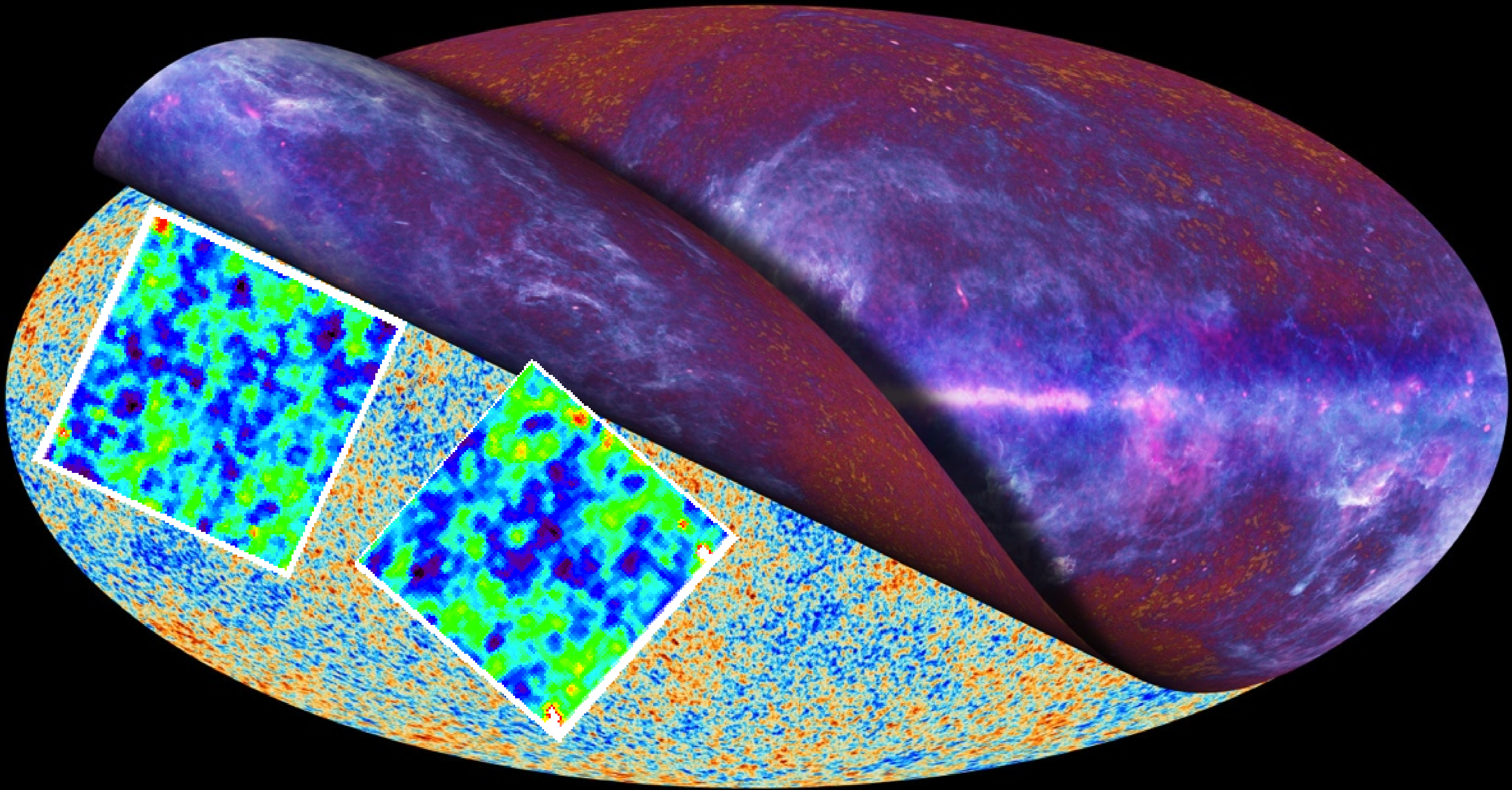


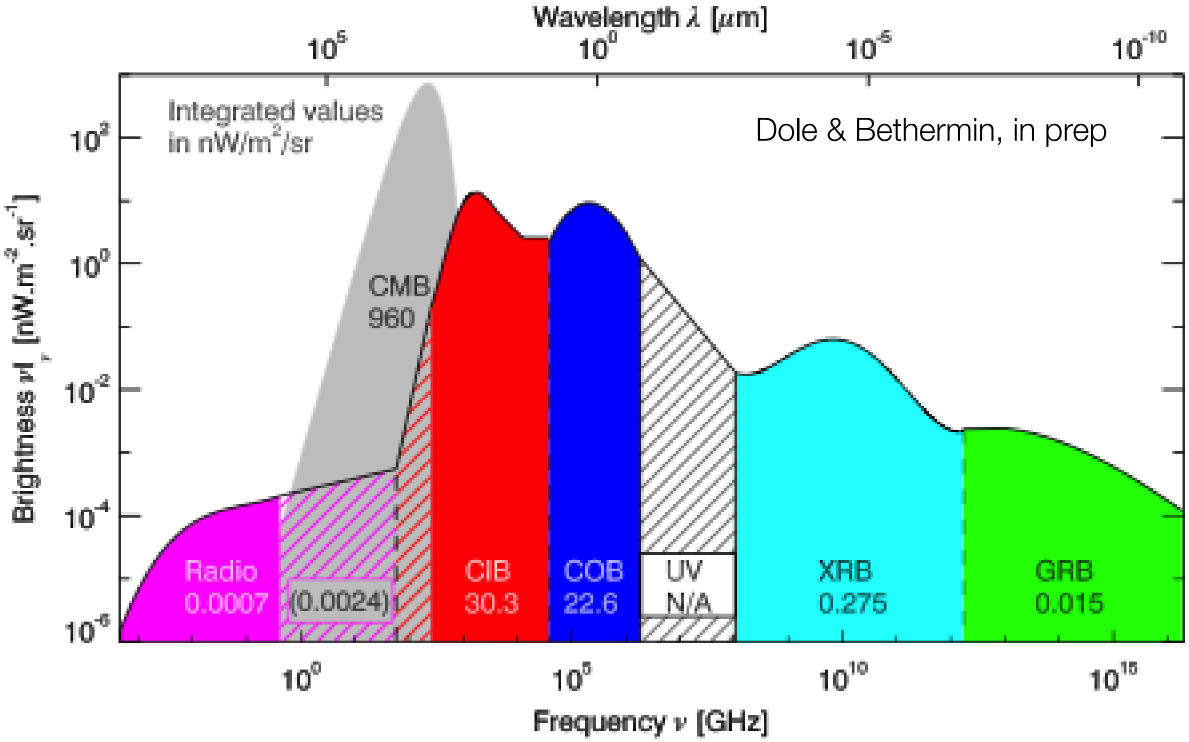
Planck unveils the Cosmic ~~Microwave~~ Infrared Background

Cosmic Infrared Background measurement and Implications for star formation

Guilaine Lagache
Institut d'Astrophysique Spatiale
On behalf of the Planck collaboration

Cosmic Infrared Background

- Cosmological, diffuse, background light produced by the integrated emission from galaxies formed throughout cosmic history

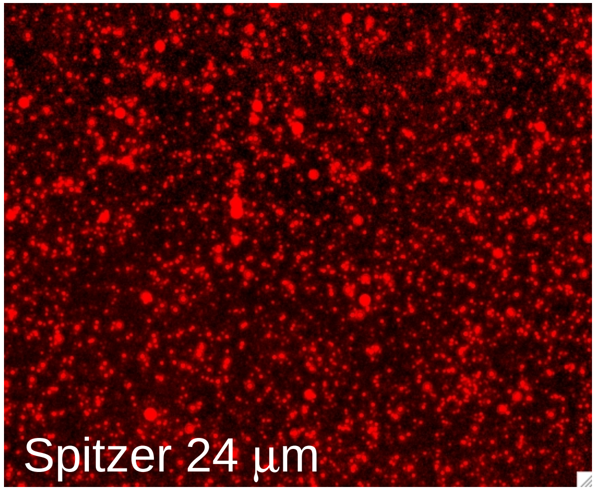


Dole & Bethermin, in prep

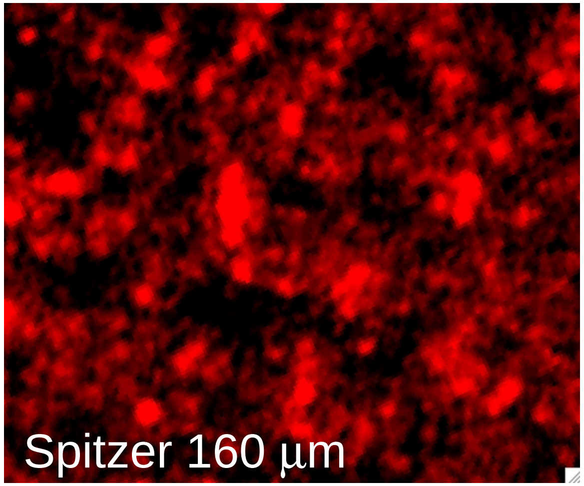
- CIB (8-3000 μm or 100-4 104 GHz) : star-heated dust within galaxies => wealth of information about the process of star formation.
- CIB = a way to study statistically dusty-galaxy evolution.

Origins of CIB anisotropies

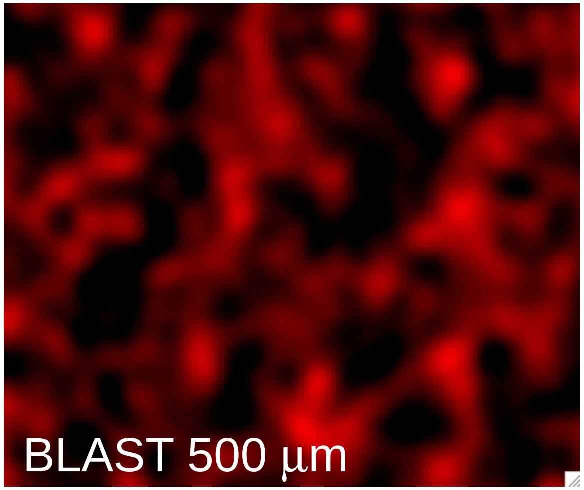
Extragalactic-sources confusion: our « business »



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 spectrum and bispectrum
- CIB anisotropies = a way to study statistically dusty-galaxy evolution AND clustering.

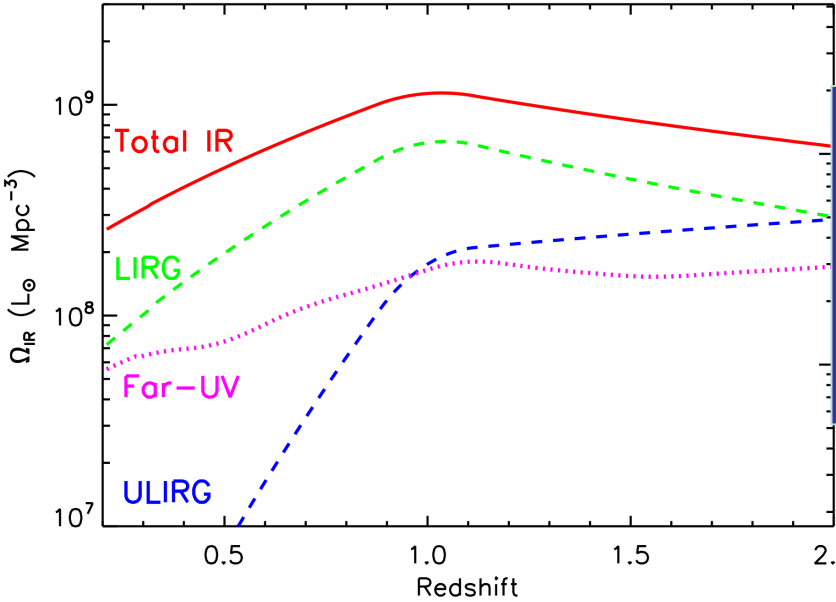
Images from M. Béthermin

CIB anisotropies and structure formation

- Angular power spectrum and bispectrum
  - A white-noise component due to shot noise

    (sampling of a background composed of a finite number of sources)
  - A correlated component due to spatial correlations between the sources of the CIB

- Correlated anisotropies:
  - Expected to trace large-scale structures
  - Probe the clustering properties of dusty, star-forming galaxies
  - Constrain the relationship between
  - Constrain the star formation history at high redshift



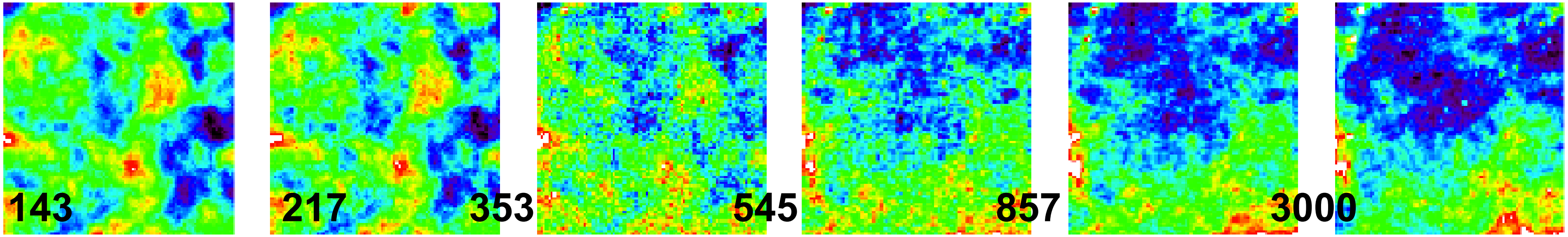
Extracting CIB maps

from 143 to 857 GHz HFI maps

+

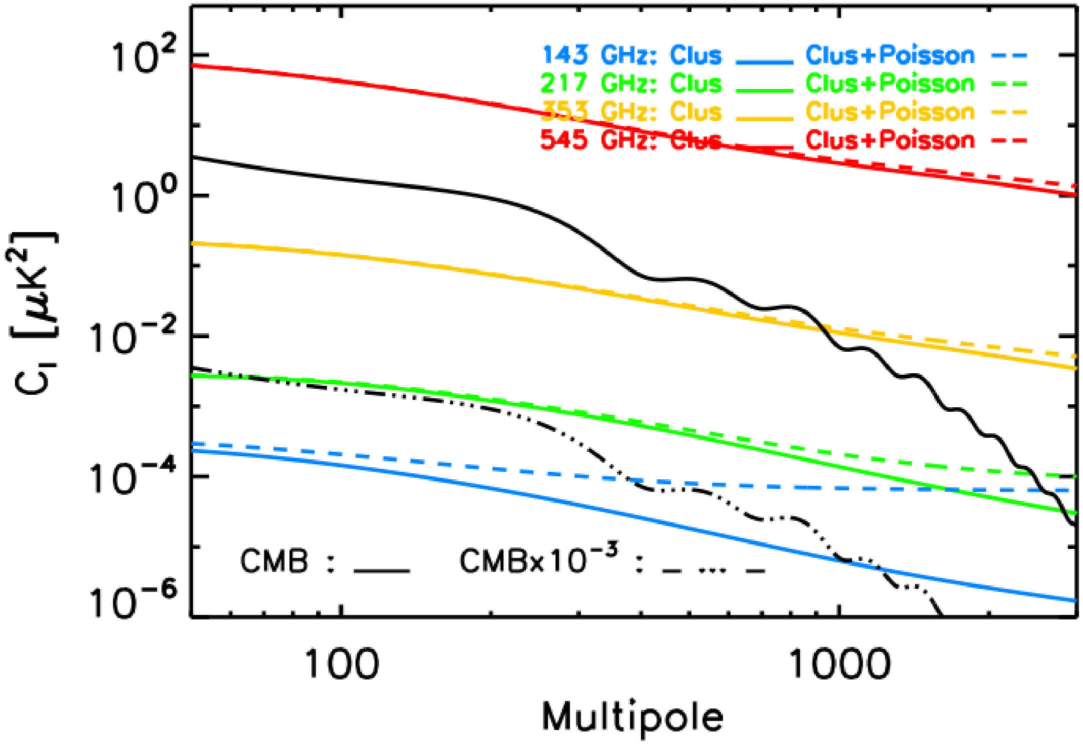
IRIS 3000 GHz map

Component separation



5ox5o field

- Removing the background CMB

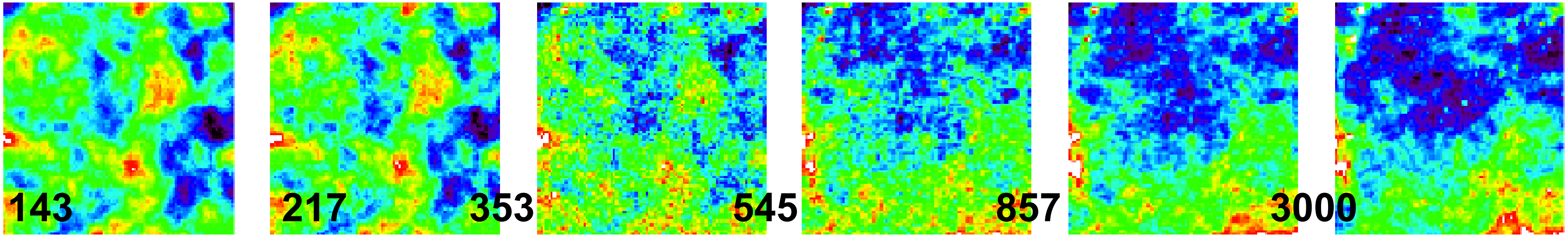


CMB/CIB power spectrum ratio at l=100:

~5000 at 143 GHz

~1000 at 217 GHz

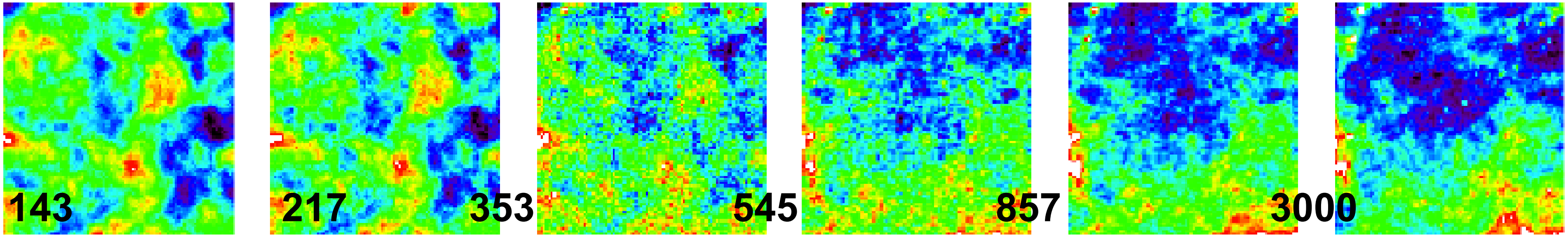
Component separation



5ox5o field

- Removing the background CMB
  - Look at CIB using various component separation CMB-removed maps
    - Among other problems: CIB leakage in CMB map
    - *For CIB, we need a dedicated CMB map => HFI 100 GHz map*
    - Advantages:
      - “internal” template, meaning its noise, data reduction process, photometric calibration, and beam are well known,
      - angular resolution close to the higher frequency channels
    - Instrument noise supressed (maps are wiener filtered)
    - Drawback: tSZ signal and spurious CIB

Component separation



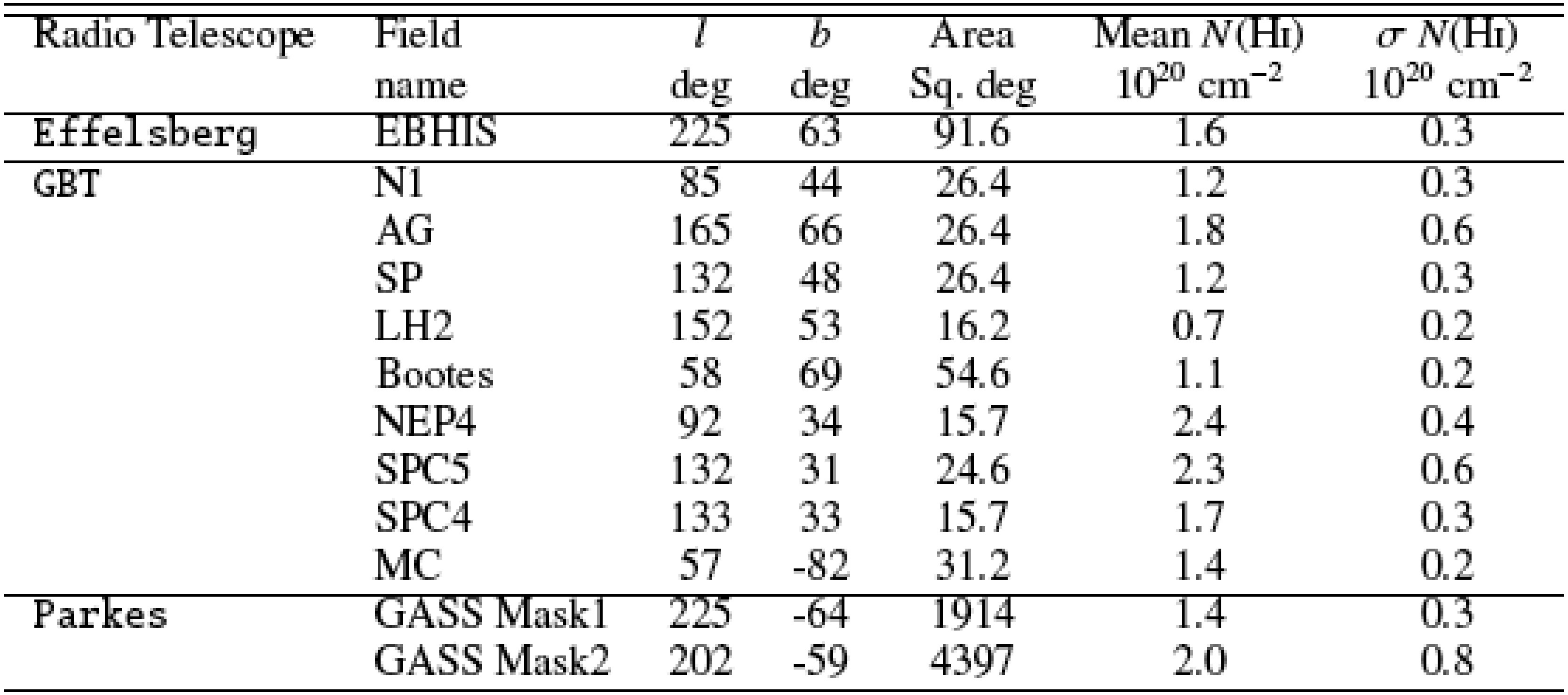
5ox5o field

- Removing the background CMB

- Removing the foreground Galactic dust
  - CIB and Galactic dust: SEDs too close, power spectra with no features (power law with index -2.7 versus -1)
  - HI 21cm line as a tracer of diffuse dust at high Galactic latitude
  - Need high-angular resolution HI data

- Masking point sources
  - Use the PCCS (and IRAS FSC) to mask sources up to 80% completness

Selected fields with HI

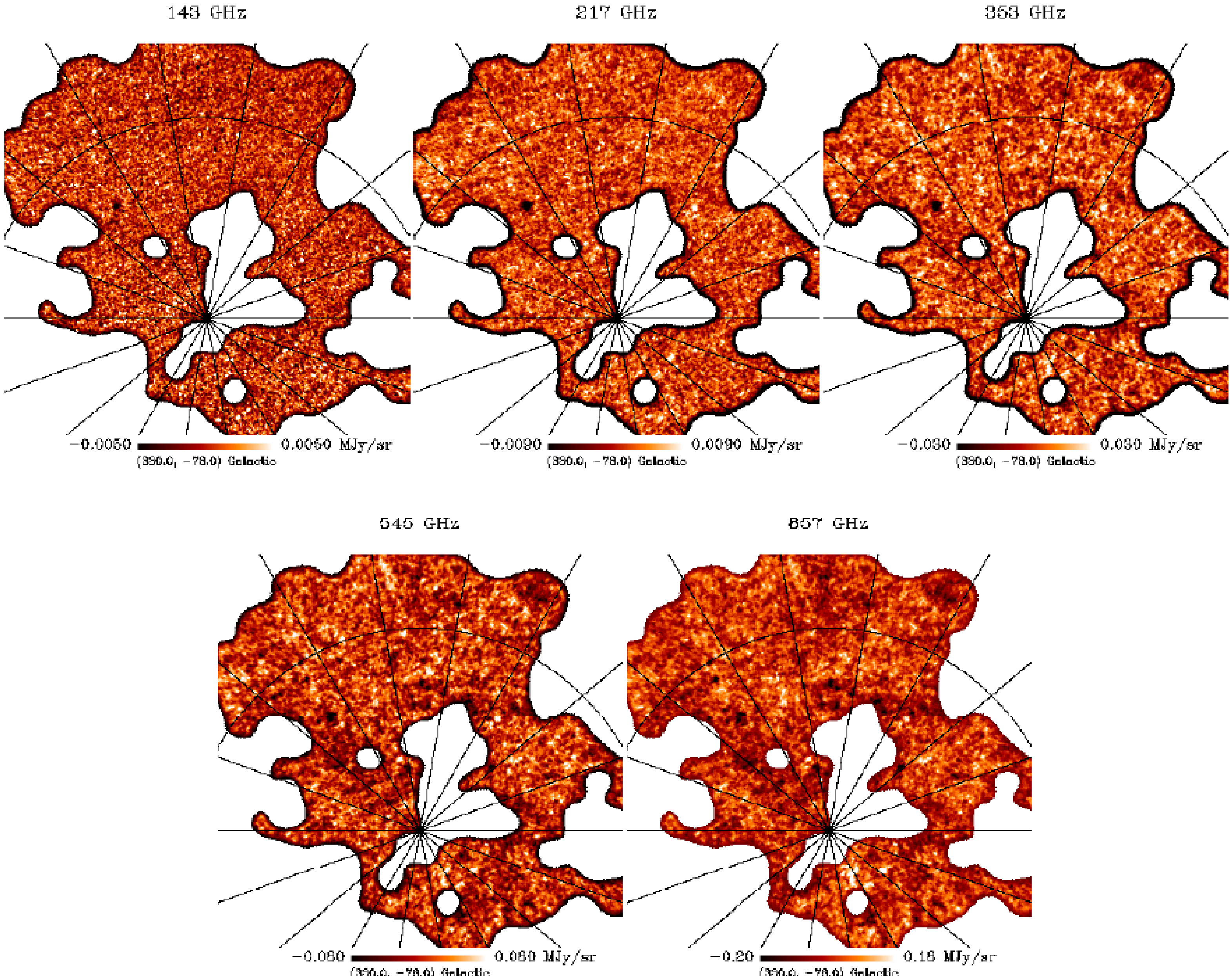


Radio Telescope	Field name	l deg	b deg	Area Sq. deg	Mean N(HI) 10^{20} cm^{-2}	σ N(HI) 10^{20} cm^{-2}
Effelsberg	EBHIS	225	63	91.6	1.6	0.3
GBT	N1	85	44	26.4	1.2	0.3
	AG	165	66	26.4	1.8	0.6
	SP	132	48	26.4	1.2	0.3
	LH2	152	53	16.2	0.7	0.2
	Bootes	58	69	54.6	1.1	0.2
	NEP4	92	34	15.7	2.4	0.4
	SPC5	132	31	24.6	2.3	0.6
	SPC4	133	33	15.7	1.7	0.3
	MC	57	-82	31.2	1.4	0.2
Parkes	GASS Mask1	225	-64	1914	1.4	0.3
	GASS Mask2	202	-59	4397	2.0	0.8

- ➢ CIB power spectrum: ~2240 deg2
- improves by a factor >16 over previous analysis
- ➢ CIB bispectrum: ~4400 deg2
- increases the S/N, but prevents the use of the 857 GHz

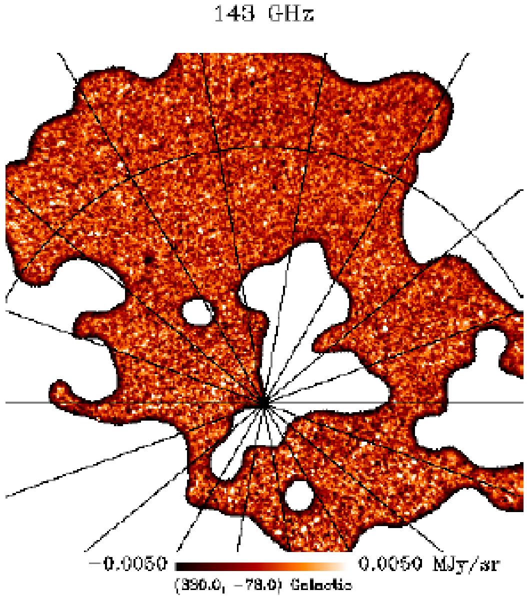
Dust and CMB-free maps

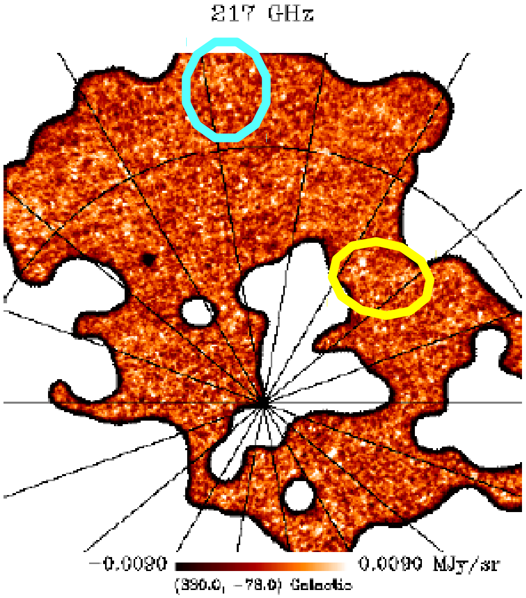
A 65x65 deg2 patch

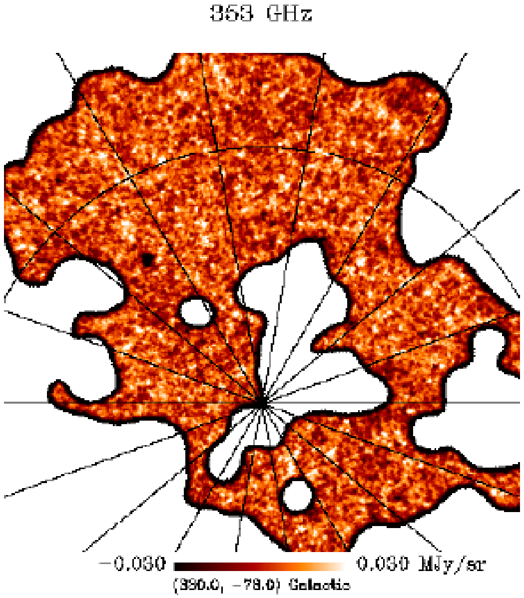


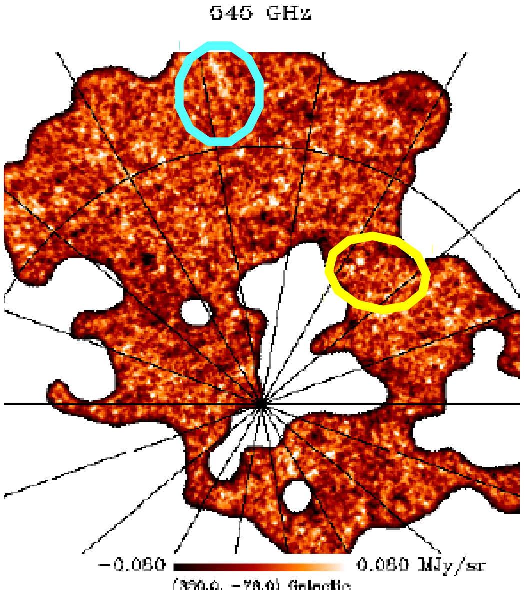
Dust and CMB-free maps

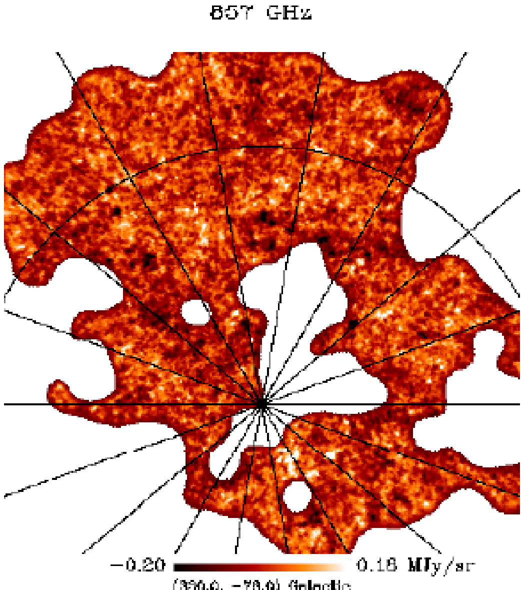
A 65x65 deg2 patch











Further corrections to CIB measurements

Most of them are induced by the use of the 100 GHz as a CMB template

- CIBxCIB spurious correlation
  - Need a CIB model
  - Compute the correction using our model in the fitting procedure
  - Factor of ~1.15 for $50<l<700$ at 217 GHz

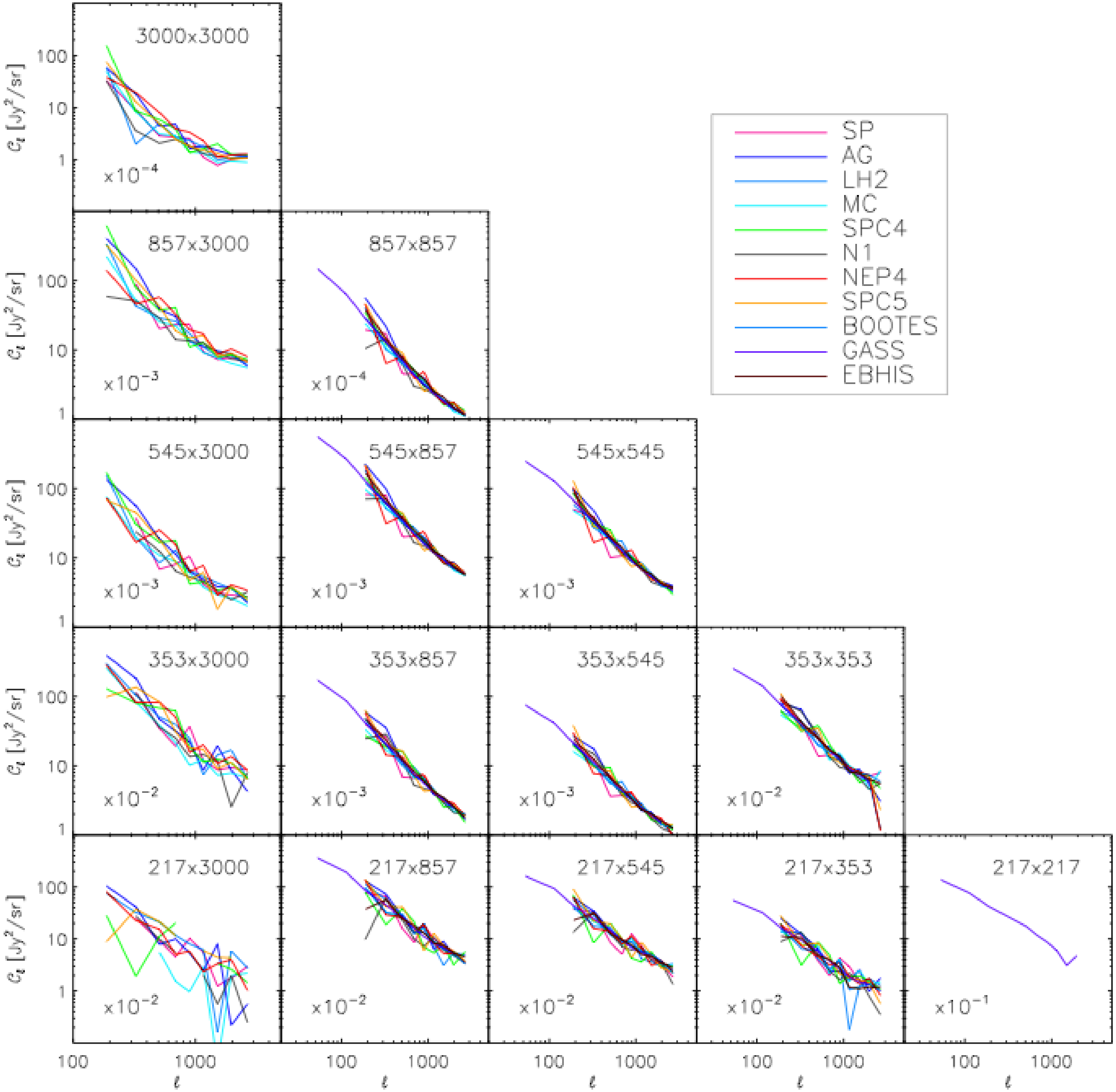
- tSZxtSZ
  - Compute the correction at the power spectrum level
  - Use Planck collab 2013 (XXI) tSZ power spectrum
  - Uncertainty = 10%

- tSZXCIB:
  - Compute the correction at the power spectrum level
  - Use Addison et al. (2012) model
  - Uncertainty = factor of 2

CIB angular power spectrum and bispectrum

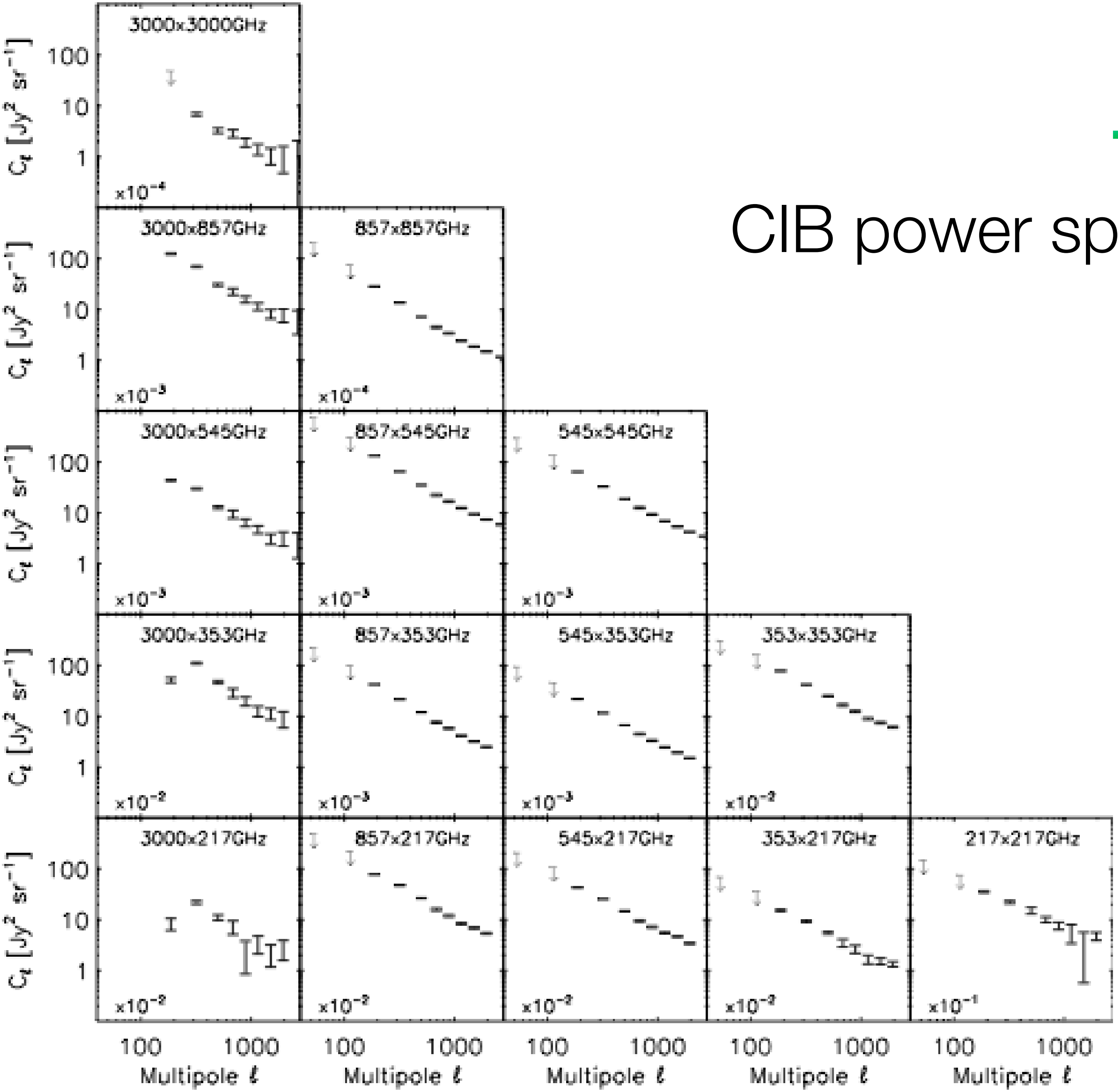
Lik

Angular power spectrum: all fields

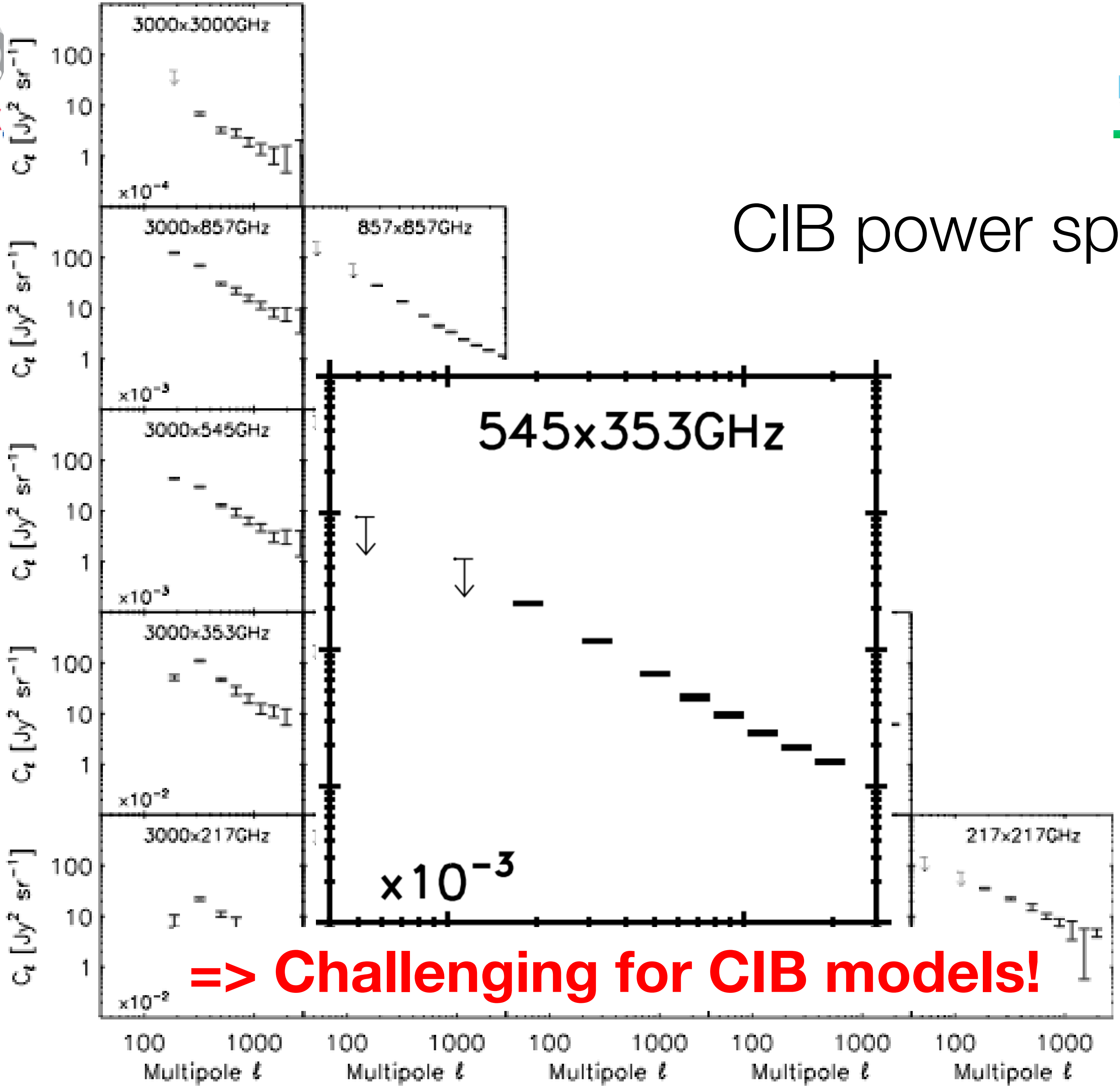


(plot from N. Ponthieu)

CIB power spectra

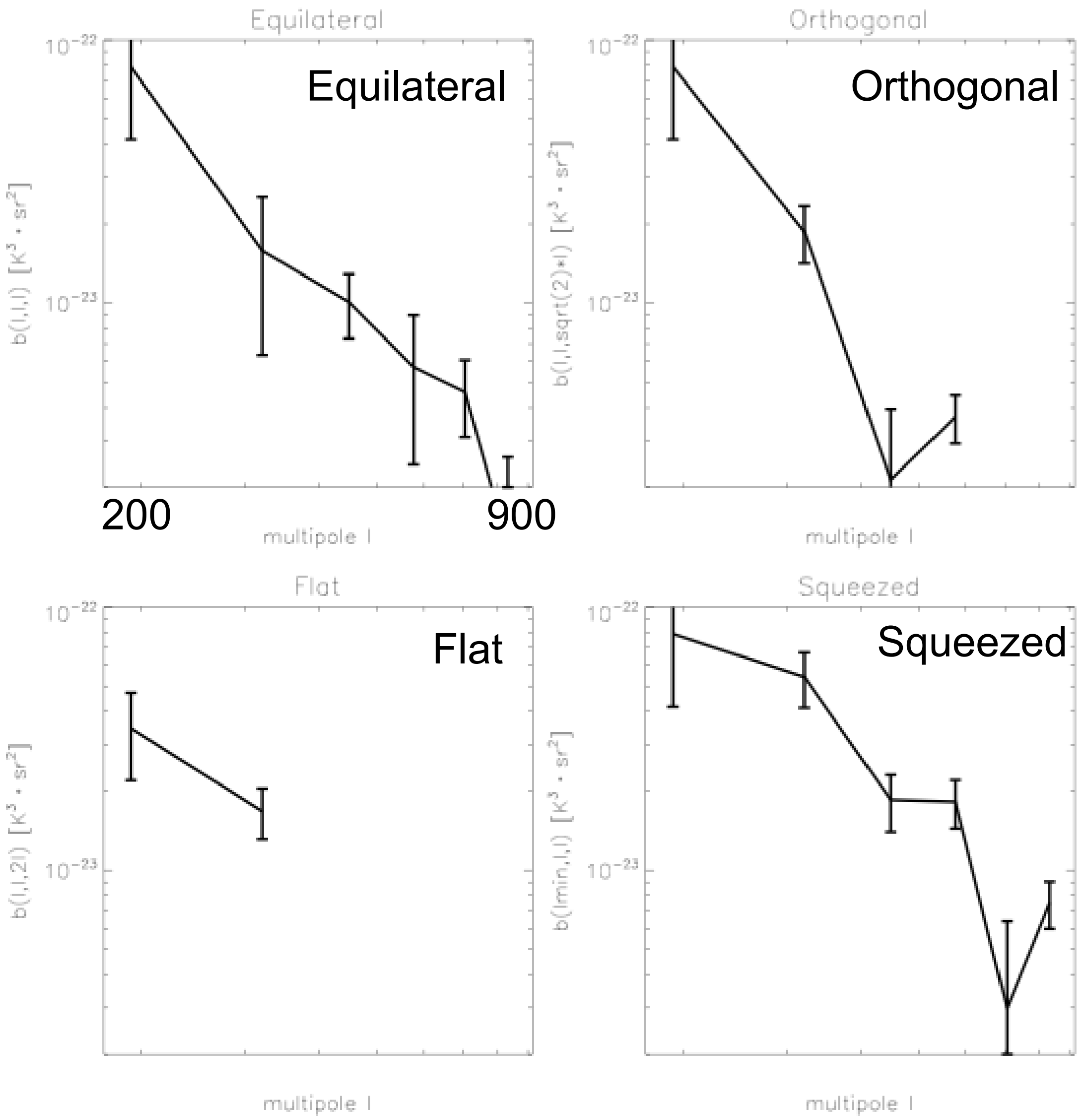


CIB power spectra



=> Challenging for CIB models!

And the bispectrum!



(plot from F. Lacasa)

- 3-point correlation function in harmonic space
- Lowest order indicator of the non-Gaussianity of the field.
- GASS Mask2, ~4400 deg2
- For 130<**l**<900, 6 multipole bins and 43 bispectrum configurations (l1,l2,l3)
- At 545GHz:
- SNR per config=4.6
- SNR tot=28.7
- At 353 GHz:
- SNR per config=2.9
- SNR tot=19.3

Interpreting CIB measurements

Basics of CIB modeling

- Angular power spectrum (Haiman & Knox 2000)

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

Where Pj, νν' is the 3-D power spectrum of the emissivity:

$$< \delta j(\vec{k},\nu)\delta j(\vec{k}',\nu') >= (2\pi)^3 \bar{j}(\nu)\bar{j}(\nu')P_{j,\nu\nu'}(\vec{k})\delta^3(\vec{k}-\vec{k}')$$

- Existing models: P*j* = P*gg*

Assuming the CIB is sourced by galaxies, and that the spatial variations in the em galaxy number density:

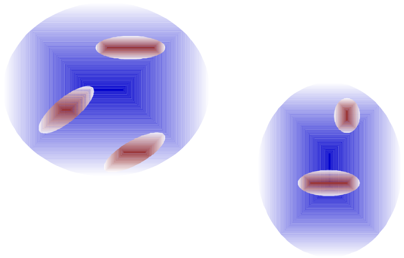
$$\delta j/\bar{j} = \delta n_{gal}/\bar{n}_{gal}.$$

(all galaxies contribute equally to the emissivity density, irrespective of the masses of their host halos)

An extended halo model for CIB

- ➢ Introduced for CIB by Shang et al. 2012
- ➢ In the framework of the halo model:

Pgg(k,z) = P2h(k,z) + P1h(k,z)



- ➢ We abandon the assumption of a mass-independent luminosity:

$$j_\nu(z) = \int dM \frac{dN}{dM}(z)\frac{1}{4\pi}\left[N_{cen}L_{cen,(1+z)\nu}(M,z) + \int dm\frac{dn}{dm}(M,z)L_{sat,(1+z)\nu}(m)\right]$$

with:

$$L_{(1+z)\nu}(m,z) = L_0\Phi(z)\Sigma(m)\Theta[(1+z)\nu].$$

Redshift evolution

SED shape

SFR-M relation (log-normal)

Parameters

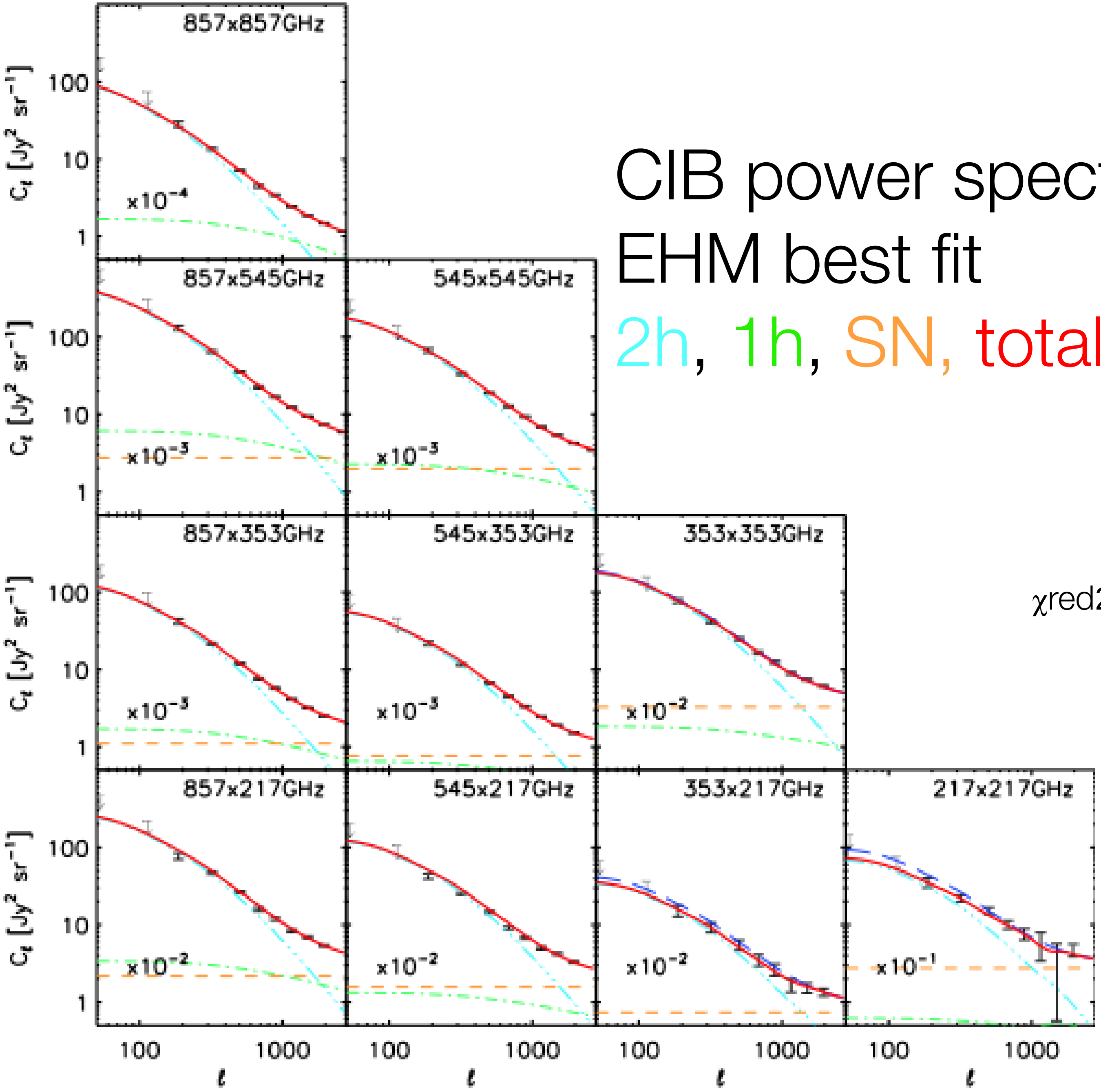
Extended Halo model

- Global normalisation of the L-M relation $(1+z)\delta$
- Mean halo mass which is most efficient at hosting star formation Meff
- SED:
  - modified BB with $T=T0(1+z)\alpha$
  - β, α, ν^*, T0, γ
- All Shot noises

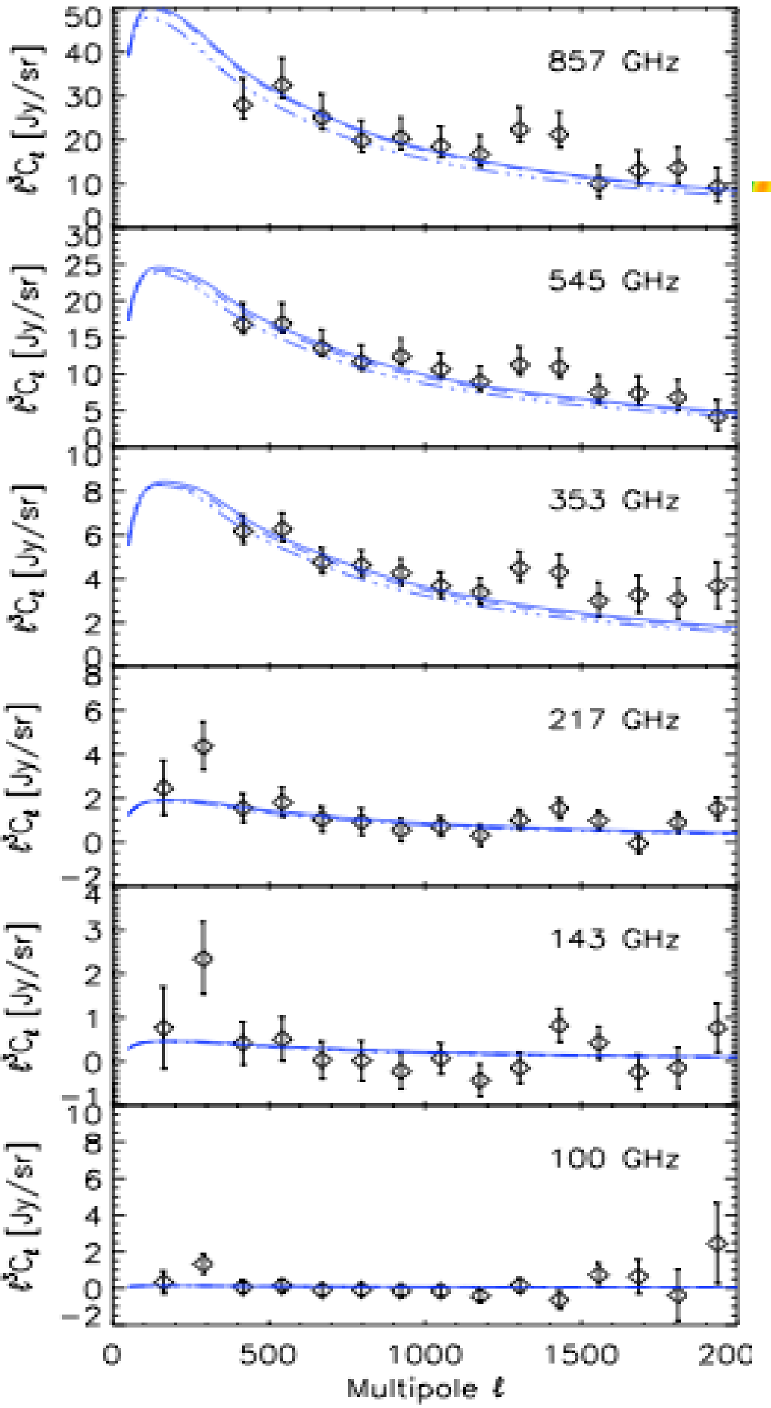
- Priors:
  - T0 € [20,60] K ; β € [1.5,2]
  - δ € [0,7]
  - SN: 20% error

CIB power spectra with EHM best fit

2h, 1h, SN, total



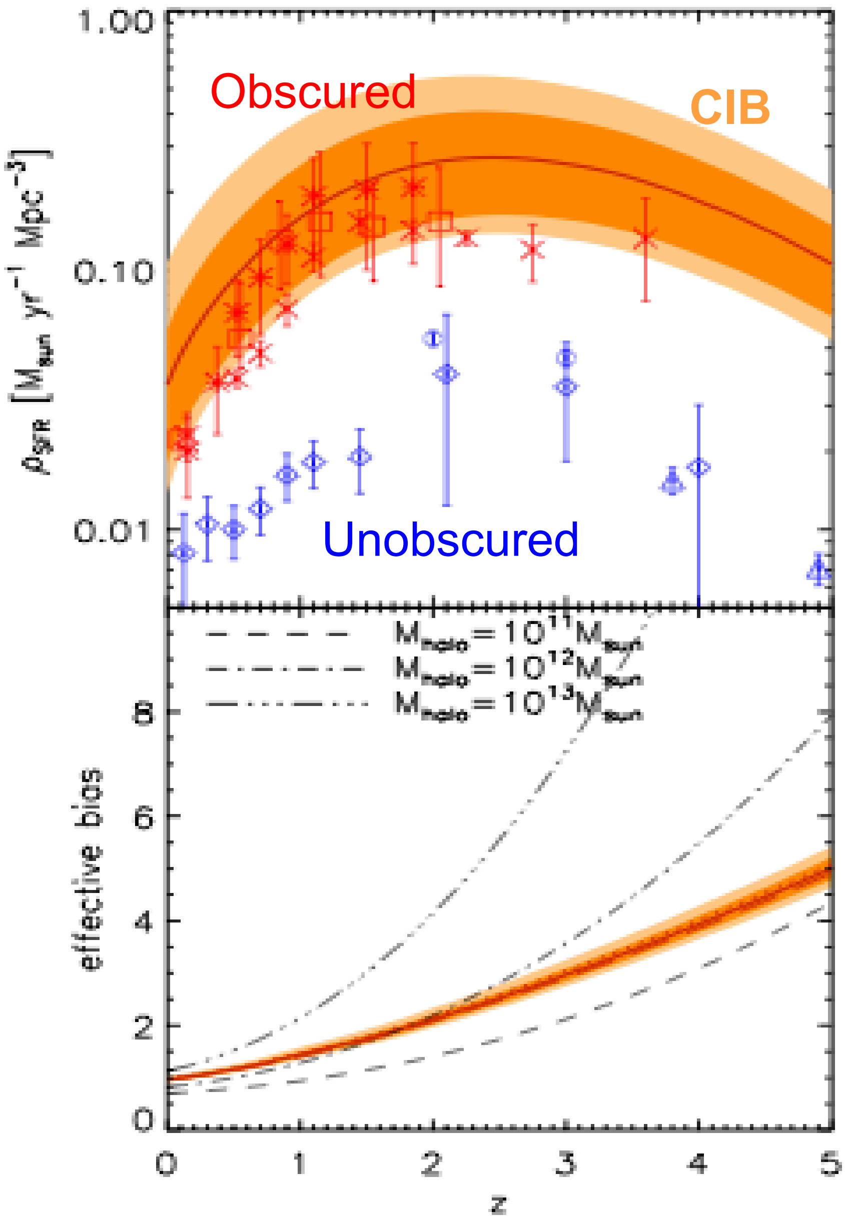
χred2= 0.92



…. that are consistent with CIBxCMB lensing measurements

(Planck collab, XVIII, 2013)

ρSFR and bias



- ➢ IR still dominating the SFRD at high redshift?
- ➢ Are UV and Lyman-break galaxy populations a complete tracer of the star formation in the early Universe?

- ➢ Increase of the bias with redshift
- ➢ Follows the 1012 dark matter halo mass track
- ➢ b(z=0) from CIB in very good agreement with galaxies observation

Changing the parametrisation of the EHM…

… to see the effect on ρSFR

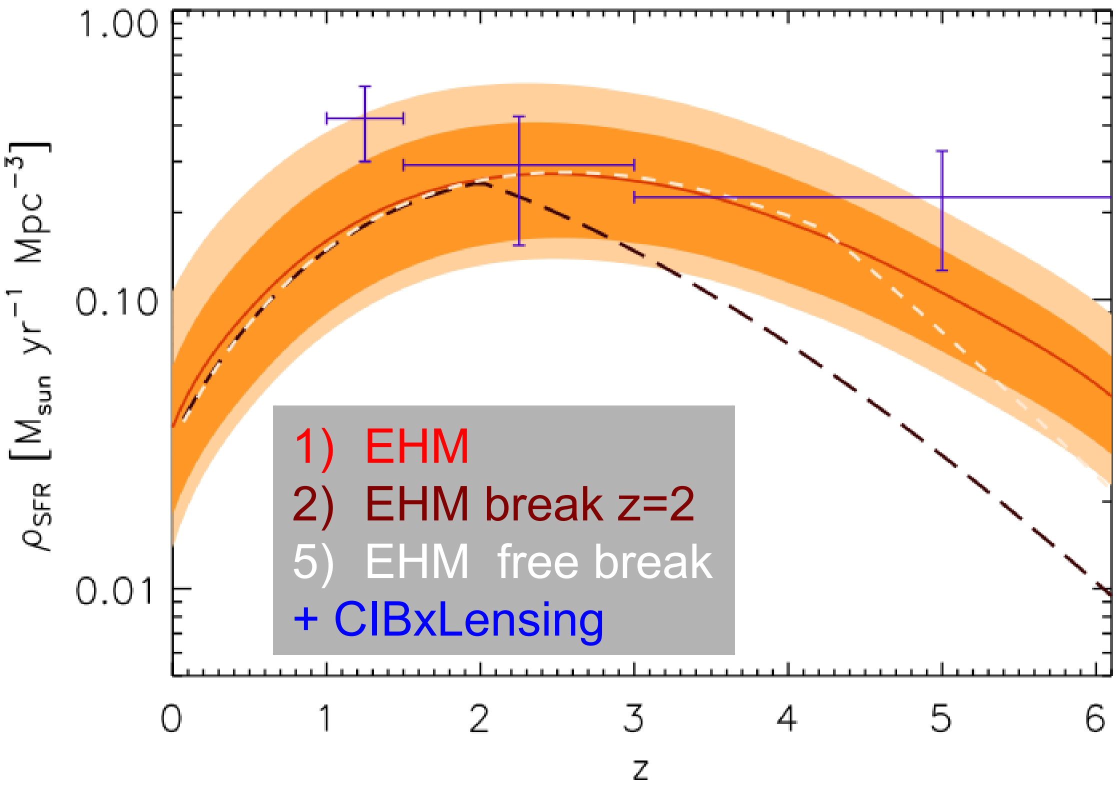
1) « Nominal » EHM

2) Imposing a break at z= 2 in the redshift normalization parameter of the L-M relation (as in Shang et al. 2012)

=> Degrade the quality of the fit

3) Fitting for a break in both the L-M relation and T(z)

=> find zbreak>2.9



The extended halo model

- Most efficient mass Meff
  - log(Meff/M⊙) = 12.2±0.13
  - Redshift evolution compatible with zero

- Variation of temperature with redshift
  - Dust spectral index: β= 1.85±0.06
  - Unavoidable, T0<21.9K, α=0.71±0.1 (very satisfactory but with zbreak!)
  - A harder interstellar radiation field up to z~2.5 (Magdis et al. 2012)

- Fit simultaneously all frequencies with only one set of parameters

- Was not able to find a good solution when:
  - The CMB was not corrected for 217x545
  - The SZ was not corrected for 217x217
  - Dust residuals were left at low ell
  - … (the cosmological parameters were set to wmap9 rather than planck1!)

A simple linear model

- On large scales, in the linear regime, P*gg*=beff2Plin

  Where beff is the mean bias of dark matter halos hosting dusty galaxies at a given z, weighted by their contribution to the emissivities.

- The emissivities are computed from the star formation rate density:

$$\bar{j}(\nu, z) = \frac{\rho_{\mathrm{SFR}}(z)(1+z)s_{\nu,eff}(z)\chi^2(z)}{K},$$

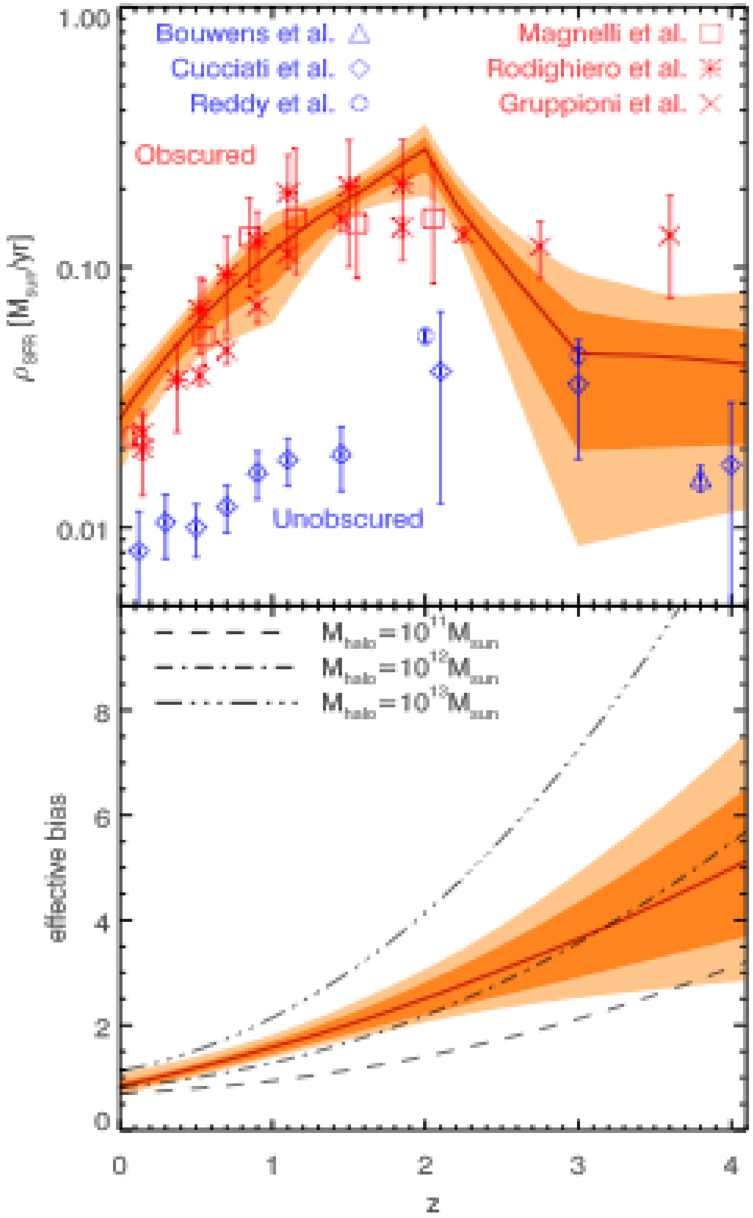
  - K is the Kennicutt (1998) constant
  - Sν,eff(z) are the effective SED of dusty galaxies at a given redshift, deduced from Béthermin et al. (2012) model

  Mix of secularly-star-forming galaxies and starburst galaxies

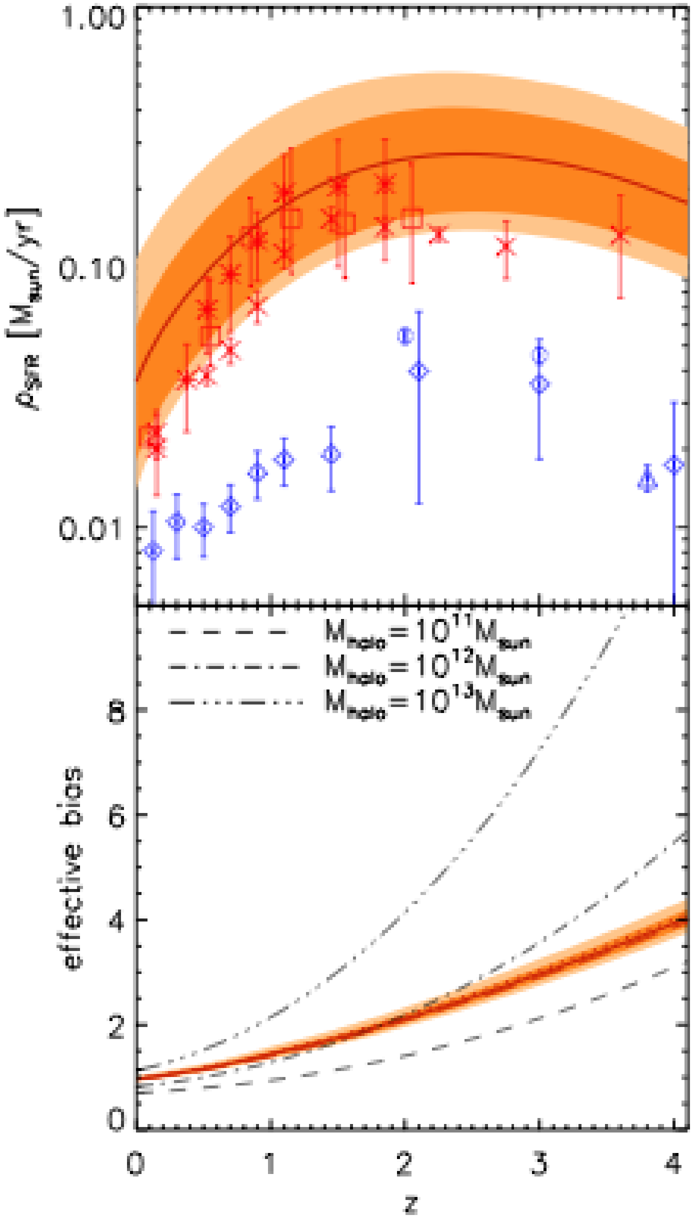
  Increase of T with z following the measurements of Magdis et al. (2012)

pSFR and bias from the two models

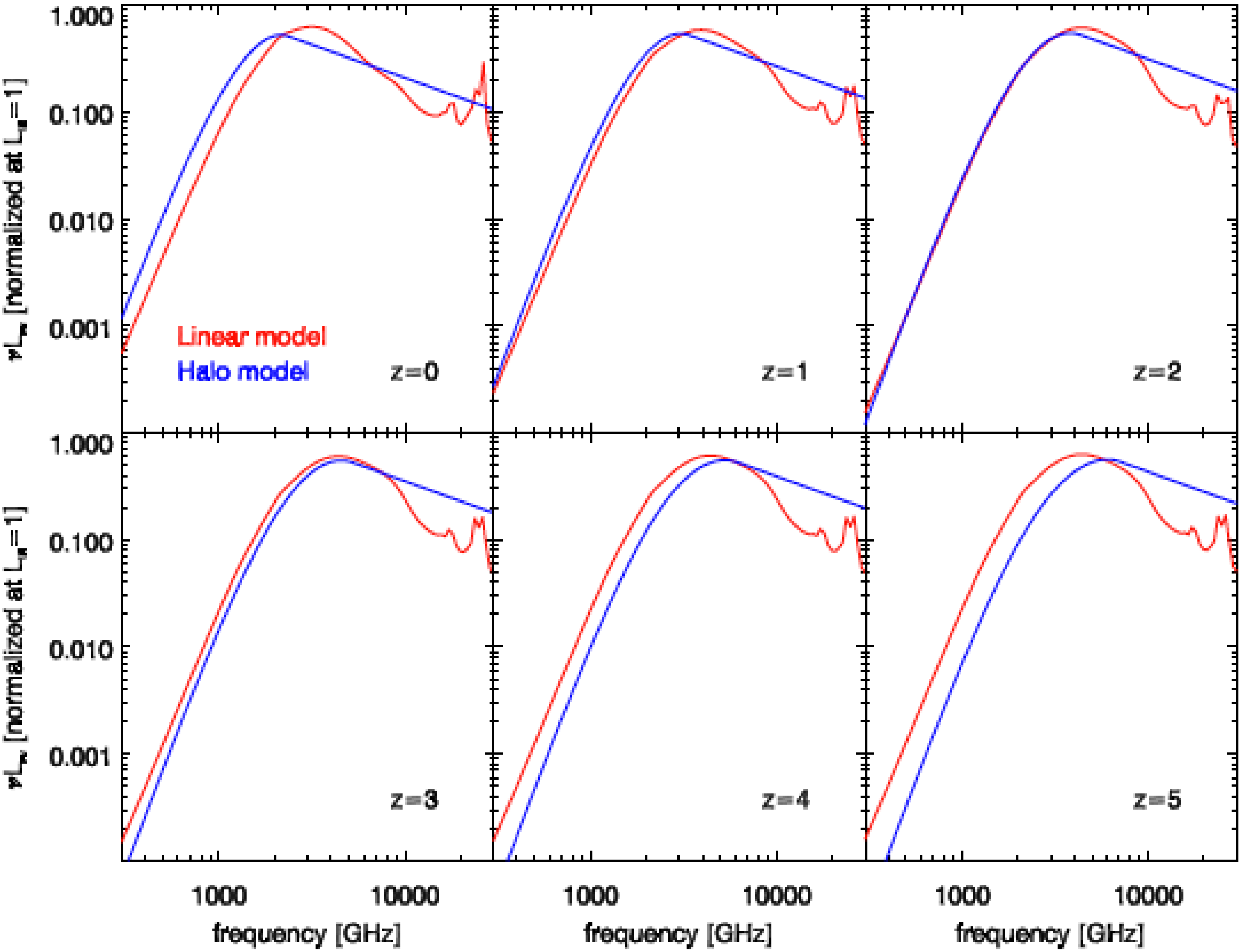
Linear Model



Extended Halo Model



Comparison of SEDs



Linear model:
- SEDs fixed
- Magdis et al. 12 T(z) up to z=2
- Extrapolation at higher z

Extended HM:
- Shape fixed by the modified BB

Good agreement for 1≤z≤3

=> Interpretation limited by the uncertainty in the SEDs of CIB galaxies

Conclusion

- A new breakthrough in CIB measurements
  - Very large area (>2200 *deg2*)
  - Angular power spectrum but also bispectrum
  - All corrections: dust, CMB, point sources, SZ, spurious CIB
  - Dedicated analysis and simulations for error bars

- A successful modeling
  - Extended halo model
    - One set of parameters for all frequencies (auto- and cross-spectra)
    - Dust spectral index and most efficient mass: compatible with “standard” values
    - Clear evolution of the dust temperature with redshift
    - Unprecedent constraints on the SFR density and bias evolution
  - Linear Model
    - Take advantage of the unique measurements of HFI at large scales
    - Framework more limited (imposed SED, priors on local values and CIB)
    - Nice cross-checks on the SFRD and bias evolution
  - Limited by our knowledge of SEDs of galaxies at high redshift

- Stay tuned: on astroph in ~1 month

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

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asdc

Planck is a project of the European Space Agency, 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.

More…

Parameters

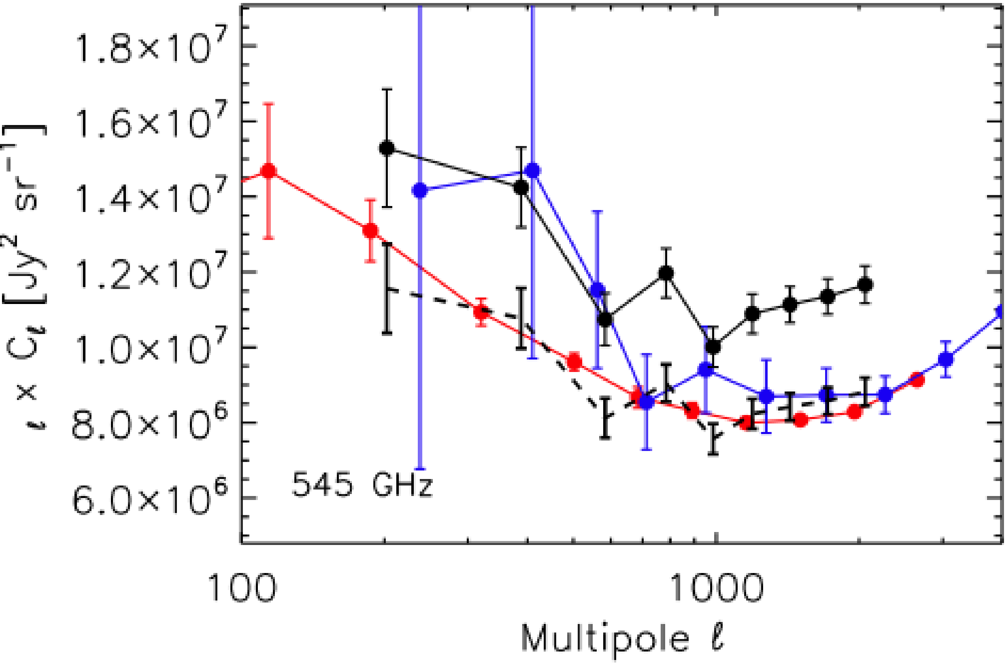
Linear model

- *b(z)* = b0 + b1z + b2z2
- ρSFR (z=0, 1, 2, 3, 4)

- Priors:
  - b0 and ρSFR (z=0)
  - CIB mean

Fit only the three large-scale CIB points - χred2= 1.15

Comparison with recent Herschel measurements



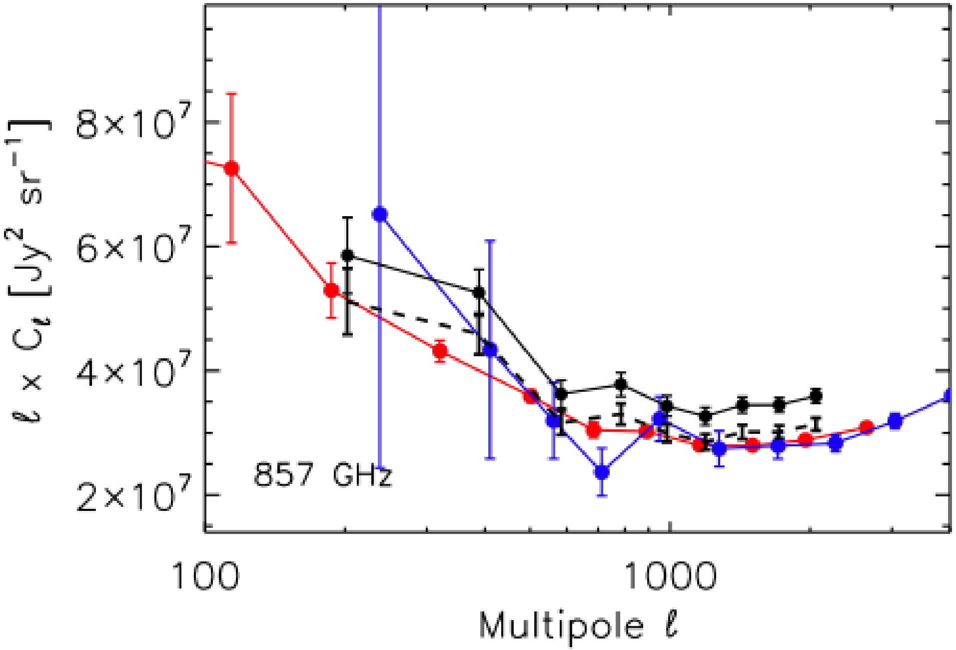
Planck PEP 2011 ———

Planck PEP recalibrated - - - -

Herschel ———

Planck 2013 ———

Herschel: Viero et al. 2013

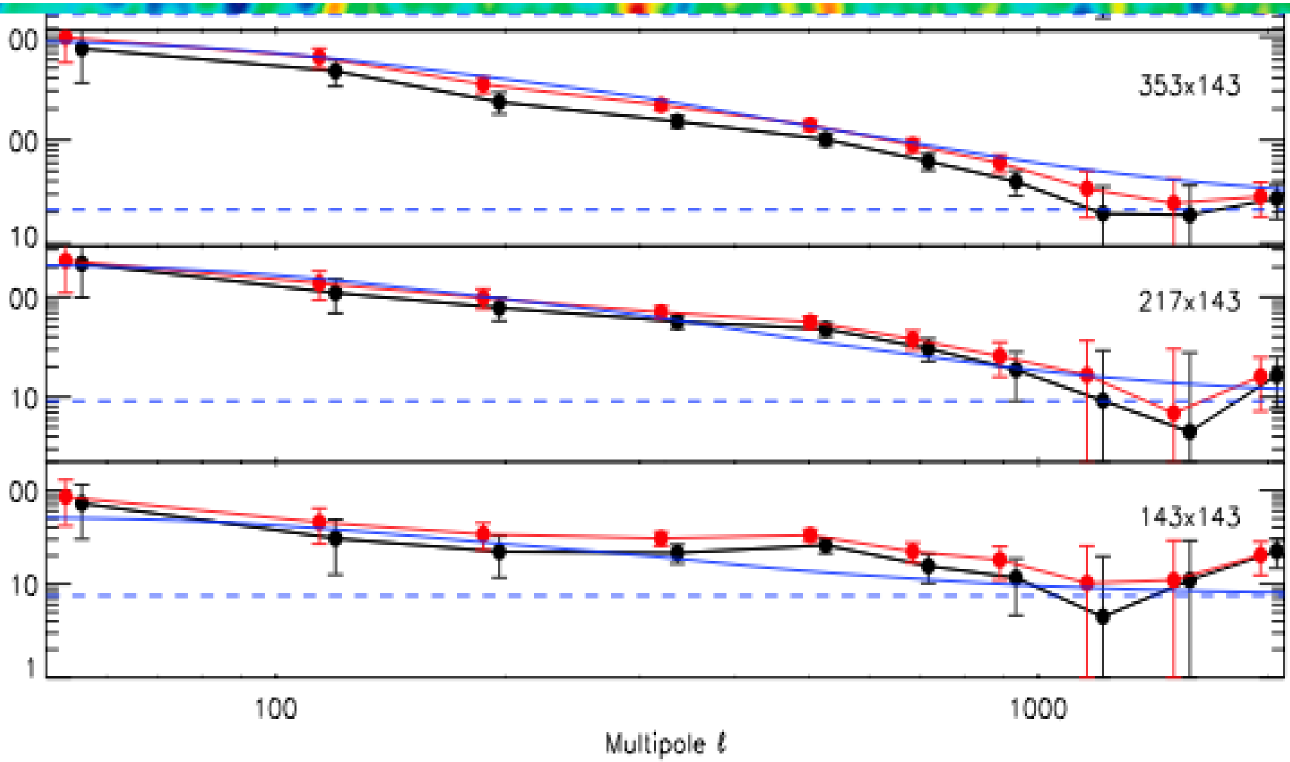


What about the 143 GHz ?

Not corrected

Corrected

EHM Predictons



Clear detection and nice measurements!
BUT large corrections due to spurious CIB and SN important
SO very model-dependent

Further corrections to CIB measurements

- Cross-spectra of CIB maps:

$$a^{\nu}_{\ell m} \times a^{\nu' *}_{\ell m} = \left[a^{CIB,\nu}_{\ell m} + a^{SZ,\nu}_{\ell m} - w_{\nu}\left(a^{CIB,100}_{\ell m} + a^{SZ,100}_{\ell m}\right)\right] \times \left[a^{CIB,\nu'}_{\ell m} + a^{SZ,\nu'}_{\ell m} - w_{\nu'}\left(a^{CIB,100}_{\ell m} + a^{SZ,100}_{\ell m}\right)\right]^{*}$$

- CI

$$C^{\nu\times\nu'}_{\mathrm{CIBcorr}} = -w_{\nu} C^{100\times\nu'}_{\mathrm{CIB}} - w_{\nu'} C^{100\times\nu}_{\mathrm{CIB}} + w_{\nu} w_{\nu'} C^{100\times100}_{\mathrm{CIB}}$$

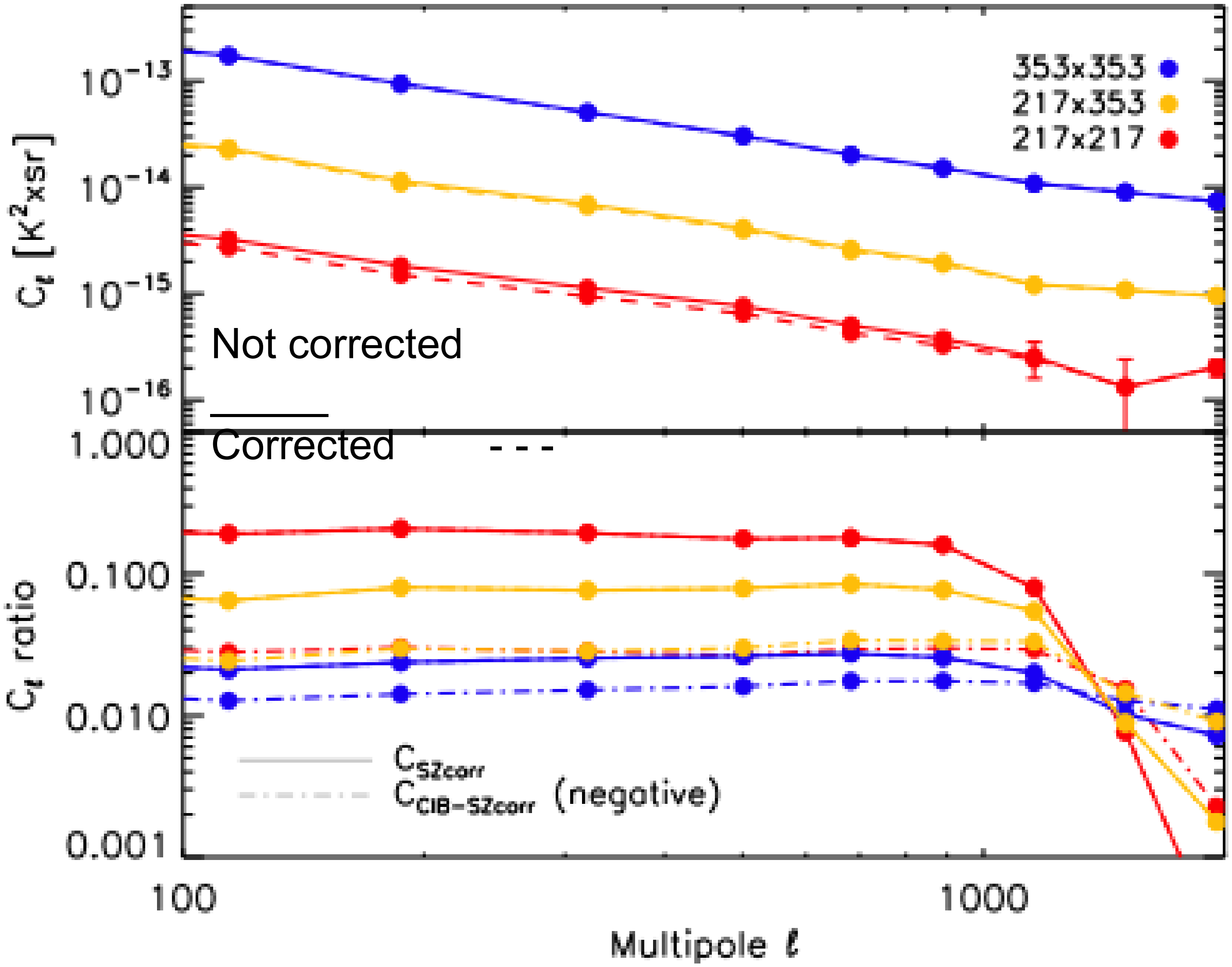
- tS

$$C^{\nu\times\nu'}_{\mathrm{SZcorr}} = C_{\mathrm{SZ}}\left[g_{\nu} g_{\nu'} + w_{\nu} w_{\nu'} g^{2}_{100} - g_{100}(w_{\nu'} g_{\nu} + w_{\nu} g_{\nu'})\right].$$

- t

$$C^{\nu\times\nu'}_{\mathrm{CIB\times SZcorr}} = C^{\nu\times\nu'}_{\mathrm{CIB\times SZ}} + C^{\nu'\times\nu}_{\mathrm{CIB\times SZ}} - w_{\nu} C^{100\times\nu'}_{\mathrm{CIB\times SZ}} - w_{\nu'} C^{100\times\nu}_{\mathrm{CIB\times SZ}} - w_{\nu} C^{\nu'\times100}_{\mathrm{CIB\times SZ}} - w_{\nu'} C^{\nu\times100}_{\mathrm{CIB\times SZ}} + 2 w_{\nu} w_{\nu'} C^{100\times100}_{\mathrm{CIB\times SZ}}$$

SZ-related corrections

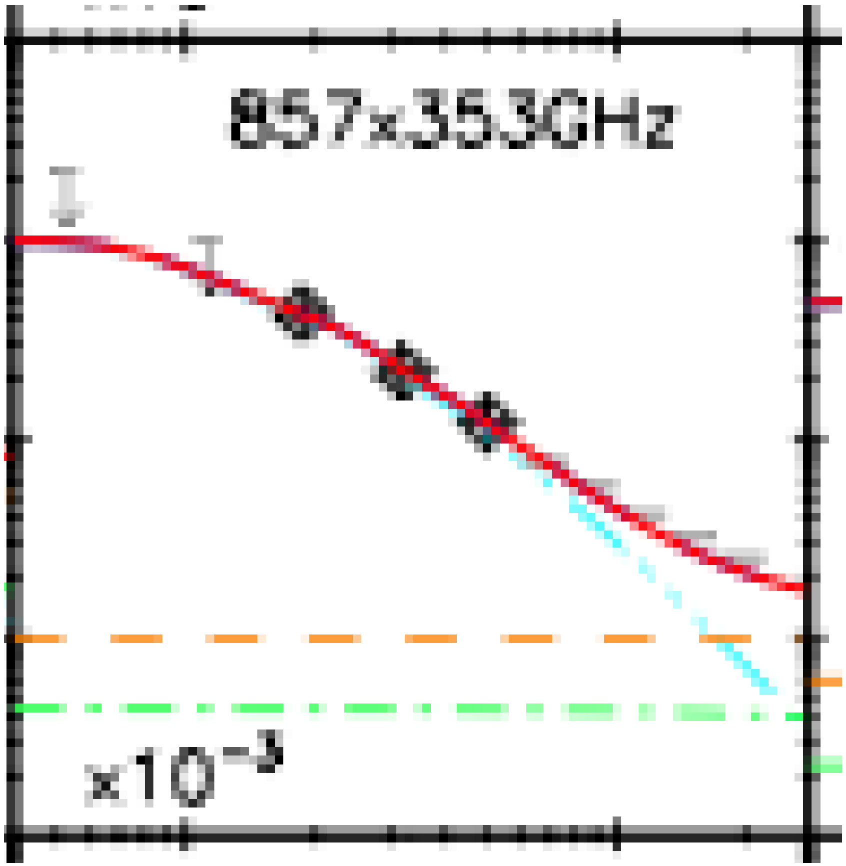


Not corrected ______

Corrected - - -

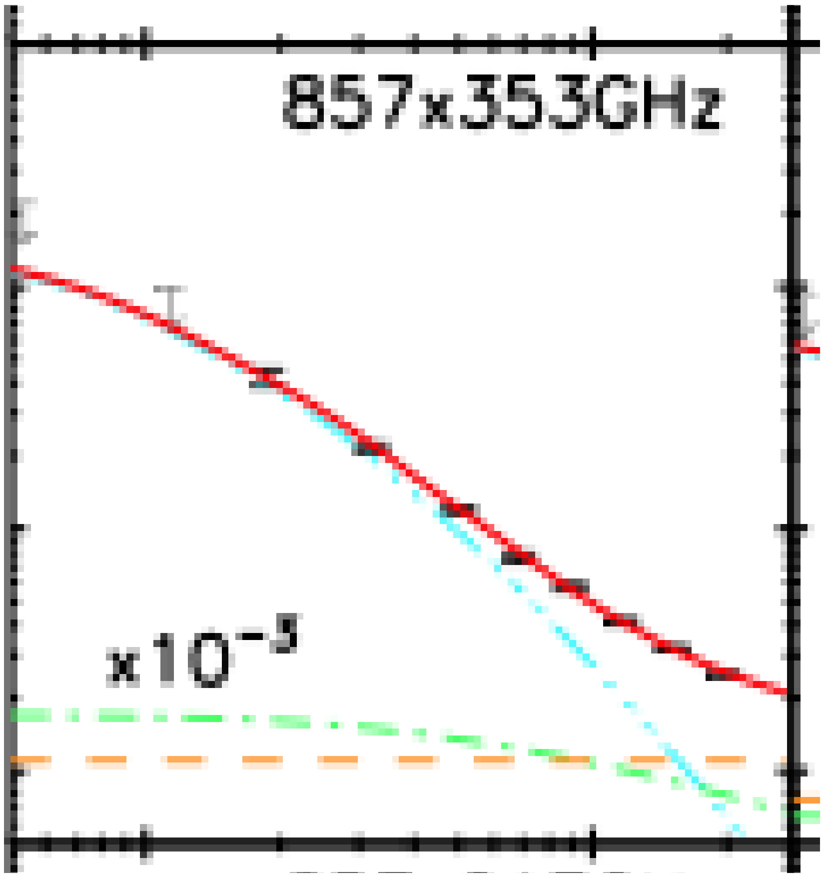
Equally good fits…

χred2= 1.15



Linear
(plot from M. Béthermin)

χred2= 0.92



Extended Halo Model
(plot from P. Serra)