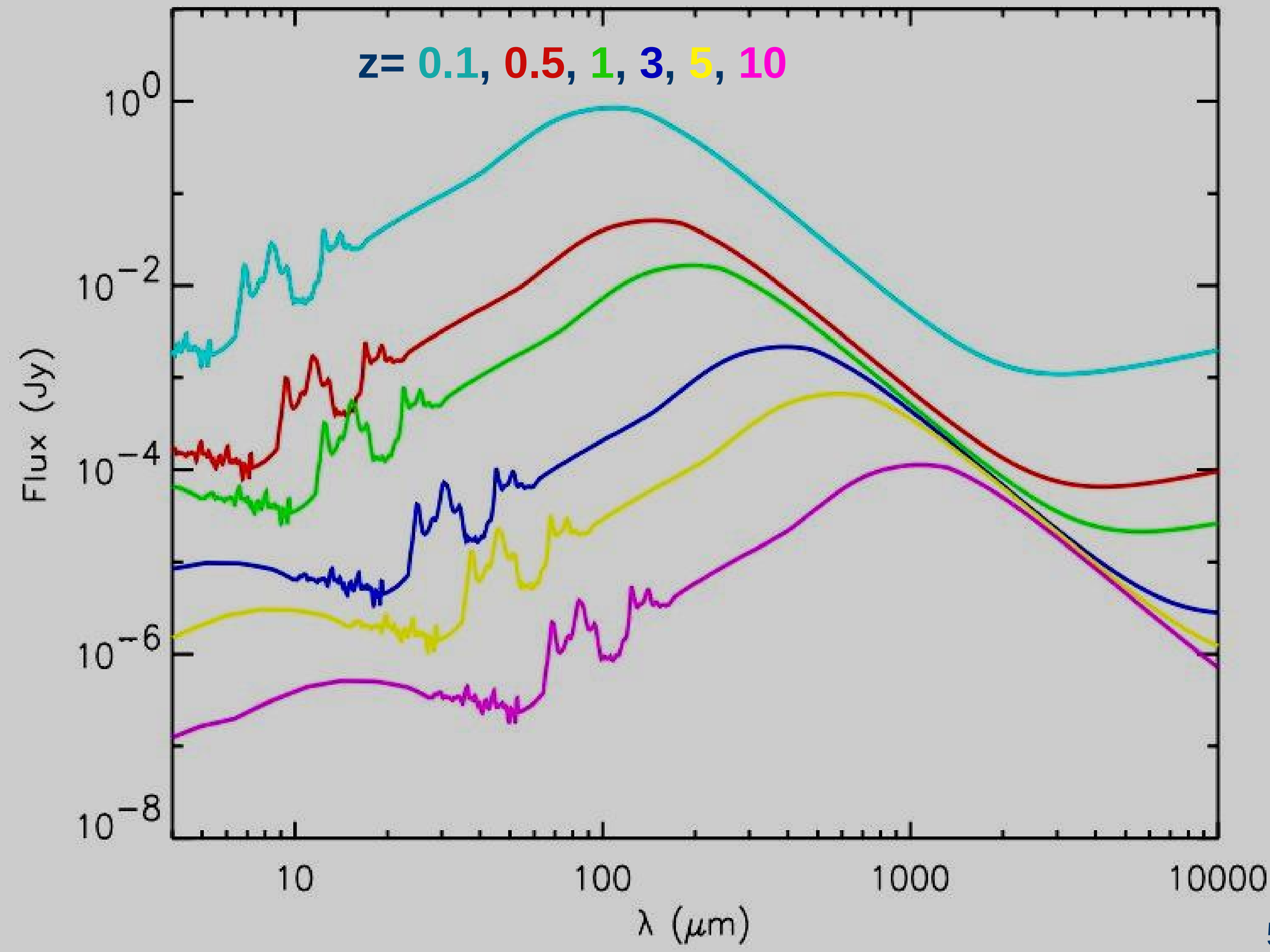
What is this talk about ?

- CIB and Planck… of course
- but mostly about star formation rate history and galaxy formation and evolution
- star formation: cold gas DOES NOT form stars as soon as you gather together more than a Jeans mass which takes into account only thermal energy content
- it is known for 35 years that internal energy in form of (MHD) turbulence and B field balance roughly gravity on many scales (“Larson’s laws”)
- large parts of some molecular complexes containing 10^5 M_{sol} of cold gas do not form stars although the gas in it is below 20K and the H2 densities typically larger than several 10^2 cm^{-3}
- some form low mass stars and, although outflow and jets feed the turbulence, they evolve into forming more massive stars
- John Bally illustrated this very well by showing the amazing observational set of information gathered especially in the last 15 years
- the process goes until the gas is expelled from the galactic disc to then fall back some 40 million years later to gather again in clouds and complexes

were are we then ?

- the cycle of star formation and dispersion of the cold complexes back to diffuse gas and clouds reforming later seems to be regulated by the longest time scales, not the local ones but the large scale properties : the feed back controls the average SFR over large scales and long times
- the detail understanding of this is far from being available
- the global SFR averaged over kpc scales and hundreds of million years is directly linked to the surface density of cold gas and the G potential well
- the FIR luminosity function is dominated by more luminous galaxies when the mass function of collapsed halos is dominated by smaller masses
- Q: what is preventing the gas collapsing and cooling at redshift 10 to 20 in the early generations of collapsed objects ?
- we know that most that gas is NOT transformed into stars
- we do not understand why
- measuring the SFR at high redshift and its distribution with respect to large scale structure is probably key to guess what are the driving mechanisms

CIB: how galaxies at different redshifts contribute



Differential counts and emissivities

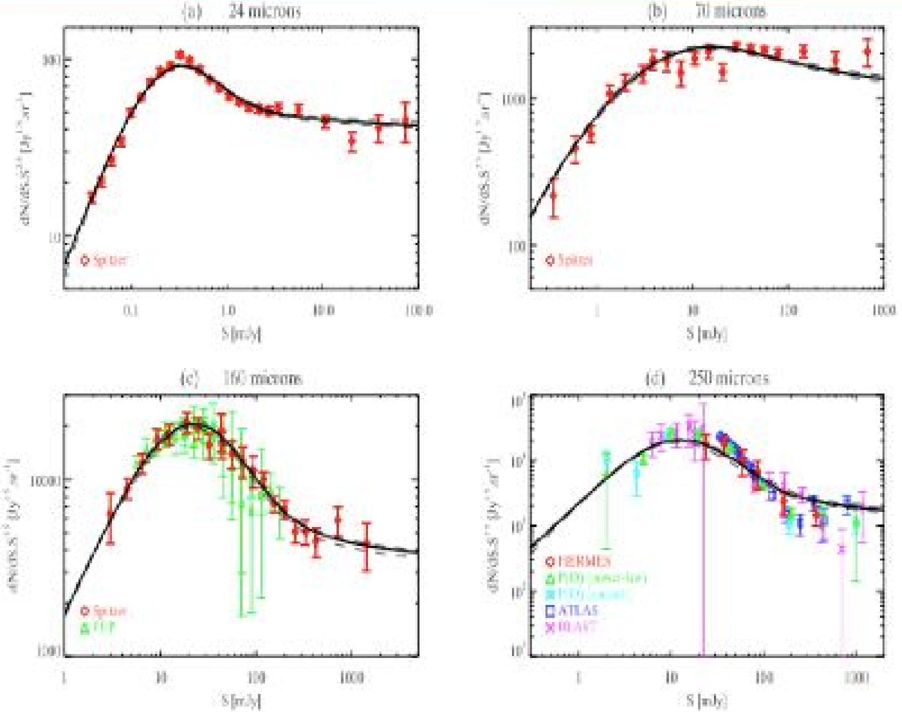
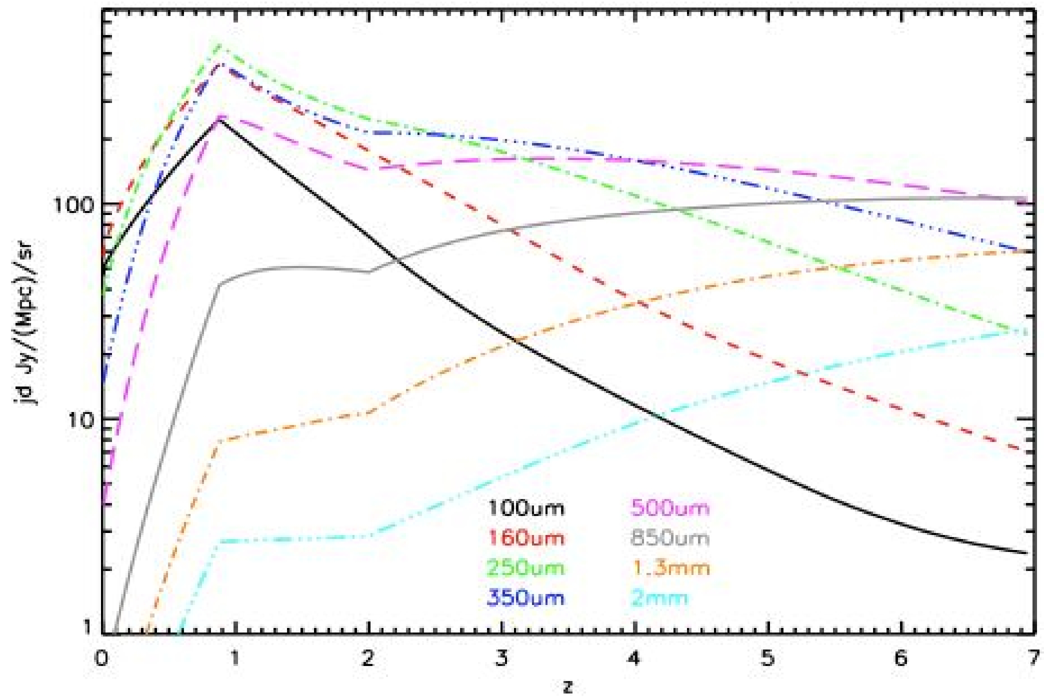


Fig. 1. Differential counts at 24, 70, 160 and 250 μm. The black continuous line shows the fit of the model of Béthermin et al. (submitted). (a) to (c): Red diamonds: Béthermin et al. (2010a)Spitzer legacy number counts. (c): Green triangles: Berta et al. (2010) Herschel/PEP number counts. (d) : Red diamonds: Oliver et al. (2010)Herschel/Hermes number counts. Green triangles: Glenn et al. (2010) Herschel/Hermes P(D) analysis. Purple crosses: Béthermin et al. (2010b) BLAST number counts.

$$\bar{j}_\nu(z) = (1+z)\int_0^{S_{\rm cut}} dS\ S\ \frac{d^2N}{dS\,dz}$$



Matthieu Béthermin et al. 2011

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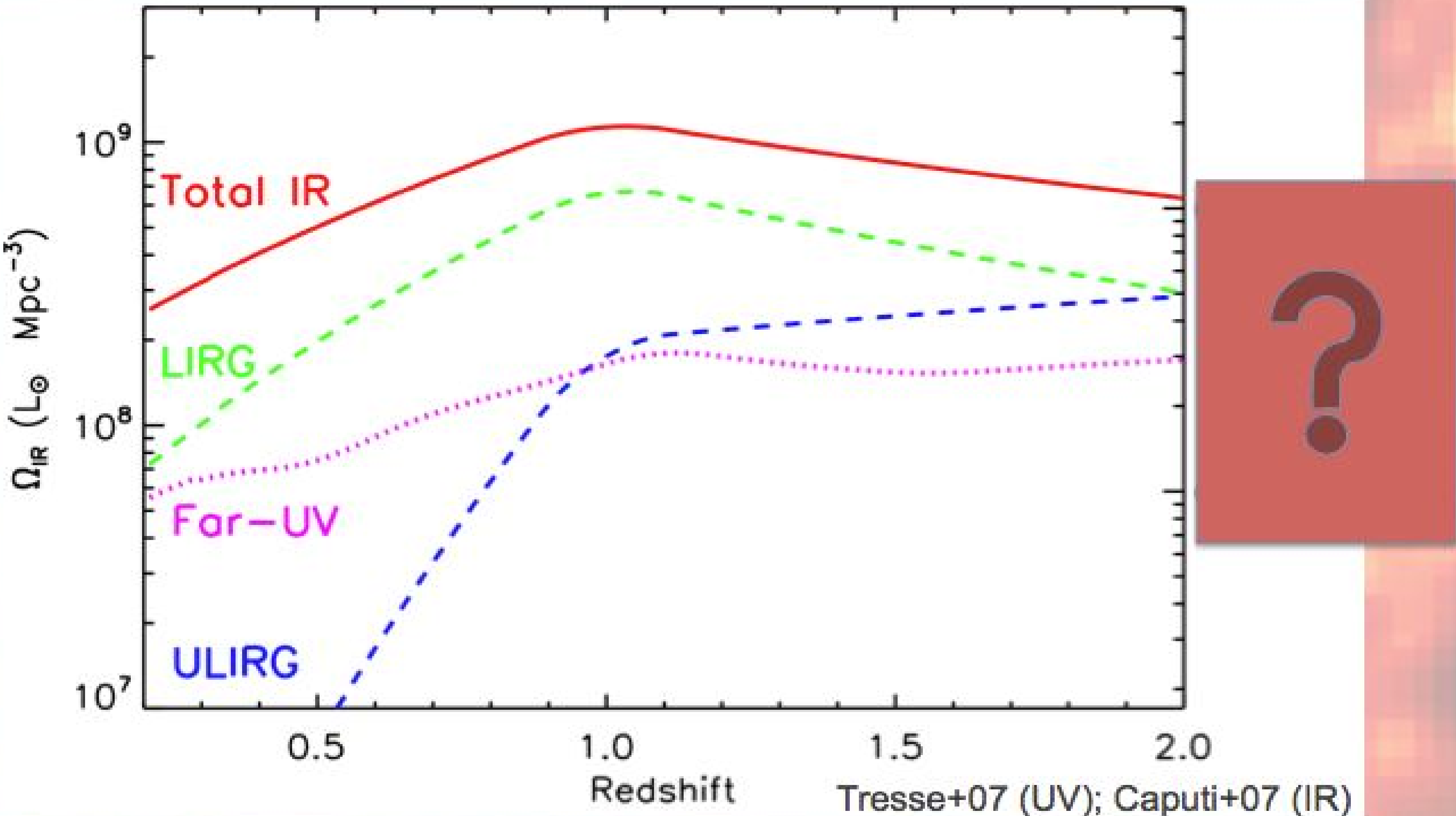
Star formation history

LIRGs and ULIRGs: >70% of the star formation activity at 1<z<2

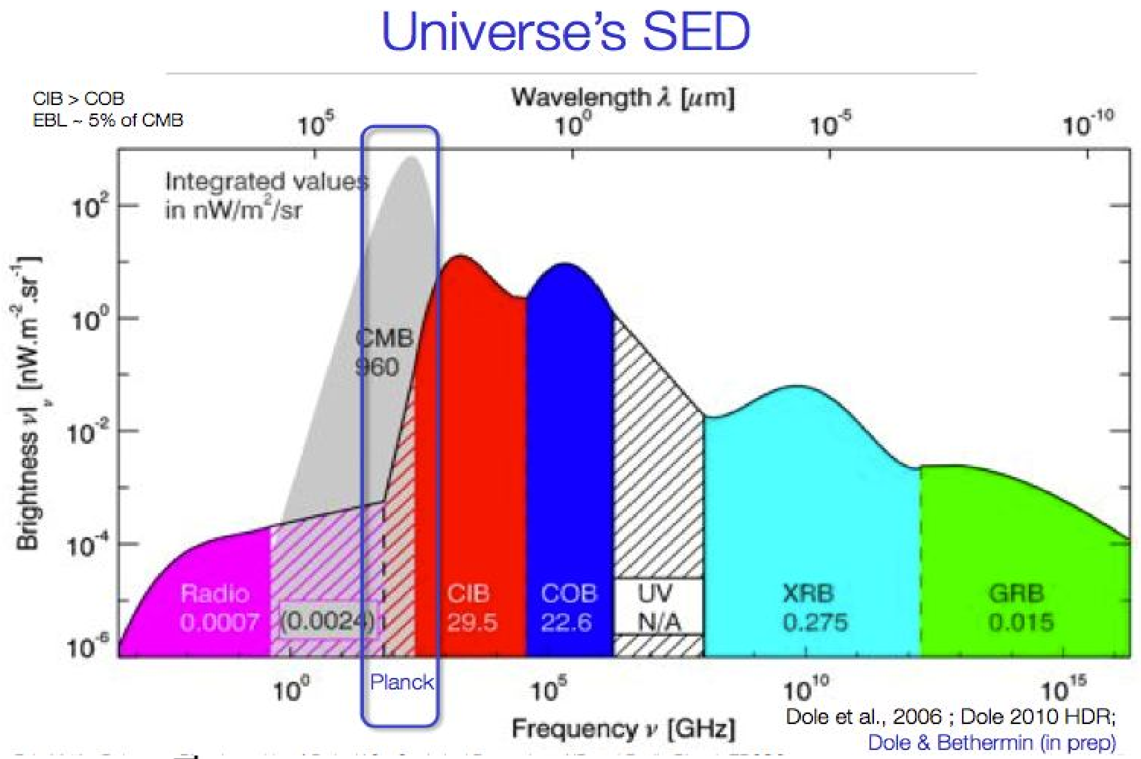


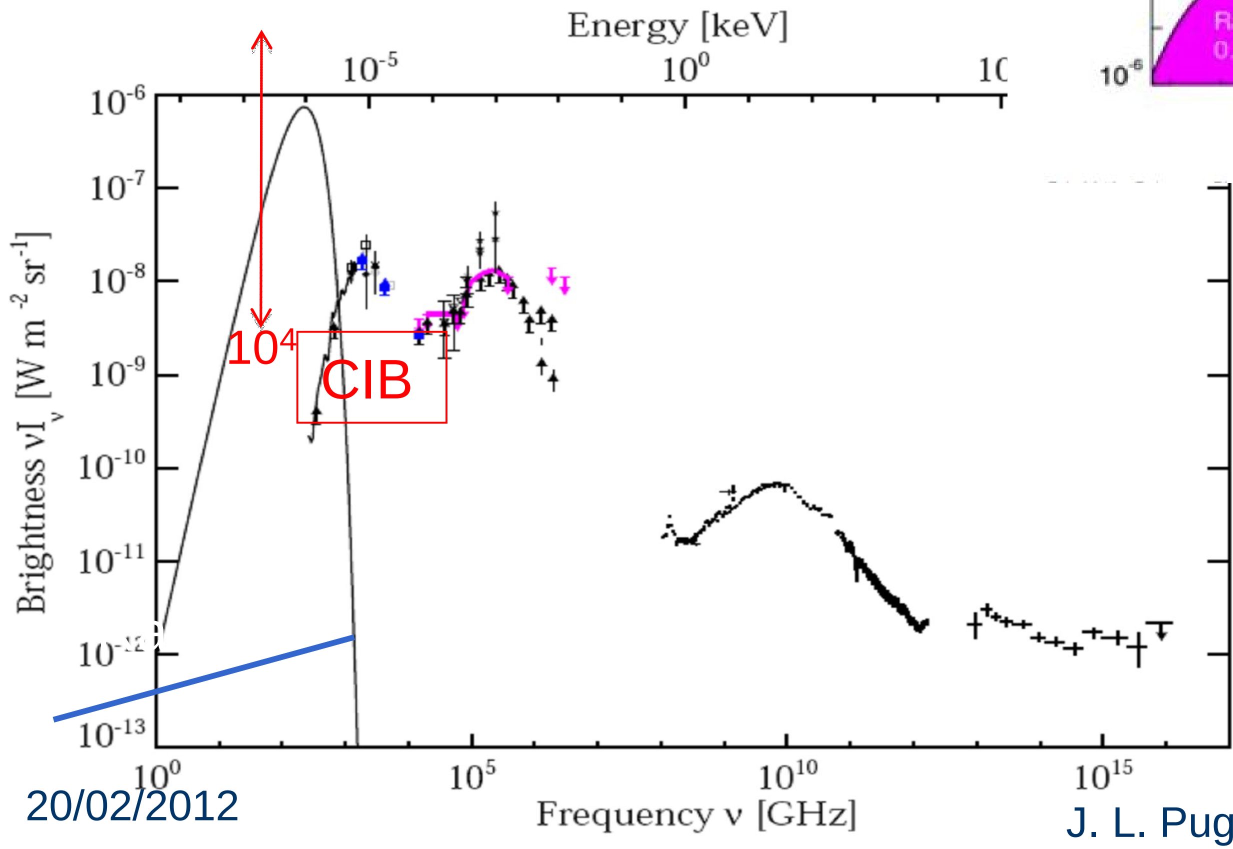
Tresse+07 (UV); Caputi+07 (IR)

cosmic backgrounds (radio to gamma rays)

- FIR /optical ~ 0.3 locally
- FIR /optical ~ 1 integrated over redshifts

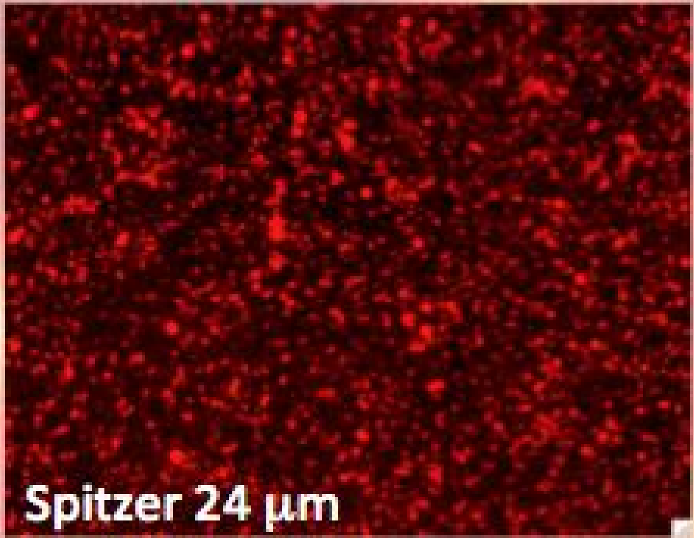
→ FIR /optical > 1 at high z



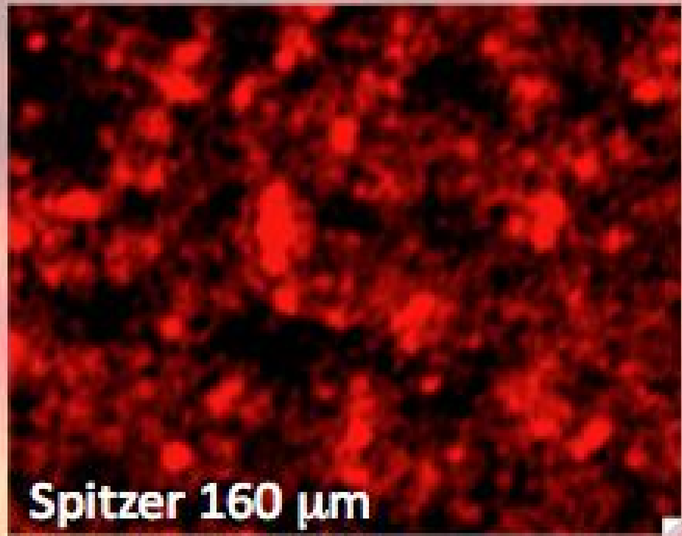


Origins of CIB anisotropies

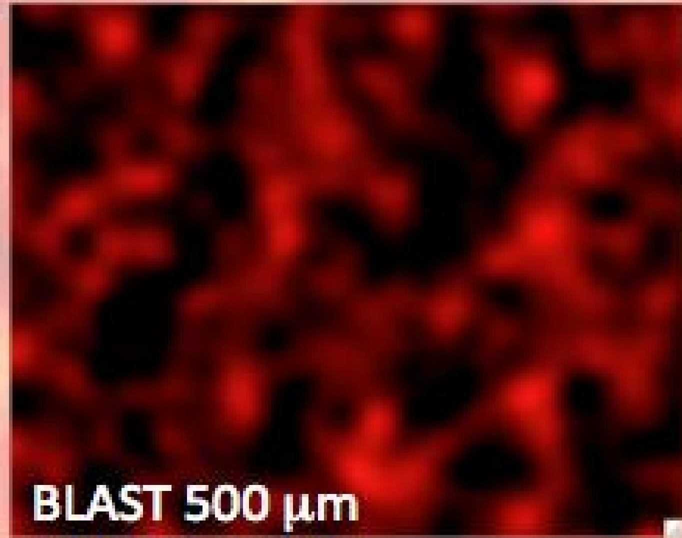
Extragalactic-sources confusion: our « business »



Resolved CIB: 80%



Resolved CIB: 15%



Resolved CIB: <1%

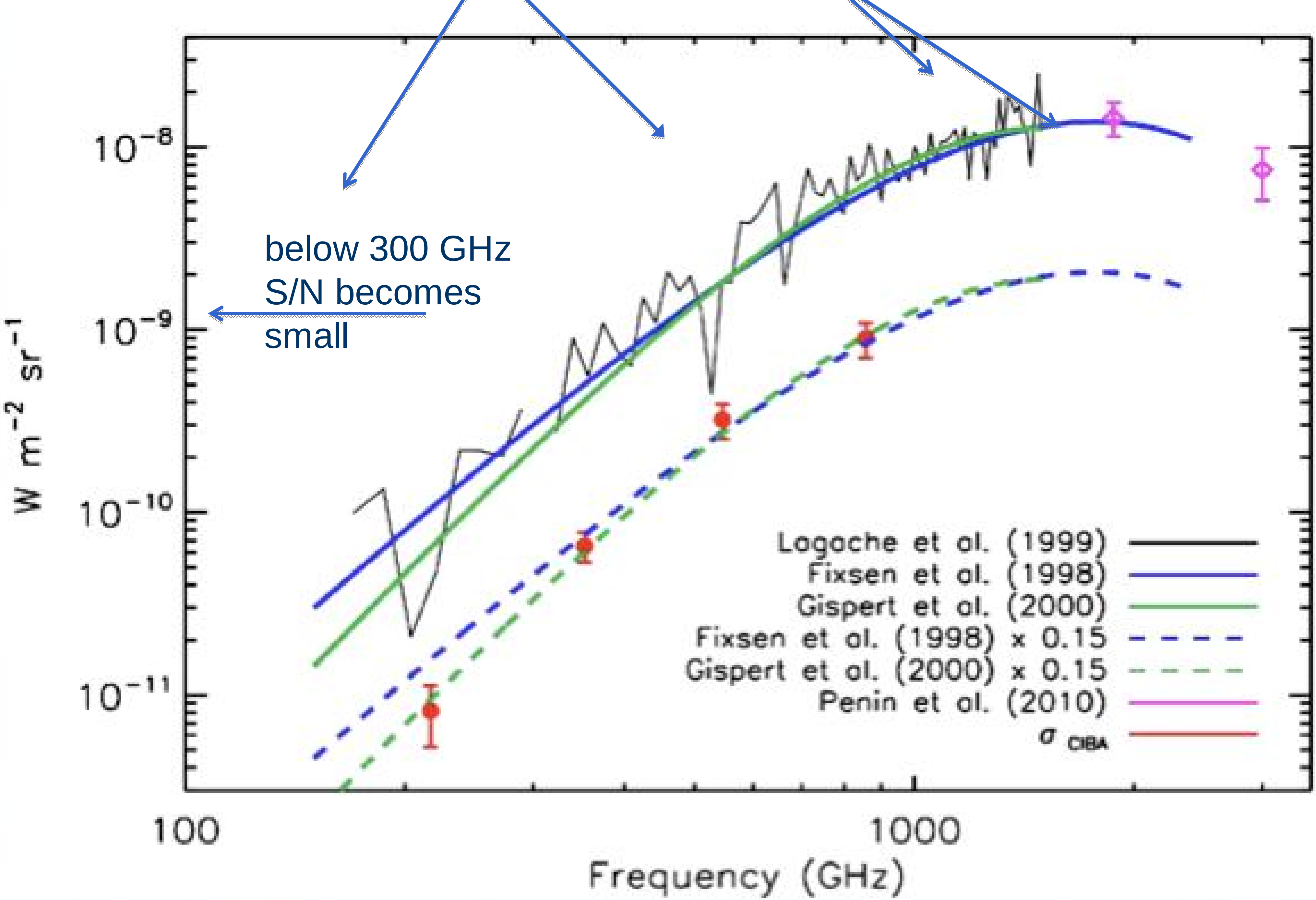
In the far-IR, submm and mm:

⇒ Maps of diffuse emission: a web of structures, characteristic of CIB anisotropies

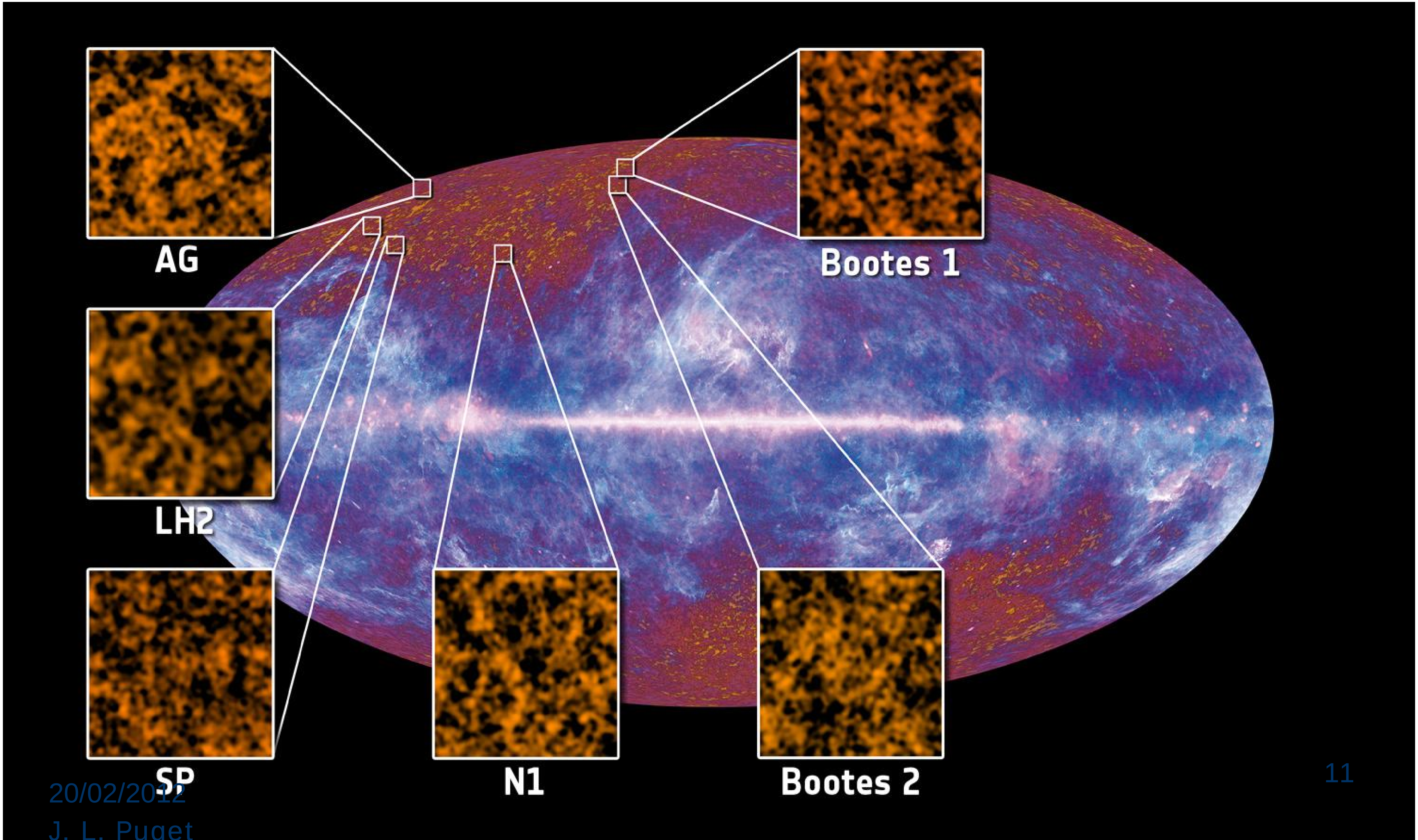
⇒ P(D) analysis, stacking of known populations, angular power spectra

Images from M. Béthermin

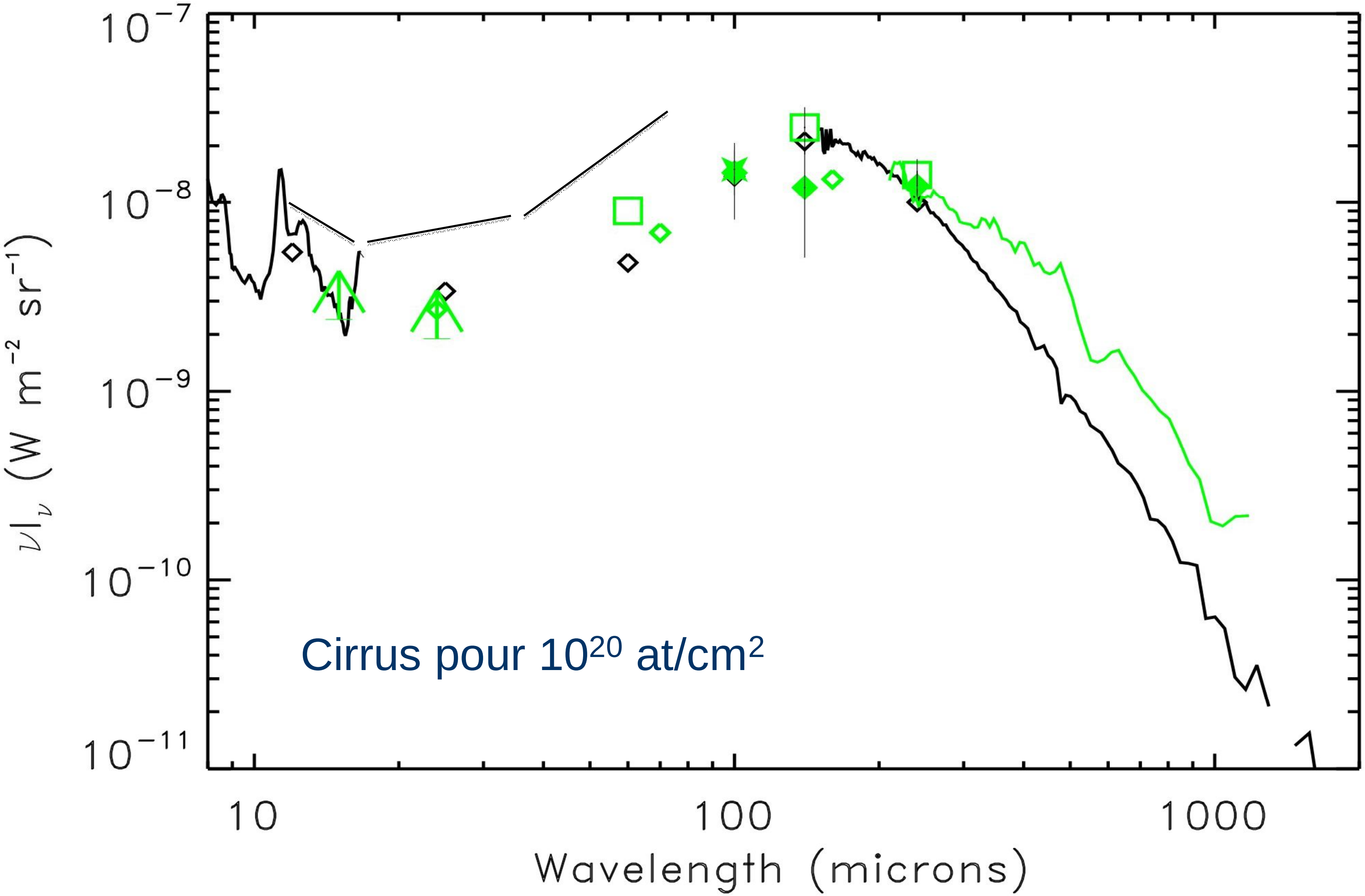
CIB spectrum from FIRAS and DIRBE+SPITZER



The 6 fields studied by Planck for CIB



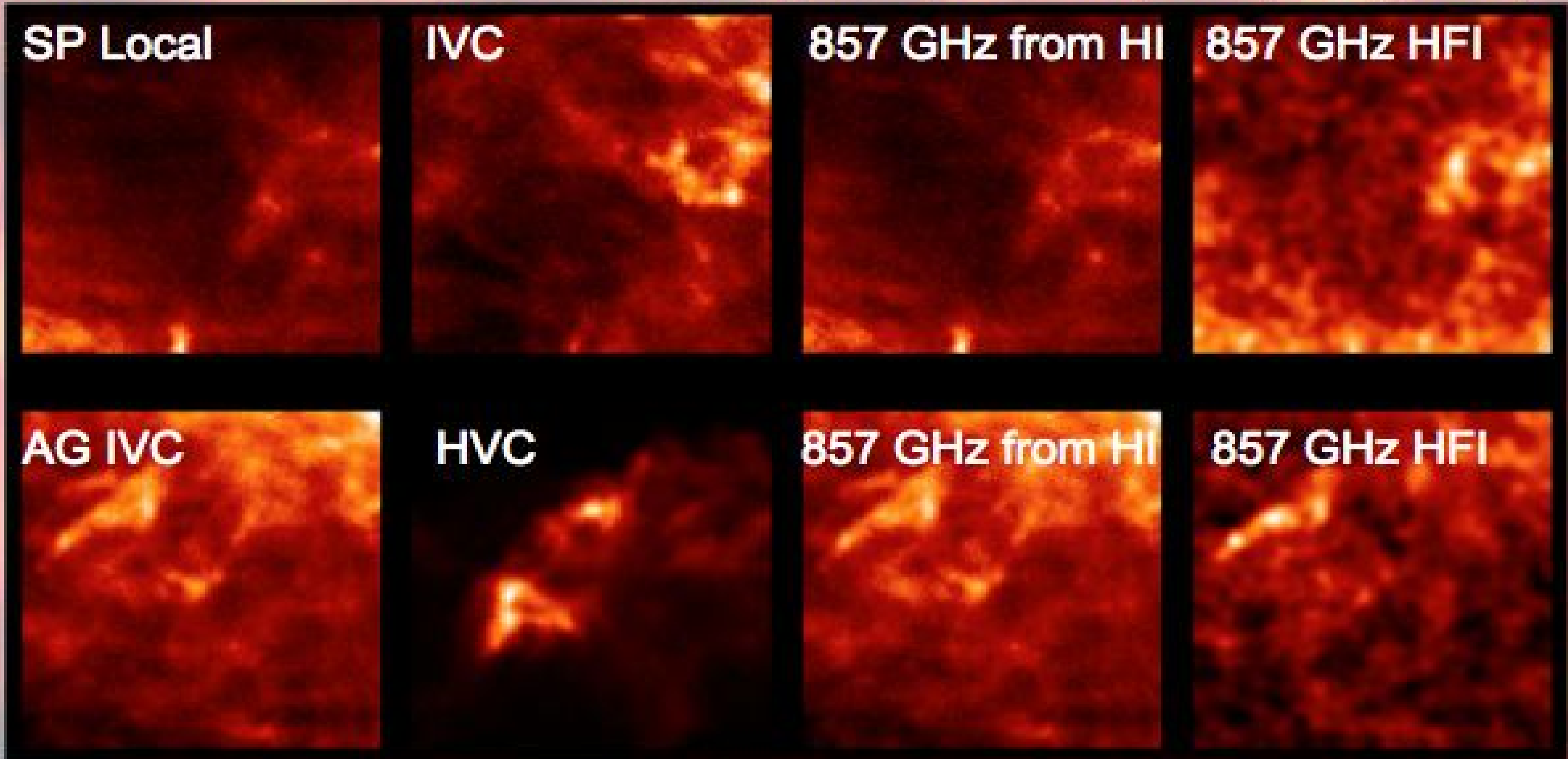
Spectre CIB/cirrus



1) Component separation: removing galactic dust

HI: best tracer of dust emission in the diffuse sky

- HI data in each field: different velocity components (local, IVC, HVC)

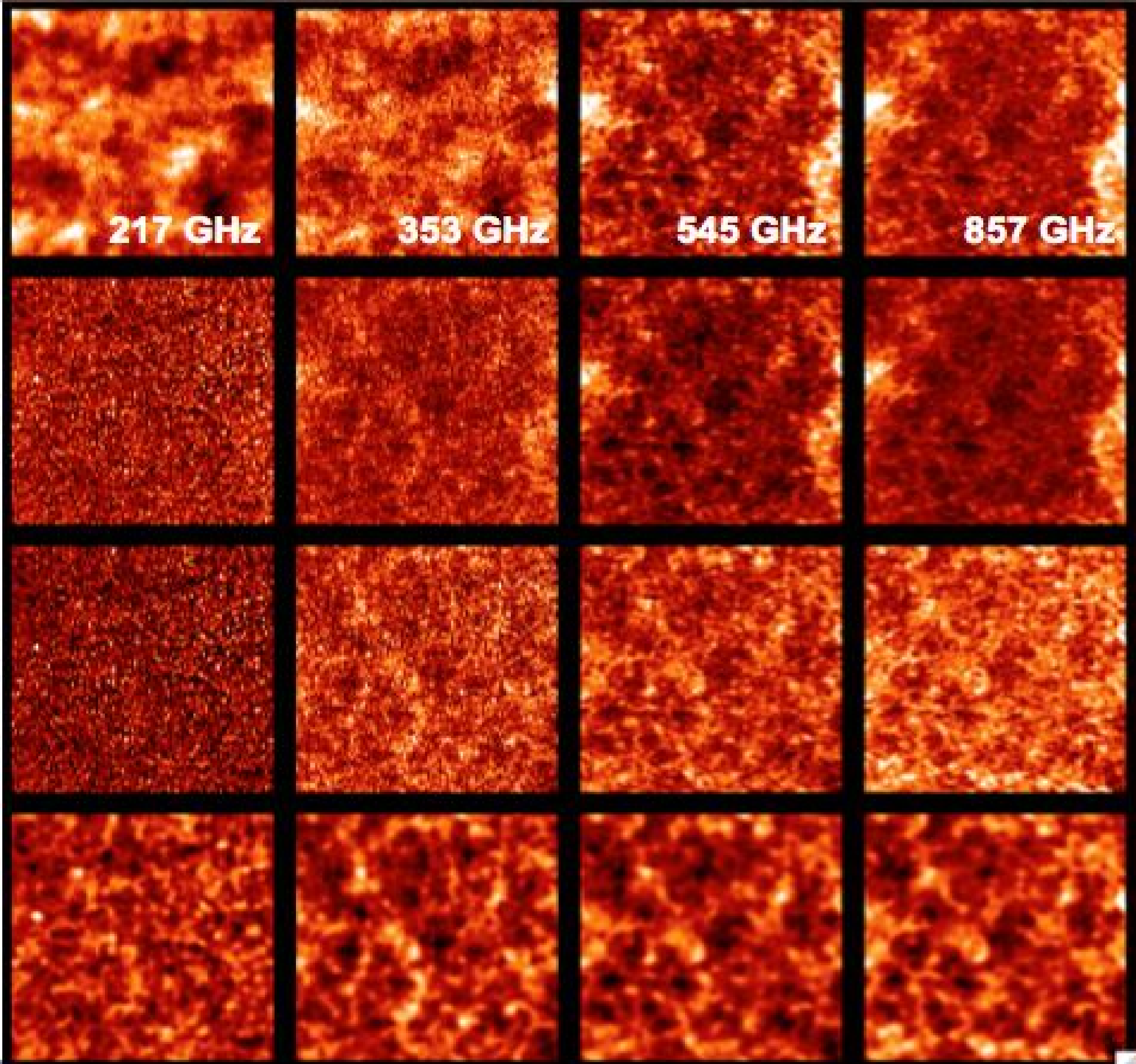


(See astroph 1101.2036)

- Model: *Planck*/HFI at each ν

$$I_\nu(x,y) = \sum_i \alpha_\nu^i N_{HI}^i(x,y) + C_\nu(x,y)$$

1) Component separation: residual maps

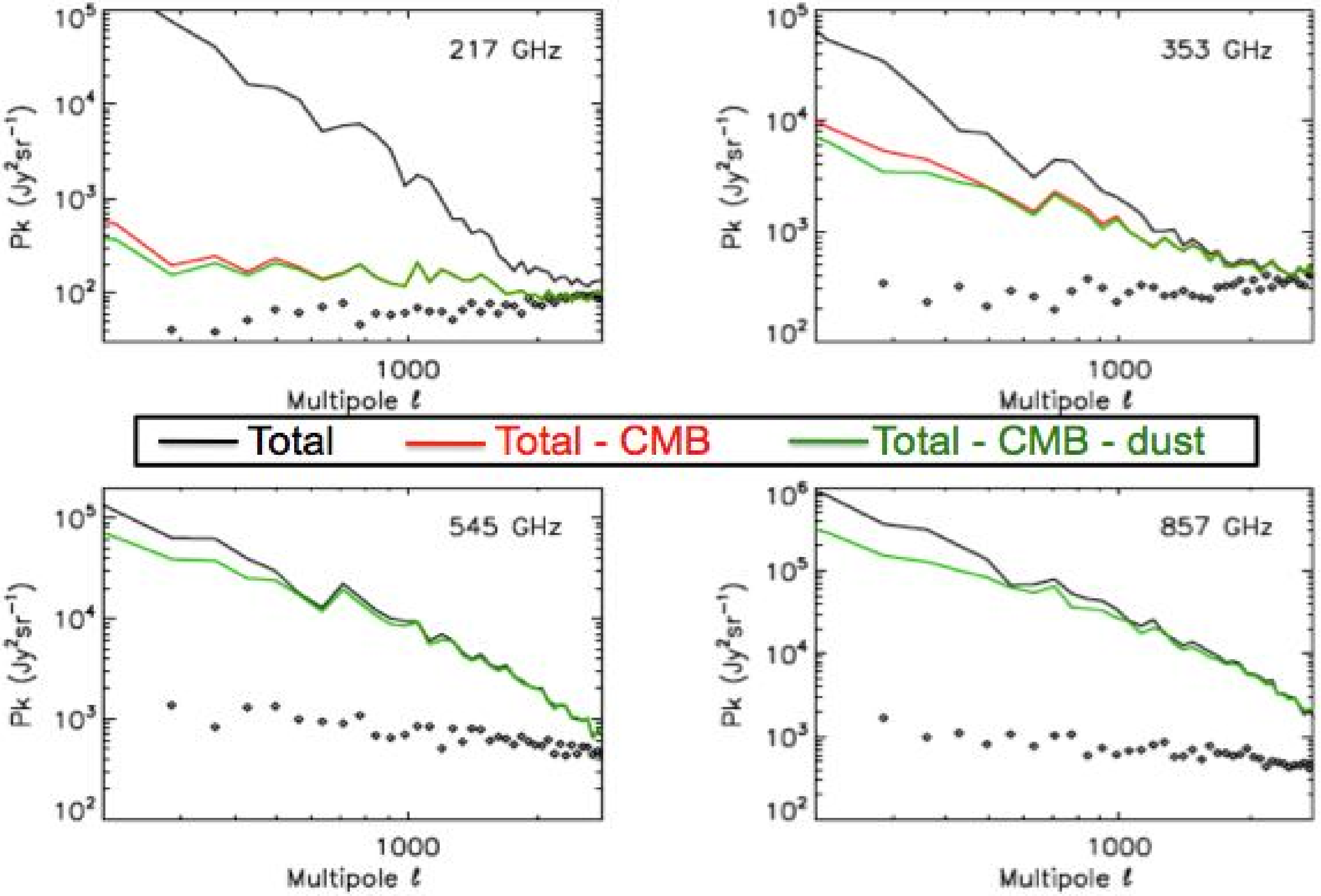


HFI « raw » maps
26.4 Sq. Deg.

Raw maps
– CMB
– ERCSC point sources

CIB maps
= Raw maps
– CMB
– ERCSC point sources
– Galactic dust

CIB maps @ 10 arcmin



217 GHz

l=200 CMB is 99.7%

CIB 0.2% dust 0.1%

l=1000 CMB is 95%

CIB is 5% dust negligible

857 GHz

l=20 dust is 99%,

CIB 1%

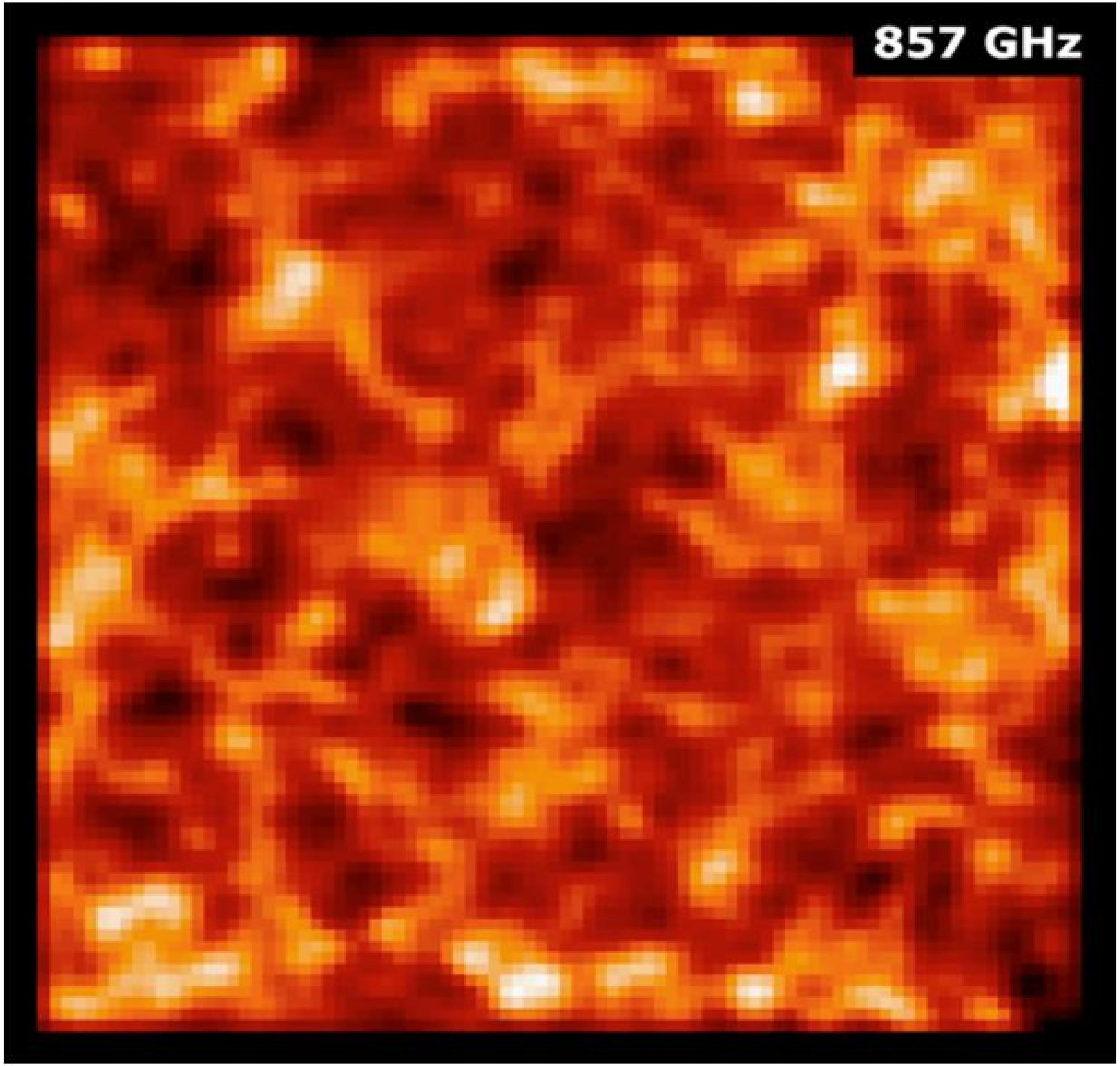
l=200 dust is 70%,

CIB is 30%

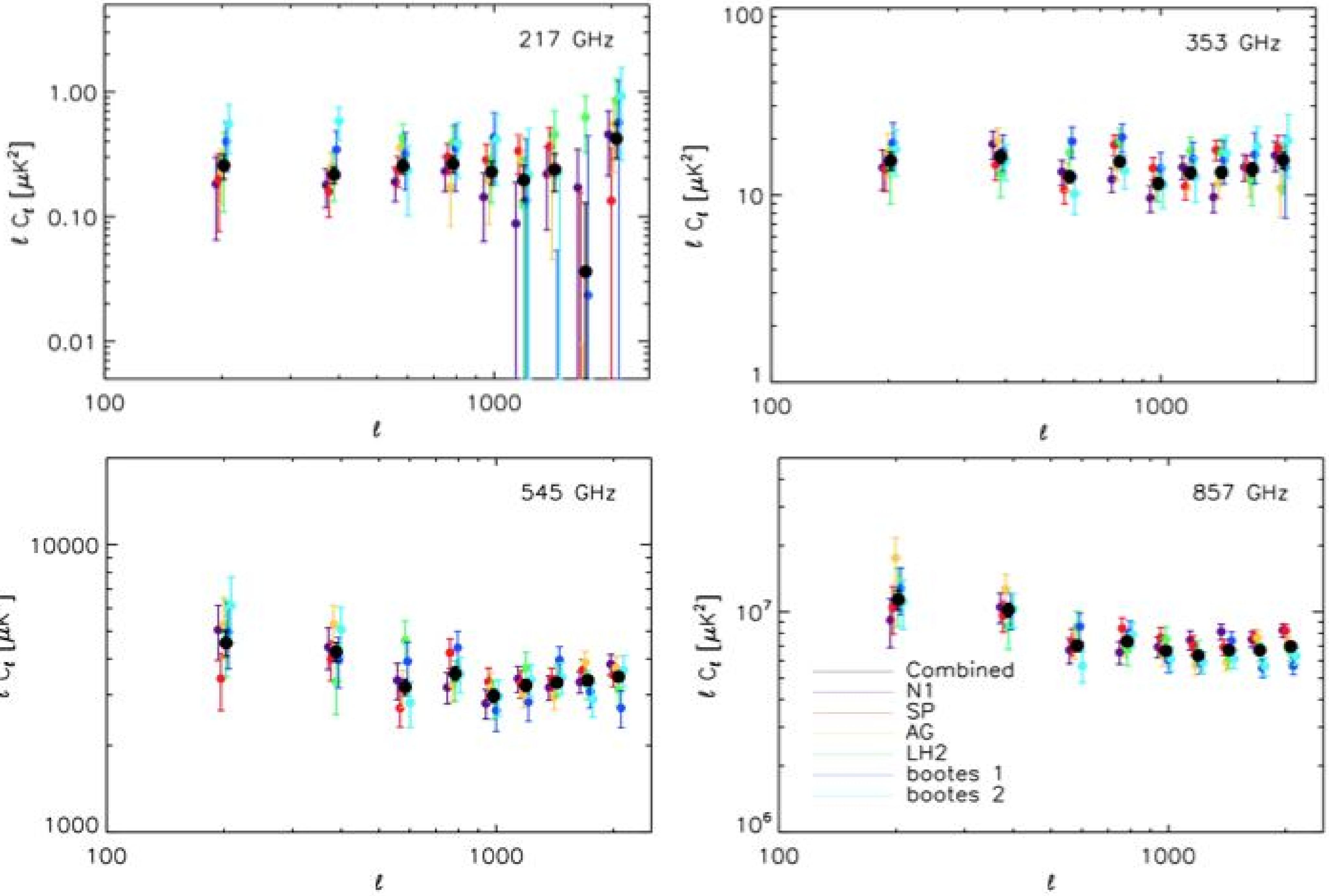
l=1000 CIB is 70%,

dust is 30%

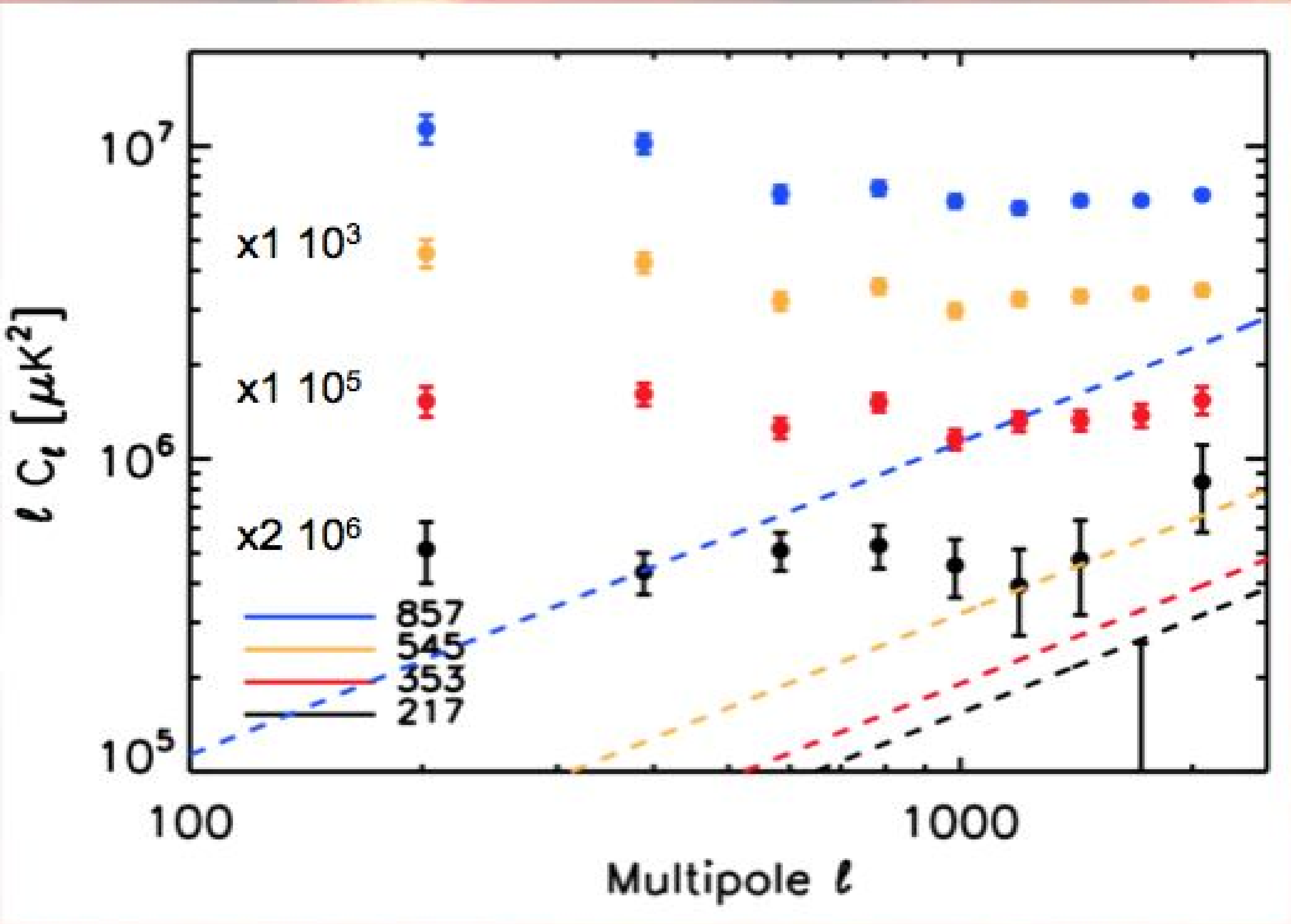
Planck maps at 217, 353, 545 and 857 GHz



- As seen in Guilaine Lagache's earlier talk
- High SNR sub-degree structures at all frequencies
- Assuming sources at z~2, we are measuring clustering at 30 Mpc/h (k~0.03 h/Mpc) or less scales
- Structures partially correlated across frequencies
- Obviously cosmologically very interesting! What can we learn from these maps?


217 GHz
353 GHz
545 GHz
857 GHz
Combined
N1
SP
AG
LH2
bootes 1
bootes 2

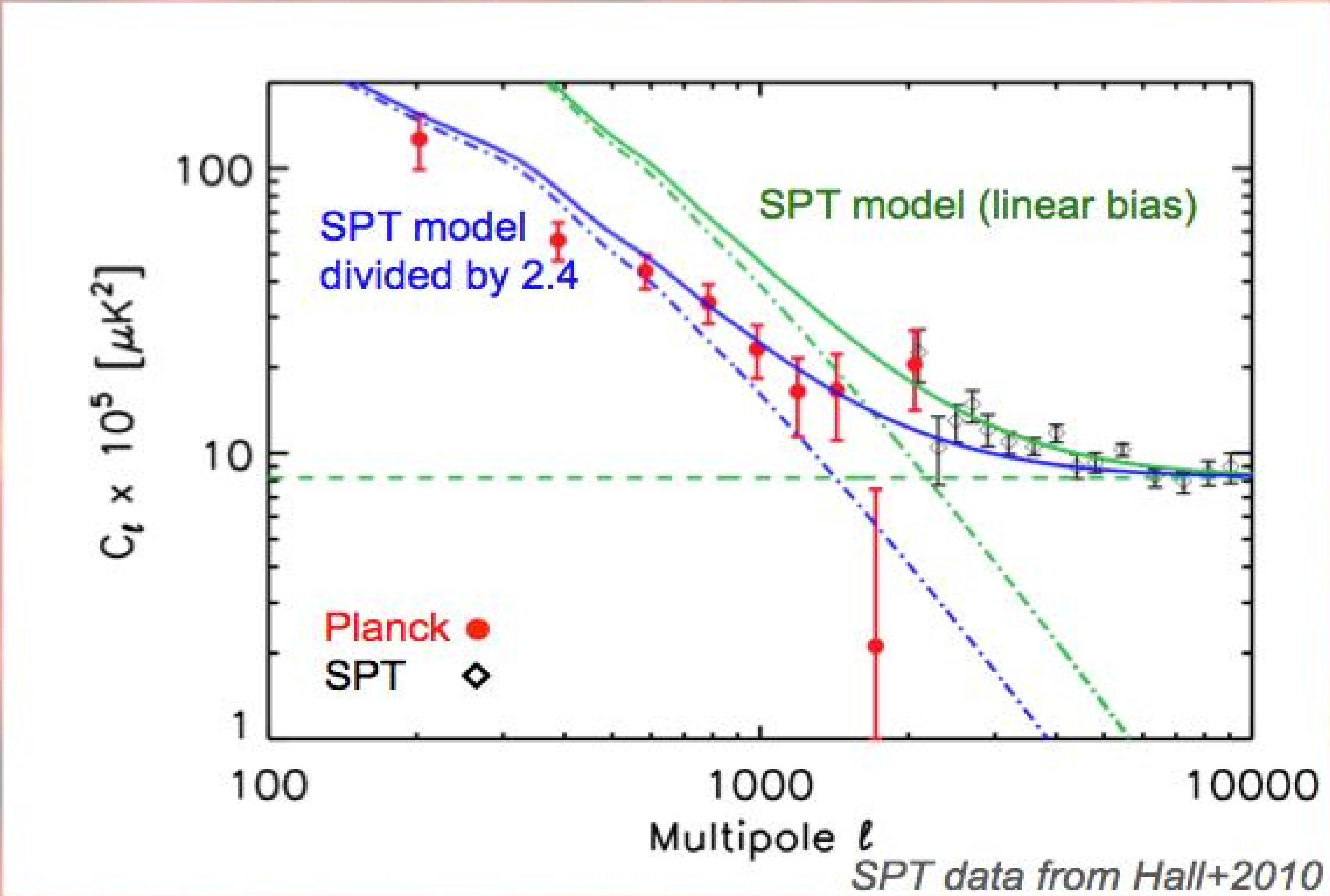
Combined power spectra



Shot noise:
not measurable

Cl shape:
Remarkably similar

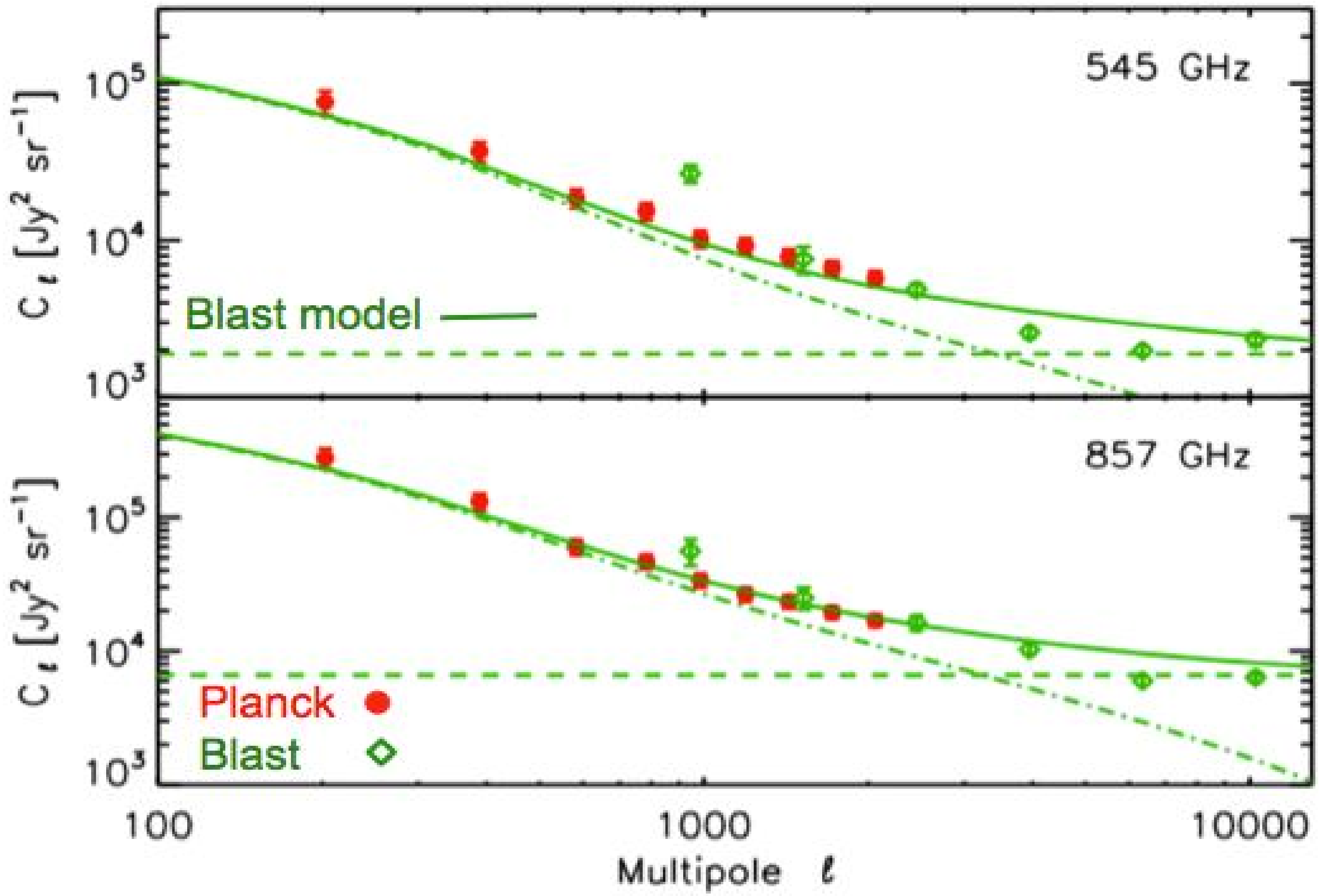
Comparison with SPT (ACT)



SPT data points are color corrected using the CIB mean spectrum, factor 1.04

Combination with Blast

Blast data from Viero+2009

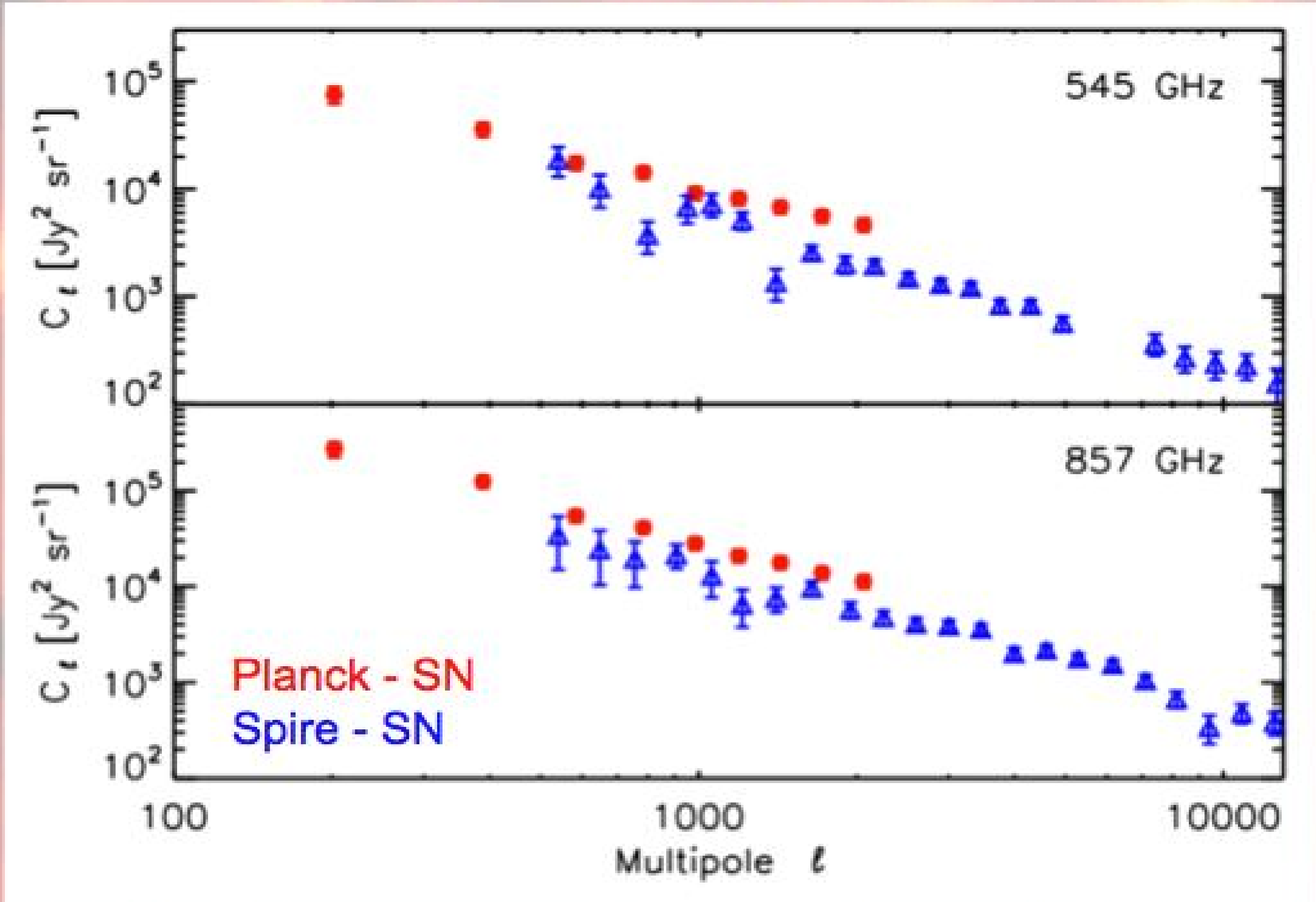


Blast and Planck:
~ Same S_{cut}
=> Same SN

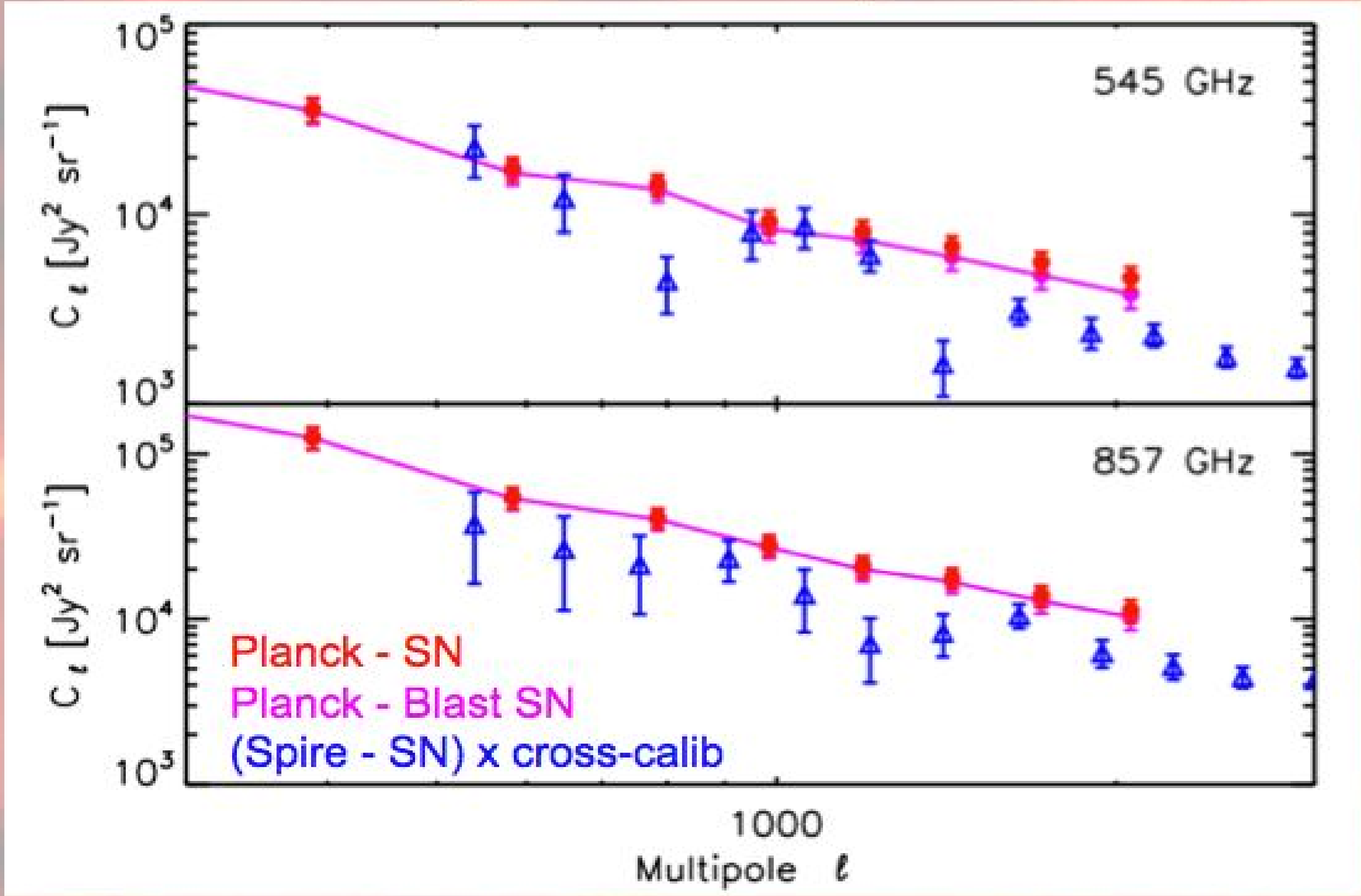
Blast data points are color corrected using the CIB mean spectrum, factors 1.05 at 857 GHz, 0.7 at 545 GHz

Comparison with Spire
Shot-noise subtracted CIB power spectra

Planck@857GHz Scut=710 mJy -- Spire@857GHz Scut=50 mJy
=> Different SN level



Comparison with Spire

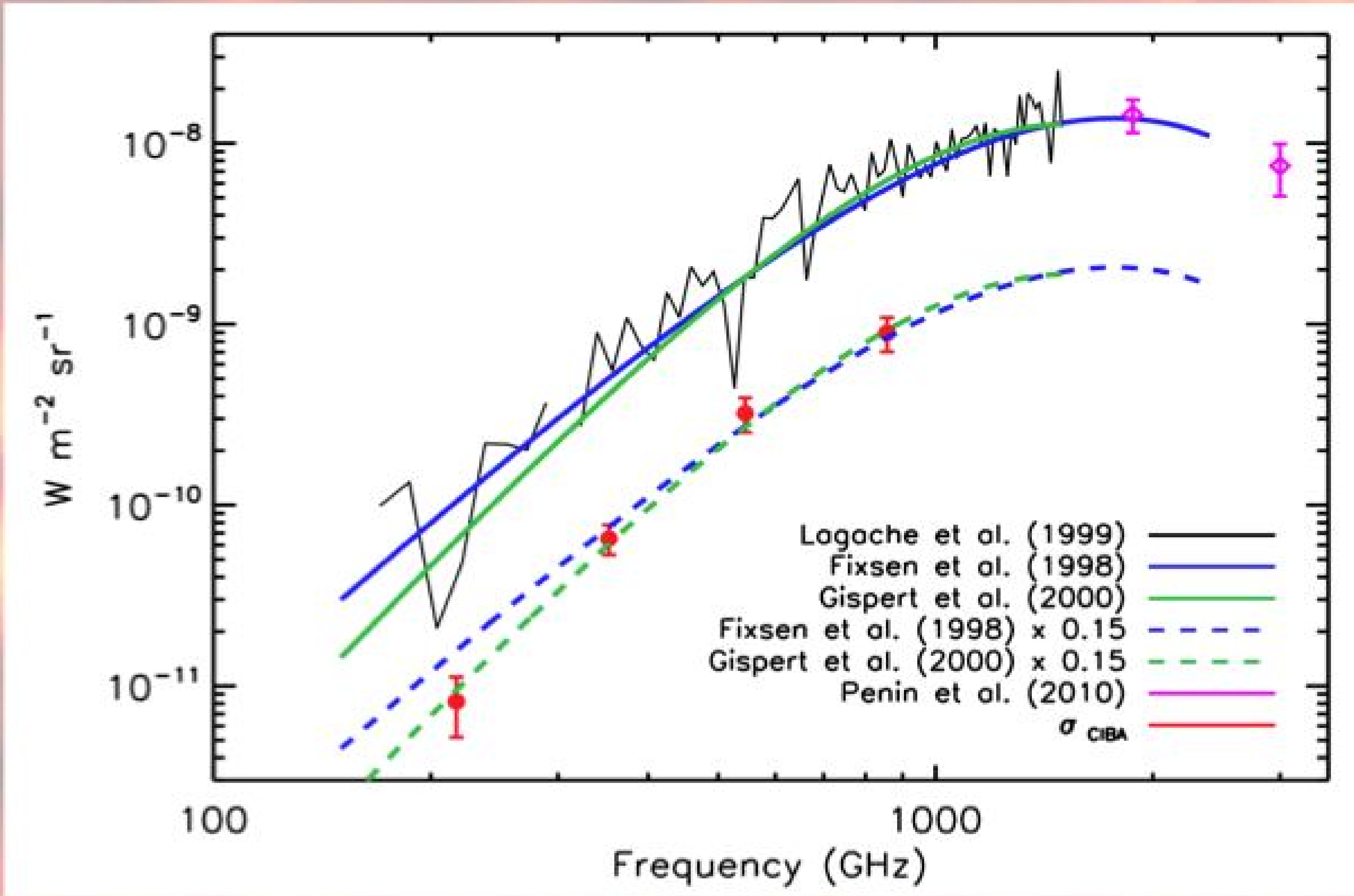


⇒ Cirrus contamination overestimated in Spire Cl?

⇒ Decrease of the correlated CIB Cl with S_cut (i.e. not only SN)?

⇒ Mask effect in Spire Cl

CIB mean and anisotropies SED

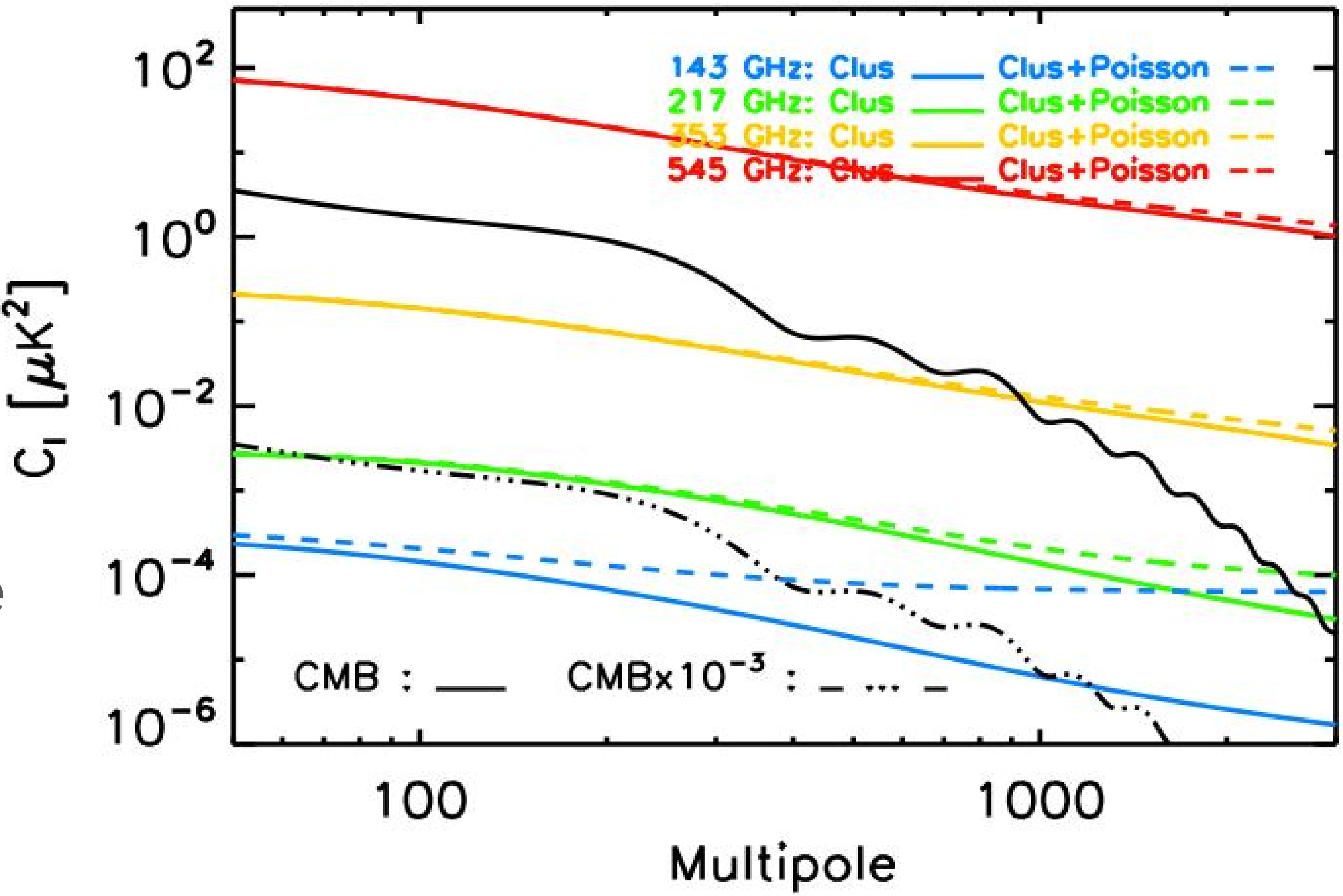


ΔI / I =15%

Which CMB for CIB analysis?

- The 143 and 217 GHz chanels are worrysome
- Current tests on full simulations using m-GMCA and the use (or not) of the HI templates

Any hope to measure the CIB at 143GHz?



2) Components of residual HFI maps power spectra

$$C_\ell(\nu) = b_\ell^2(\nu)\left[C_\ell^{d,\mathrm{clust}}(\nu) + C_\ell^{d,\mathrm{shot}}(\nu) + C_\ell^{r,\mathrm{shot}}(\nu)\right] + N_\ell(\nu)$$

Astrophysical components

Shot Noise: $C_\ell^{\mathrm{shot}} = \int_0^{S_{\mathrm{cut}}} S^2 \frac{dN}{dS}\, dS$

S_{cut} given by the ERCSC flux limit in our fields

dN/dS: Dusty, star-forming galaxies (Béthermin+2011), Radio galaxies (De Zotti+2005)

Frequency (GHz)	143	217	353	545	857
Flux cut (mJy)	245	160	325	540	710
IR shot noise ($Jy^2\ sr^{-1}$)	1.6±0.3	13.8±2.9	159±22	1078±92	5646 ±367
Radio shot noise ($Jy^2\ sr^{-1}$)	7.1	4.0	<3.4	<5.7	<7.4

Modeling CIB power spectra

$$C_\ell^{\nu\nu'} = \int dz \left(\frac{d\chi}{dz}\right)\left(\frac{a}{\chi}\right)^2 \bar{j}_\nu(z)\bar{j}_{\nu'}(z)P_{gg}(k=\ell/\chi, z)$$

Mean emissivity per comoving unit volume at frequency ν and redshift z:

$$\bar{j}_\nu(z) = (1+z)\int_0^{S_{\rm cut}} dS\, S\, \frac{d^2N}{dS\,dz}$$

Computed using the dusty-galaxies evolution model of Béthermin+2011

Power spectrum of galaxies:

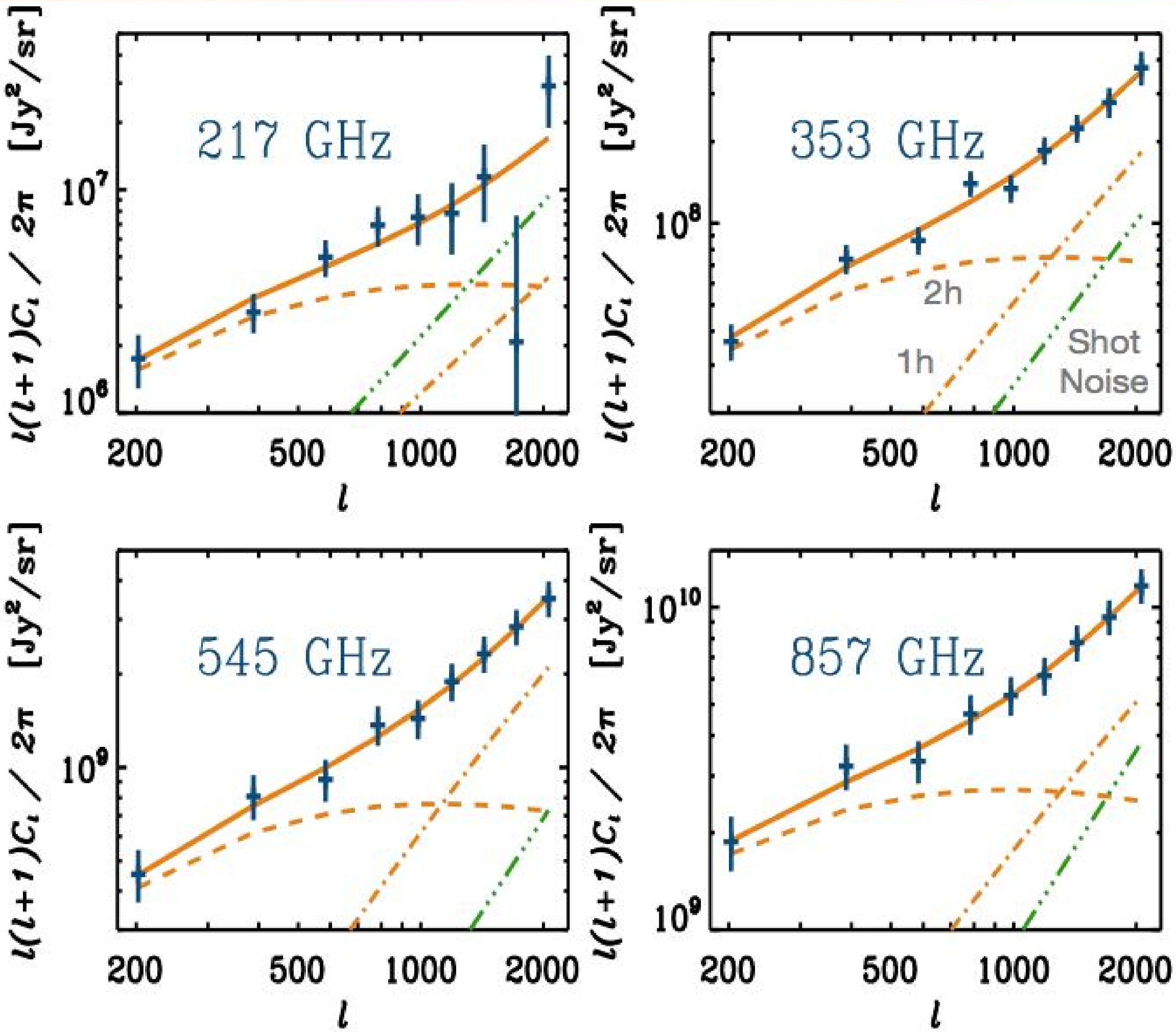
Constant bias model: $P_{gg}(k,z) = b_{\rm lin}^2 P_{\rm lin}(k,z)$

Halo model and Halo Occupation Distribution: $P_{gg}(k) = P_{1h}(k) + P_{2h}(k)$

Pénin+2011

=> See the presentation by Olivier

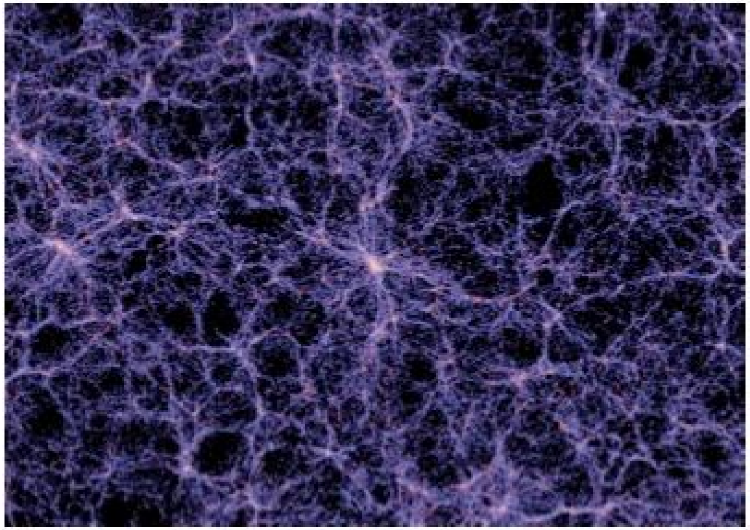
HOD model fits

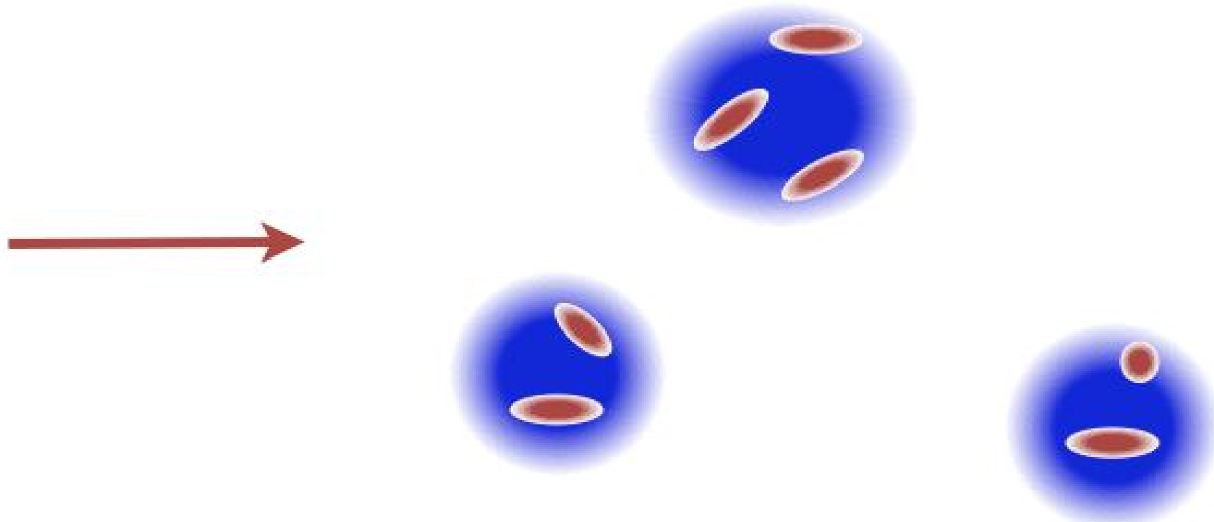


- Varying two HOD parameters (and optionally one j bin for z>3.5) per frequency provides excellent fits (χ^2/dof~1)
- The angular scales we probe clearly require a careful modeling of the 1h and 2h terms
- Clear degeneracy between shot-noise level and 1-halo term. It explains the unphysical linear model results

HOD modeling - I

- Halo model: dark matter resides in spherical halos
- HOD: galaxies live in halos with a density fixed by the halo mass.
- The probability of having N galaxies in a halo of mass M is given by the halo occupation density (hod).
- Small scale clustering determined by galaxy distributions; large scale clustering determined by halo clustering
- Halo clustering follows DM clustering (with a cut-off due to halo exclusion) up to a multiplicative bias





HOD modeling - II

$$P_{gg}(k) = P_{1h}(k) + P_{2h}(k)$$

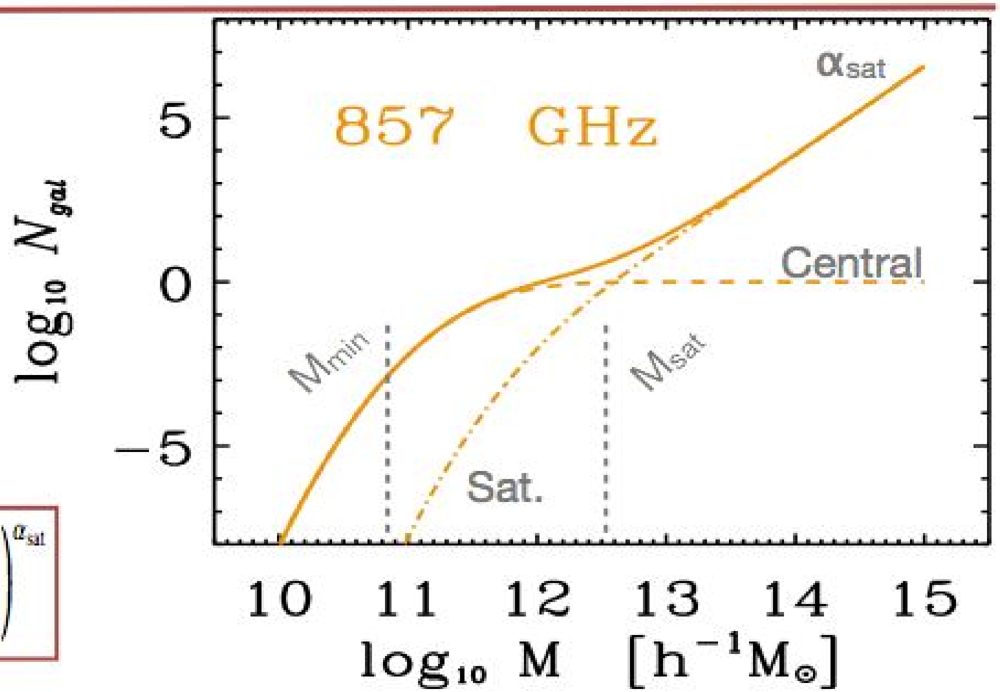
$$P_{1h}(k) = \int dM \frac{dN}{dM} \frac{\langle N_{gal}(N_{gal}-1)\rangle}{\bar{n}_{gal}^2} u^2(k,M)$$

$$P_{2h}(k) = P_{lin}(k)\left[\int dM \frac{dN}{dM} b(M) \frac{\langle N_{gal}\rangle}{\bar{n}_{gal}} u(k,M)\right]^2$$

$$\langle N_{gal}\rangle = N_{cen} + N_{sat}$$

$$N_{cen} = \frac{1}{2}\left[1+\mathrm{erf}\left(\frac{\log M - \log M_{min}}{\sigma_{\log M}}\right)\right]$$

$$N_{sat} = \frac{1}{2}\left[1+\mathrm{erf}\left(\frac{\log M - \log 2M_{min}}{\sigma_{\log M}}\right)\right]\left(\frac{M}{M_{sat}}\right)^{\alpha_{sat}}$$



- The Halo Occupation Distribution defines the clustering of galaxies (bias) and its redshift evolution
- We use an ansatz from Zheng et al. 05 and Tinker et al. 08 validated on N-boby simulations and optical data (z~<2)
- A full study of the parameter space suggests that current CIB clustering data alone can neither constrain cosmology nor the galaxy evolution model. The latter is mostly constrained by number counts and redshift evolution
- We restrict ourselves to two HOD parameters: M_{min} and α_{sat}. We set $M_{sat} = 10\ M_{min}$ and $\sigma_{\log M}=0.65$. We assume Poissonian distribution for N_{gal} .
- M_{min} roughly corresponds to the smallest halo mass hosting a CIB contributing galaxy. α_{sat} fixes the total number of galaxies and the ratio of contributing high/low mass halos

Pénin, O.D., Lagache, Béthermin, 2011, in prep.

HOD modeling best fit parameters

Frequency (GHz)	$\log_{10} M_{\rm min}$ $[h^{-1}\mathrm{M}_\odot]$	$\alpha_{\rm sat}$	$j_{\rm eff}$ [Jy/(Mpc/h^{-3})/sr]	χ^2/(#bins-#params)
217	10.52 ± 39.5	1.27 ± 2.57	$0.20 \pm 3.39 \times 10^3$	1.38
353	10.50 ± 13.9	1.34 ± 1.03	$0.87 \pm 4.72 \times 10^3$	0.93
545	10.70 ± 11.8	1.25 ± 0.82	$2.44 \pm 13.3 \times 10^3$	0.26
857	11.57 ± 1.23	1.17 ± 0.05	$3.02 \pm 2.72 \times 10^3$	0.23
217	11.73 ± 0.31	1.45 ± 0.09	N/A	1.19
353	12.37 ± 0.07	1.82 ± 0.07	N/A	0.93
545	10.92 ± 1.19	1.32 ± 0.10	N/A	2.17
857	12.47 ± 0.18	1.30 ± 0.07	N/A	0.30

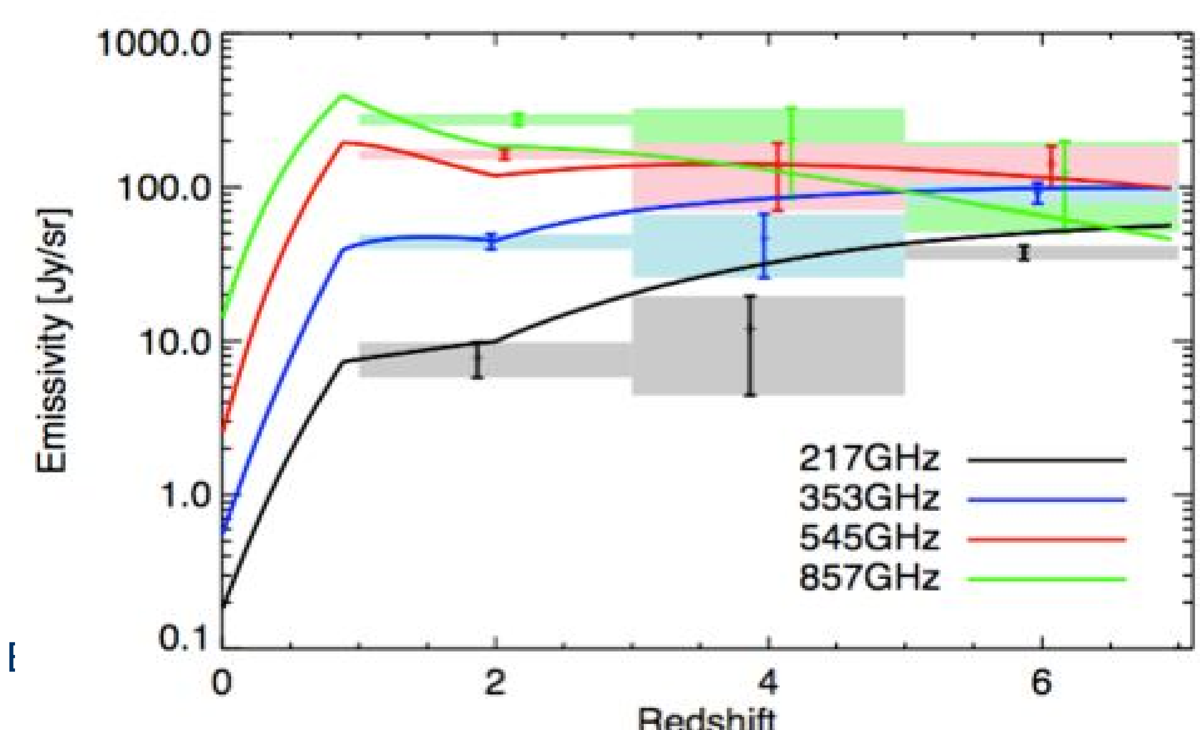
solving for $j_{\rm eff}$

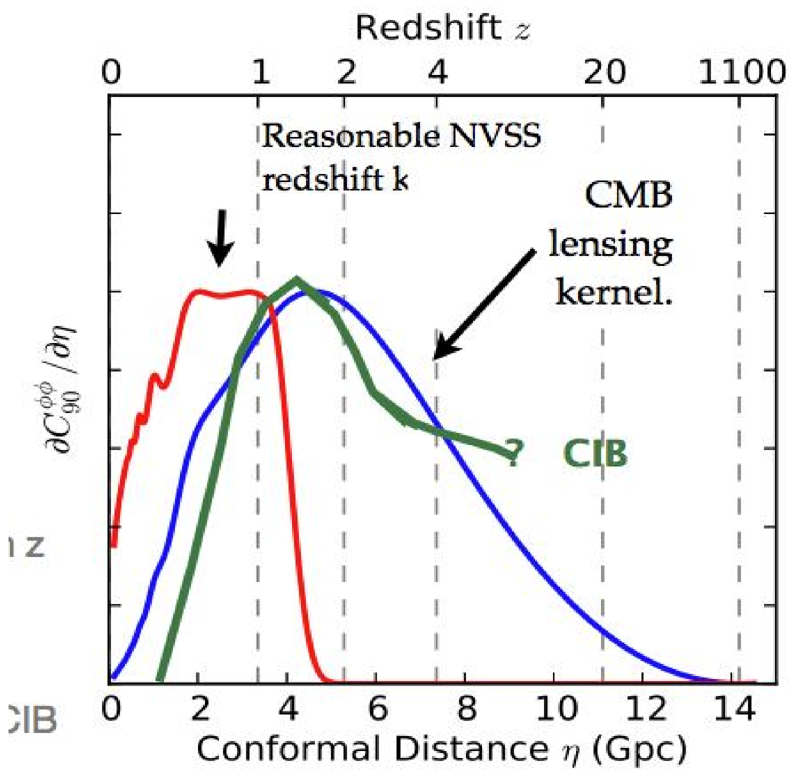
setting j to model extrapolation

- We observe a strong $M_{\rm min}$ - $j_{\rm eff}$ degeneracy limit our interpretative power
- This greatly limits what we can tell about the the clustering of "CIB-contributing" galaxies
- Consistently requires a higher $\alpha_{\rm sat}$ than optical data

we expect a strong lensing CIB correlation and resolving the j(z) by CIBxCIB correlation

- we should detect this correlation with high S/N
- this will be an important cosmological Planck result
- we also expect to derive the evolution of the star formation rate at high z from the cross correlation of the CIB in the Planck bands
- these could be published this year (in preparation)
- redshift larger than 7 will depend on our ability to use the CIB at 143GHz, it is unlikely that we could produce a map but we could be able to detect its cross correlation with higher frequencies





conclusions

- CIB observations combined with Hershel and ground based observations of individual sources should give us
  - luminosity function z dependence: how far the increase of L_* with z goes ?
  - FIR output as a function of z: what is the redshift where it decreases significantly ?