Extragalactic Radio and Far-IR Sources in the Planck Frequency Range

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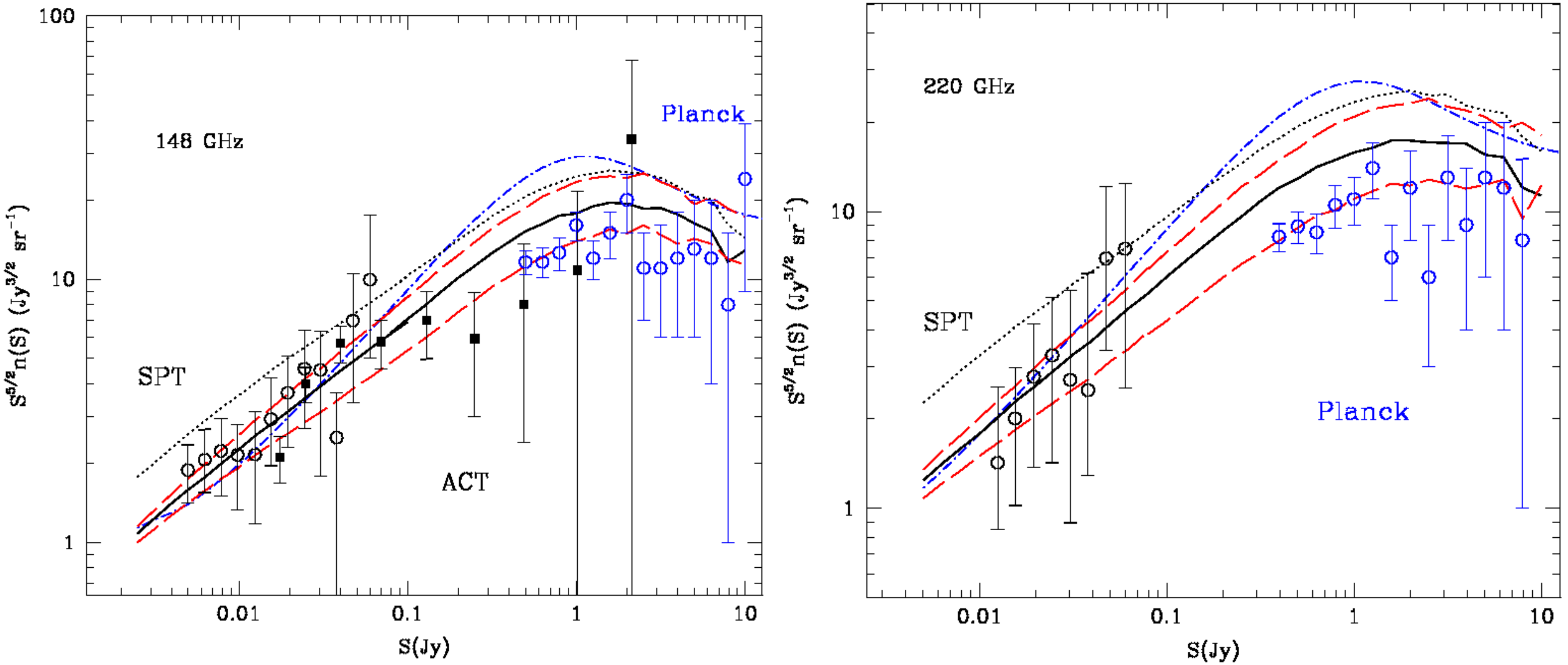
thanks to: Marcel Clemens, Mattia Negrello, Laura Bonavera

Radio sources - 1

- A lot of results on radio sources presented in Planck Early Papers and described at the Paris conference last year (Planck early results. XIII, XIV, XV).
- Major result: realization that for blazars (flat-spectrum radio quasars - FSRQs - and BL Lacs) already a ~ 70 GHz we are observing the spectral bending indicative that we are approaching the synchrotron peak
- Result unexpected in the framework of the `blazar sequence’ model according to which the peak frequency is anticorrelated with radio luminosity and occurs in the millimetric region only for the rare exceptionally luminous objects, not for the general population.

Planck radio source counts

(more in **Hervé Dole's and Marco Tucci's talks)**



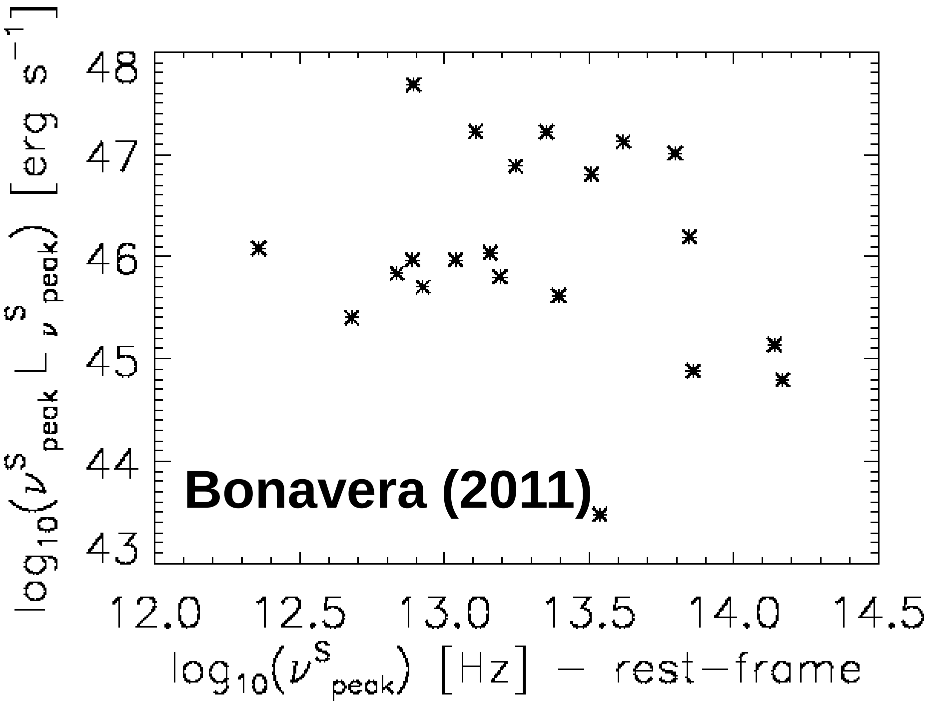
Tucci et al. (2011)

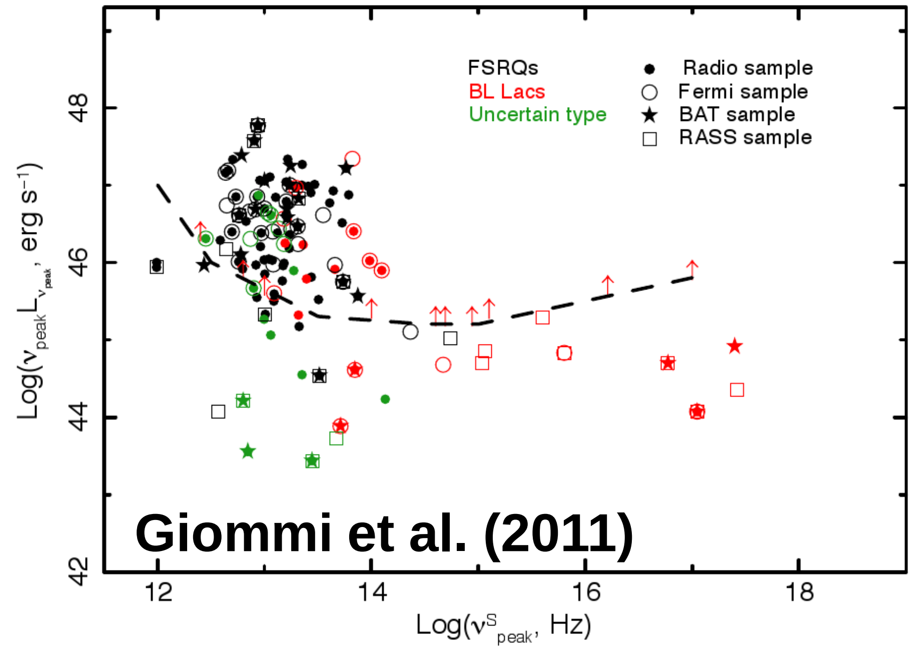
Models relying on the `blazar sequence' scenario overpredict the counts at > 100 GHz. Counts well fitted by the Tucci et al. (2011) model, although some excess over model at the faintest flux densities.

Counts and break frequencies

- Tucci et al., based on physical arguments, concluded that the spread of break frequencies for blazars must be very large, so large in fact to blur any trend with luminosity.
- For FSRQs the distribution of break frequencies should extend well below the range implied by the blazar sequence model.
- Their most successful model also envisages different distributions of break frequencies for BL Lacs and FSRQs, the former typically being an order of magnitude higher. More in **Marco Tucci's** talk.

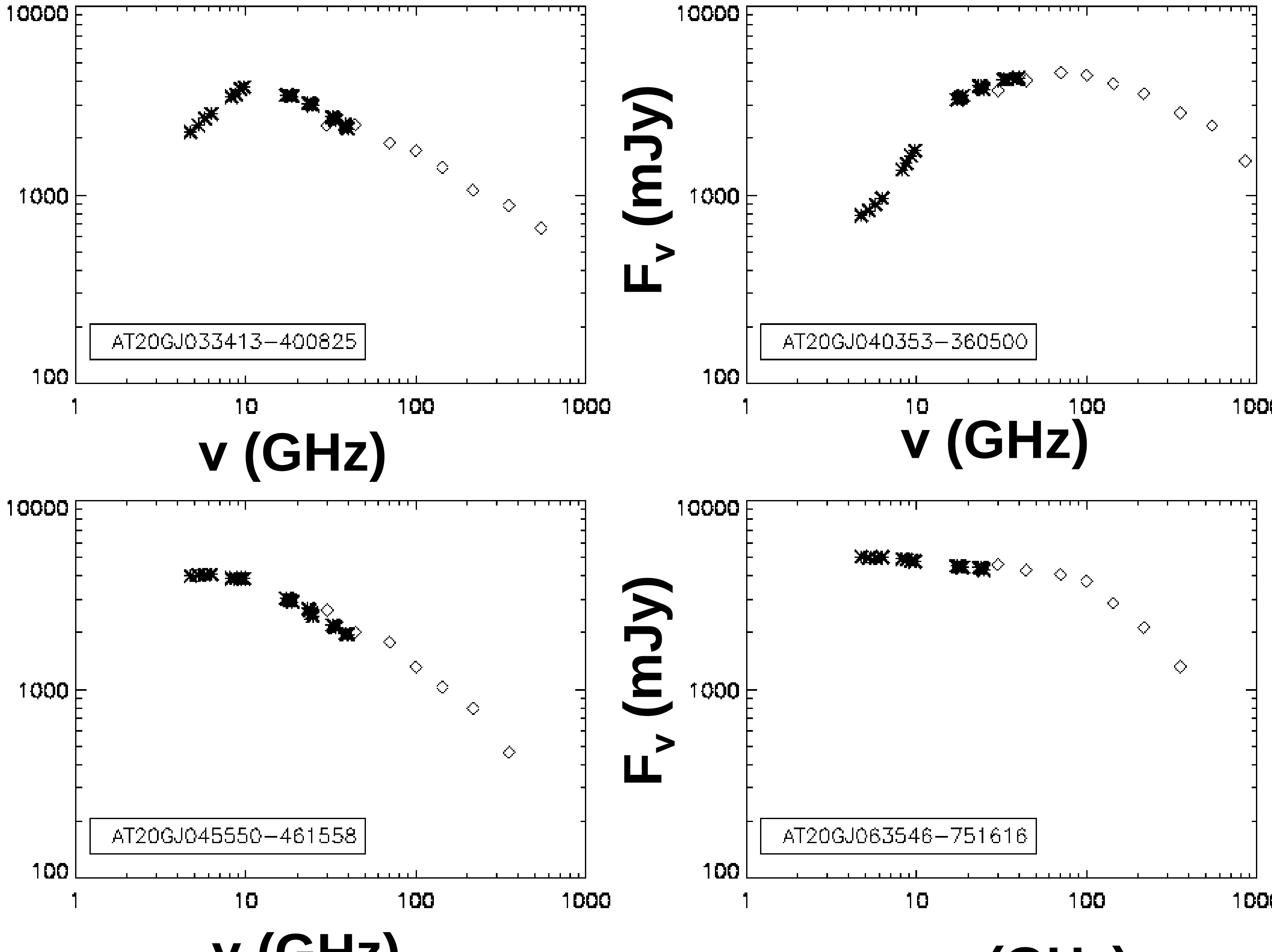
Counts and break frequencies - 3





The lack of correlation between luminosity and peak frequency, and the higher break frequencies of BL Lacs compared to FSRQs confirmed by extensive quasi-simultaneous multifrequency observations (Massardi et al. 2011; Bonavera et al. 2011; Richards et al. 2011; Planck early results. XIV, XV; Giommi et al. 2011). *Laura Bonavera's and Paolo Giommi's talks*. Above the dashed line in the right-hand panel, the non-thermal optical light of blazars is bright enough to swamp the emission from the host galaxy.

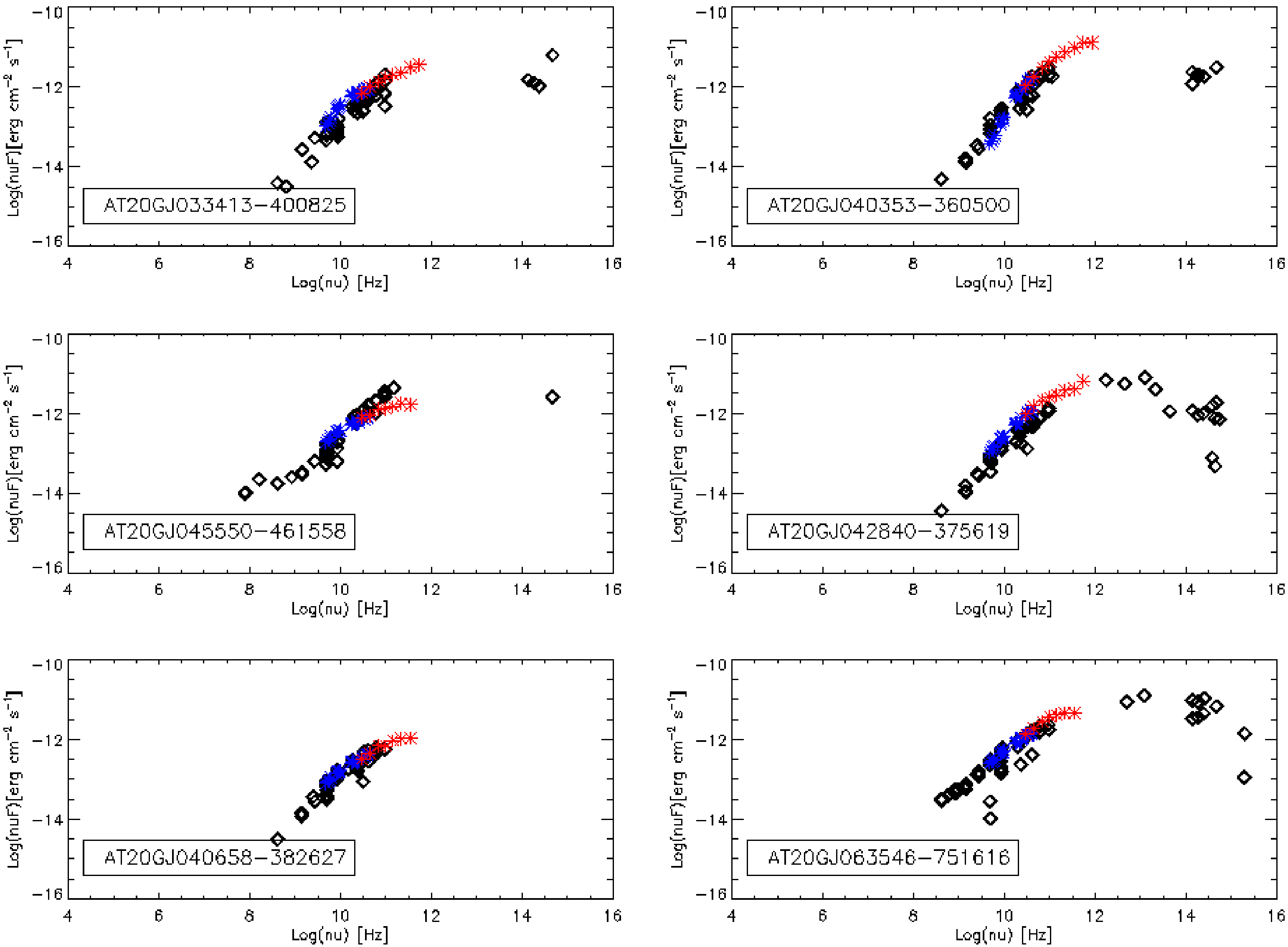
Radio sources SEDs



Bonavera et al. (2011)

Simultaneous Planck + ATCA data (PACO project, PI: M. Massardi) show remarkably smooth SEDs over about 2 decades in frequency, from ~ 6 cm to sub-mm wavelengths (see Laura Bonavera's talk also for some counter-examples **)**

Counts and break frequencies - 2



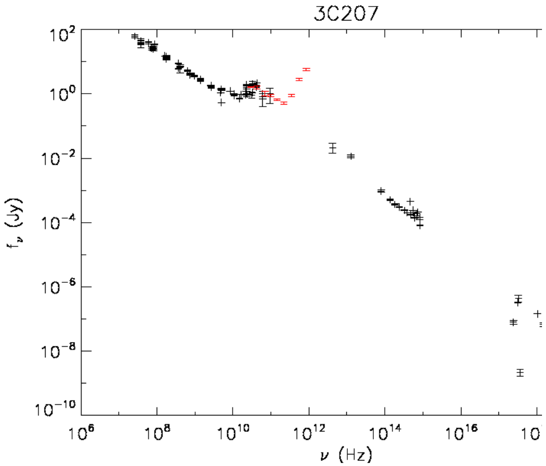
Planck data help determining the synchrotron peak and confirm the large spread of ν_{break} (Bonavera et al. 2011) …

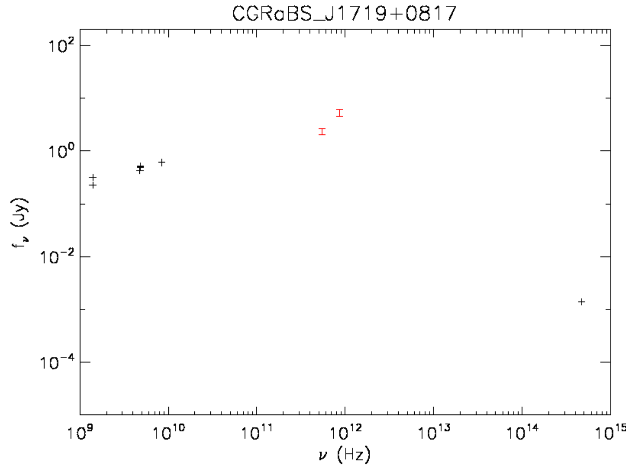
Courtesy of L. Bonavera

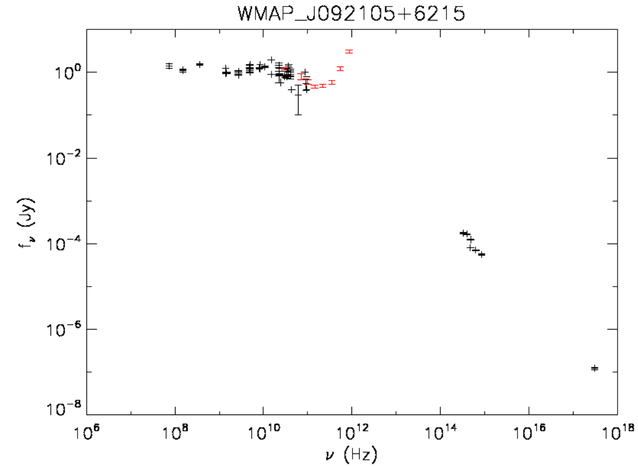
Issues with radio source counts

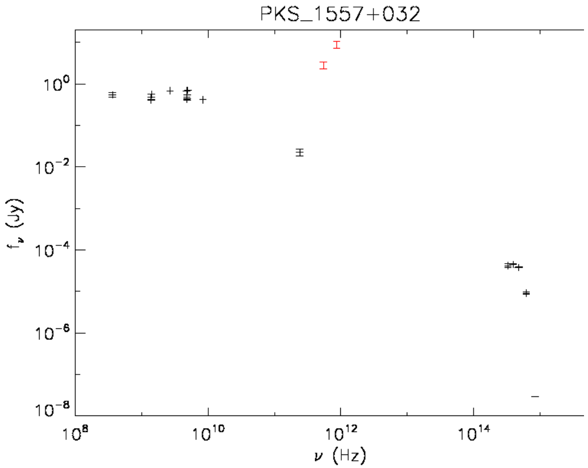
- Determinations of radio source counts in the range 30 − 217 GHz recently extended up to 545 GHz (**Hervé Dole's talk**).
- Issue with the classification of sub-mm sources due to co-existence of nuclear radio emission with dust emission from the host galaxy (emission from a dusty circum-nuclear torus may also be present but normally does not show up at sub-mm wavelengths).

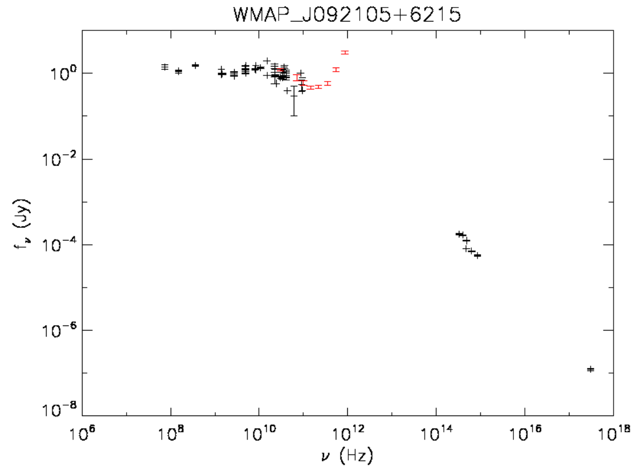
Spectral Energy Distributions







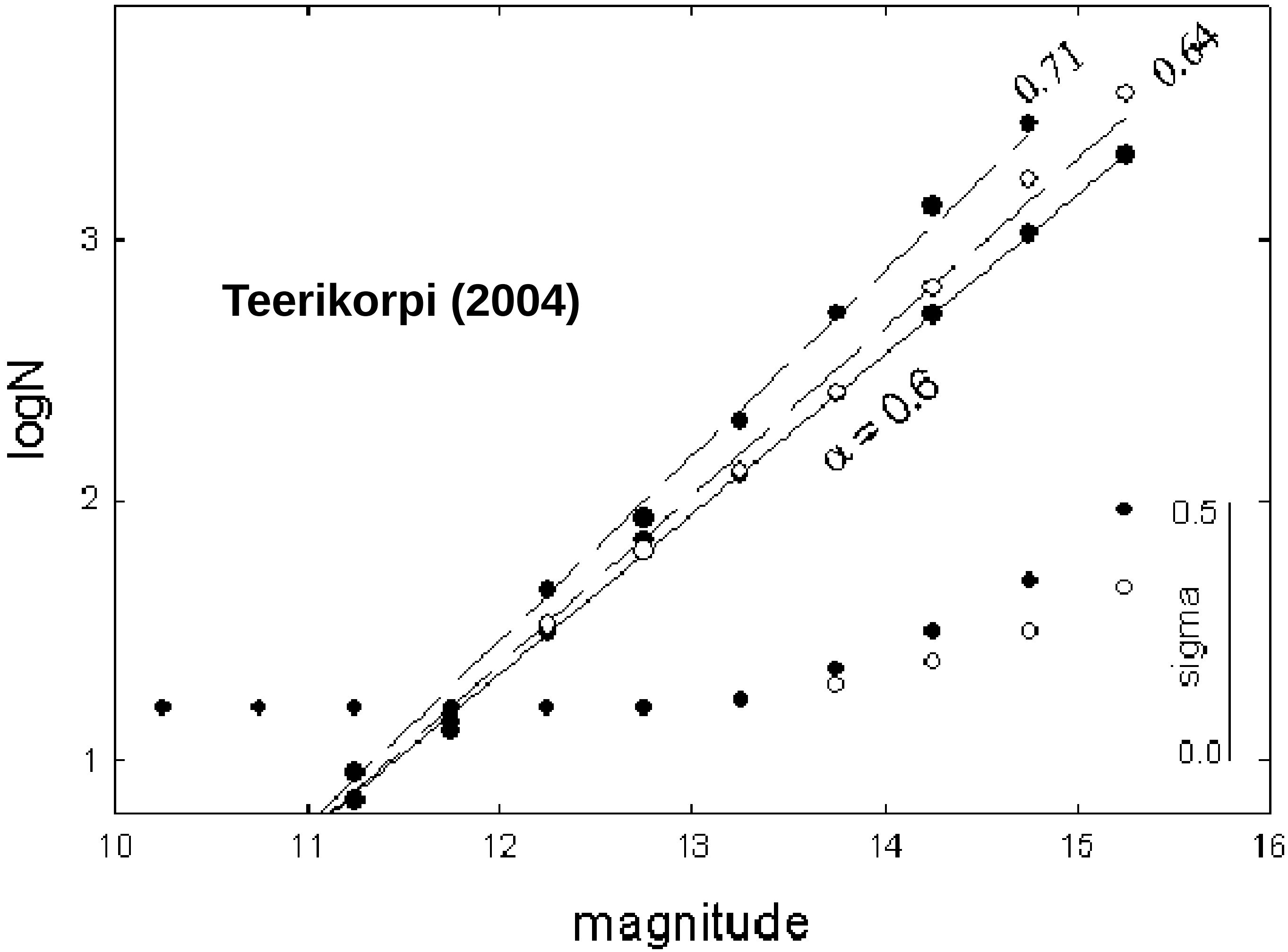




The sub-mm flux density of 5 (+1?) out of 12 (+1?) BZCAT blazars listed in the ERCSC 857 GHz catalog is dominated by thermal dust emission.

May be lost by colour selection; synchrotron/dust emission at transition frequencies may be overestimated. **Courtesy of M. Clemens**

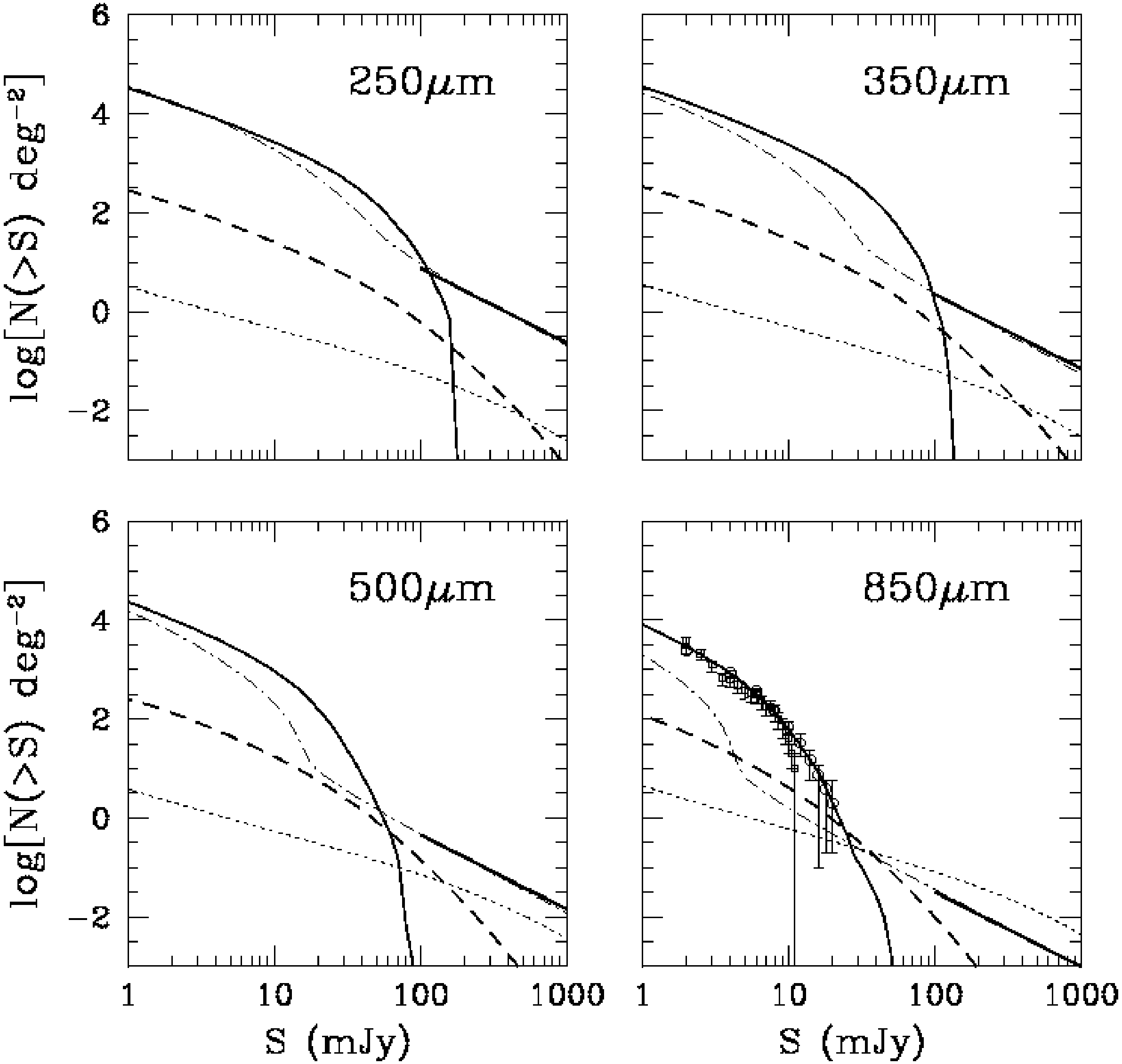
Radio source counts: Eddington bias?



Measurement errors increasing with decreasing flux density yield observed counts increasingly exceeding the true ones at faint levels (Murdoch et al. 1973). Simulation by Teerikorpi (2004) assuming a uniform distribution of sources (α=0.6). ***Larger effect for steeper counts*** (as in the case of dusty galaxies).

Dusty galaxies

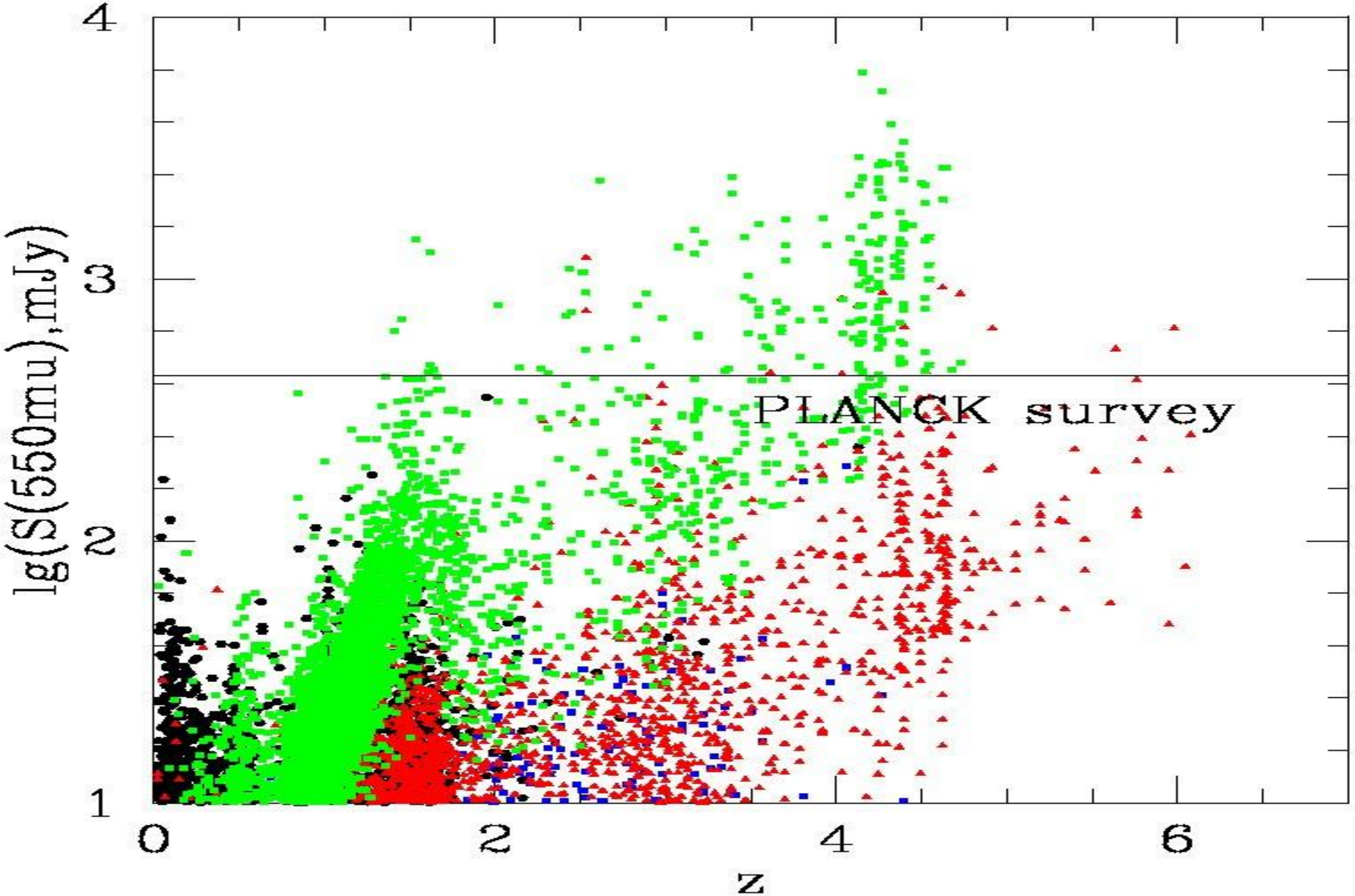
Counts (more in Herve's talk)



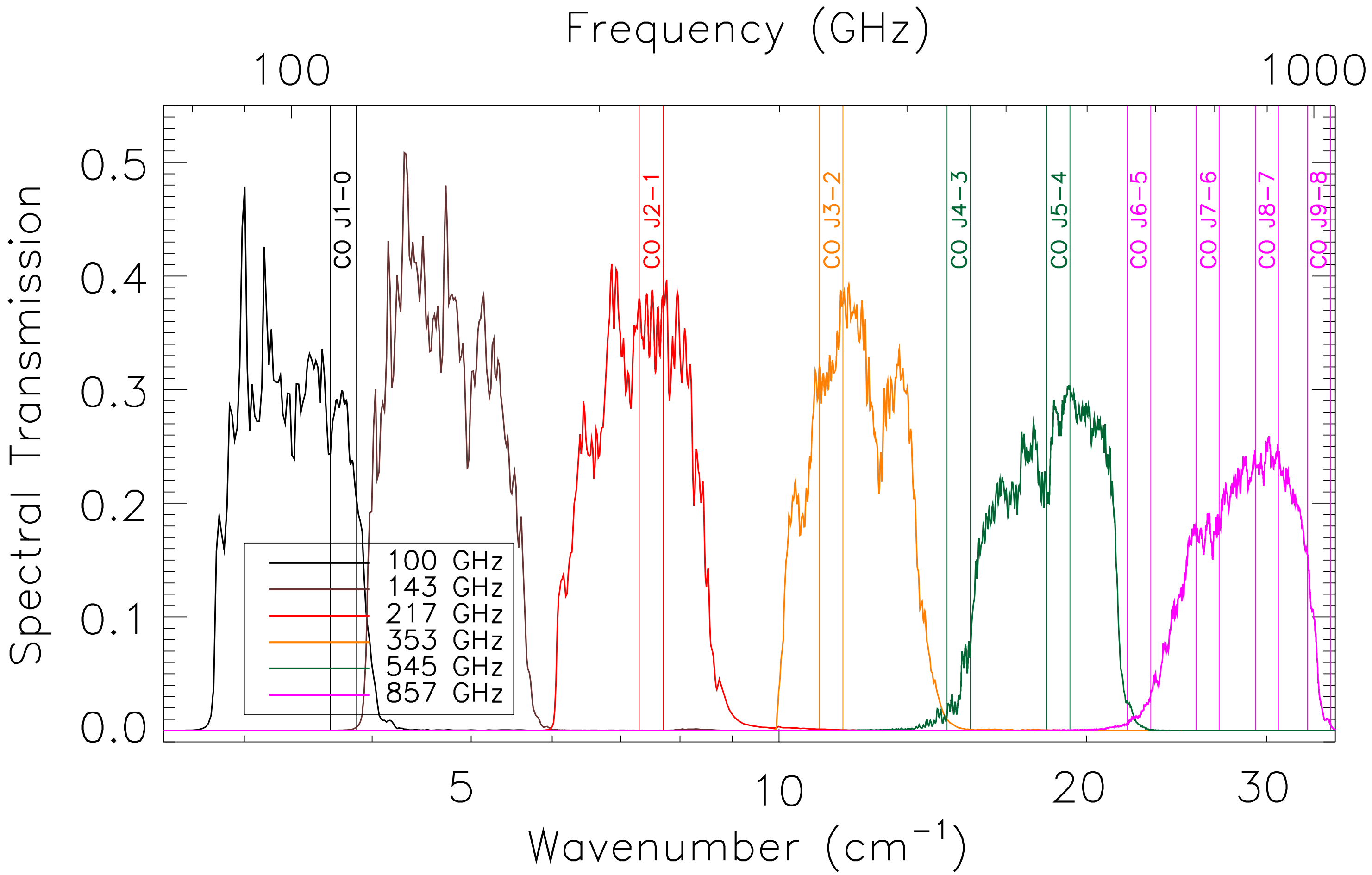
Negrello et al. (2007)

Most models (see **also Matthieu Béthermin's** talk) predict Euclidean counts above the Planck detection limit at sub-mm wavelengths

Prediction of 550μm flux densities of Spitzer-SWIRE galaxies (32 deg^2) based on photometric redshifts and infrared template fits at 3.6 – 160μm (Rowan-Robinson et al. 2008)

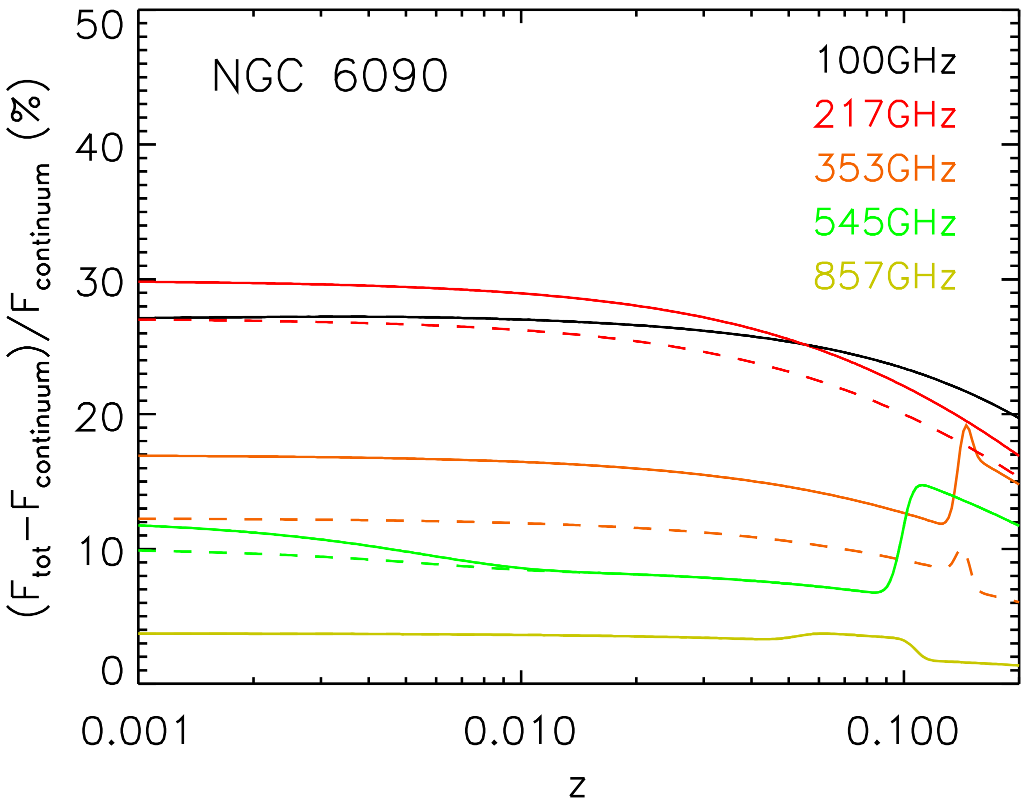


CO contribution to Planck flux measurements



Planck HFI Core Team (2011): Planck early results. VI.

CO contribution to Planck flux measurements



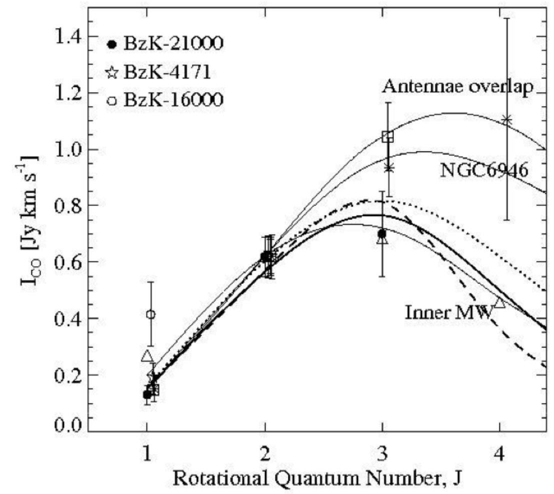


Fig. 5 Aravena et al. (2010, ApJ, 718, 177)

J	$L_{CO}(J-J\text{-}1)/L_{CO}(1-0)$
1	1
2	7.7 – 8.5
3	15.2 – 21.0
4	13.1 – 32.0
5	– 43.3
6	– 59.7
7	– 40.8
8	– 32.0
9	– 15.0

$\mathbf{L_{CO}(1\text{-}0)/L_{IR} = 7.2 \times 10^{-5}}$ (Genzel et al. 2010)

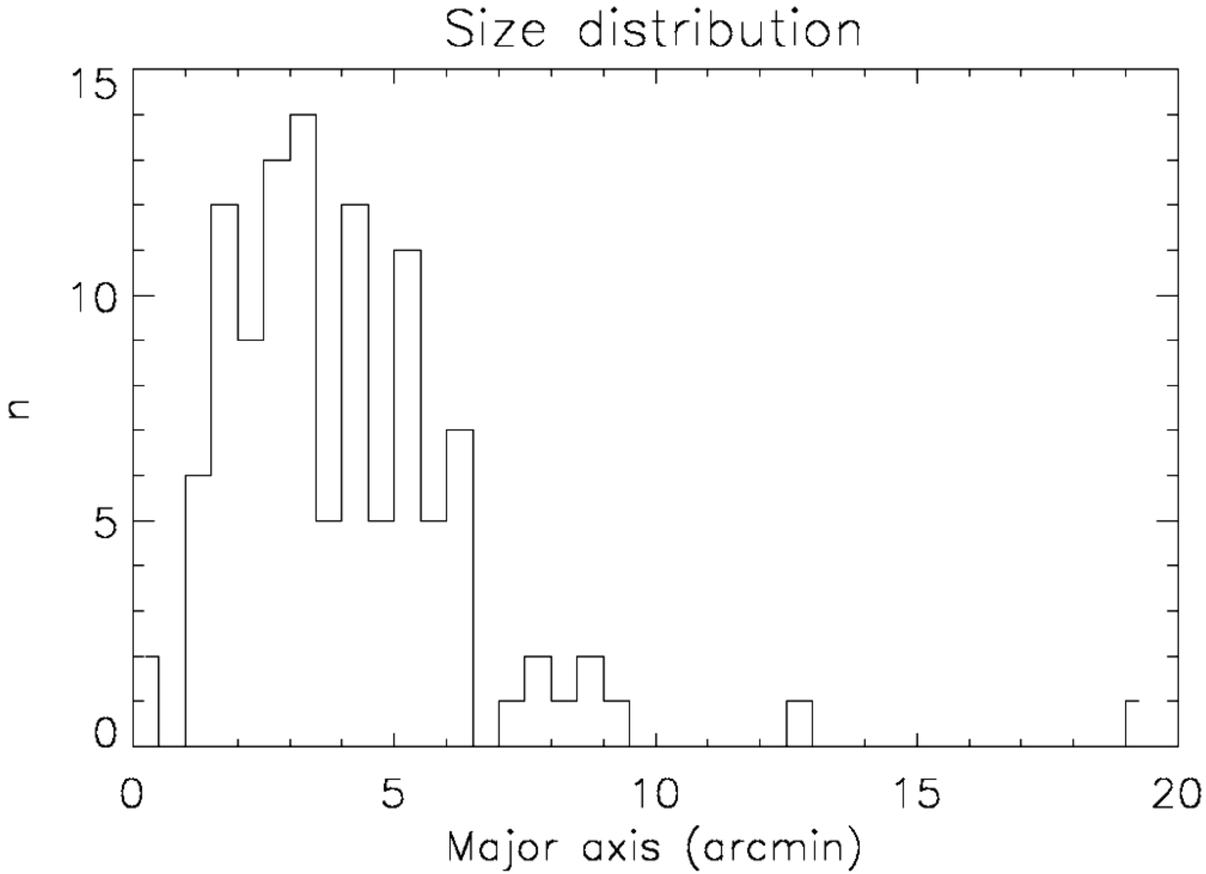
Top-hat transmission over nominal bandwidths.

Courtesy of M. Negrello

Planck flux density estimators - 1

- The ERCSC offers 4 flux density estimations:
  - ➢ FLUX: measured in a circular aperture of radius given by the nominal sky-averaged FWHM. Corrections for the flux density outside the aperture assuming point source profile.
  - ➢ PSFFLUX: estimated by fitting the source with the *Planck* point spread function at the location of the source.
  - ➢ GAUFLUX: estimated by fitting the source with an elliptical Gaussian model whose parameters are free.
  - ➢ FLUXDET: estimated by the native detection algorithm (PwS for frequencies 30–143GHz, and SExtractor for frequencies 217–857GHz).

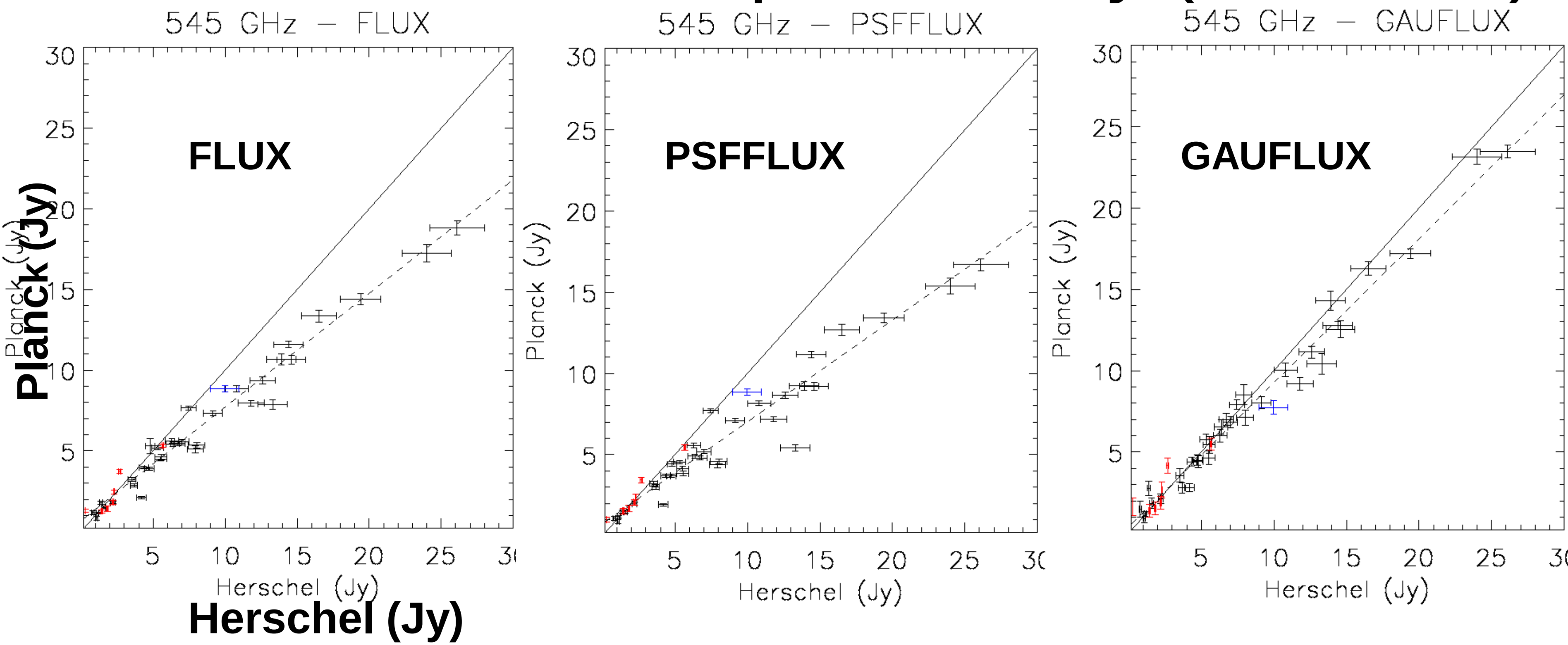
Which estimator should be used?



Distribution of optical sizes for a representative sample flux limited sample of ERCSC galaxies selected at 545 GHz flagged EXTENDED=0

FLUX most commonly used. However, even galaxies with EXTENDED=0 have sizes not much smaller than the Planck beam at high frequencies (4.41, 4.47, 4.41 arcmin at 353, 545, 853 GHz, respectively). Courtesy of M. Clemens

Planck vs Herschel photometry (545 GHz)



Galaxies at |b| > 20˚ and with EXTENDED=0 (42 objects). Black points: KINGFISH (Dale et al. 2011); red points: H-ATLAS (Herranz et al. 2012). Planck data colour corrected according to the Explanatory Supplement (factor ~0.9 for the relevant spectral indices). Colour correction on Herschel data using the individual 500µm− 350µm spectral index. ***Small impact of different estimators on source counts in the range considered in Hervé's presentation.*** **Courtesy of M. Clemens**

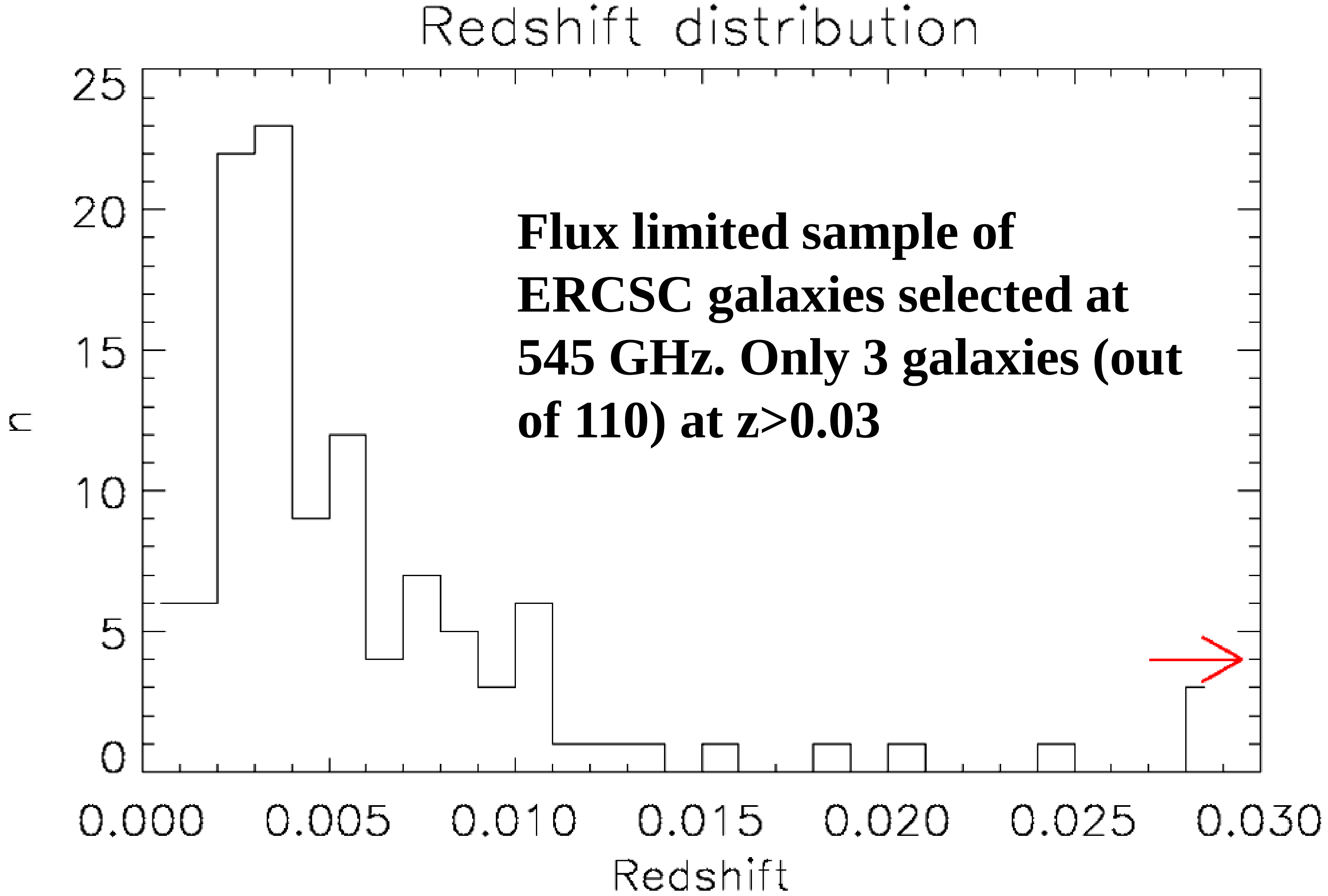
Planck vs Herschel flux densities: 545 GHz

545 GHz

	median (P-H) Jy; st. dev. (Jy) in parenthesis		
	all (42 gal)	$S \leq 10\,\mathrm{Jy}$ (12 gal)	$S > 10\,\mathrm{Jy}$ (30 gal)
FLUX	-0.84 (1.84)	-0.004 (0.32)	-1.46 (1.94)
PSFFLUX	-1.06 (2.46)	0.089 (0.24)	-2.06 (2.52)
GAUFLUX	-0.18 (0.81)	0.27 (0.55)	0.37 (0.87)

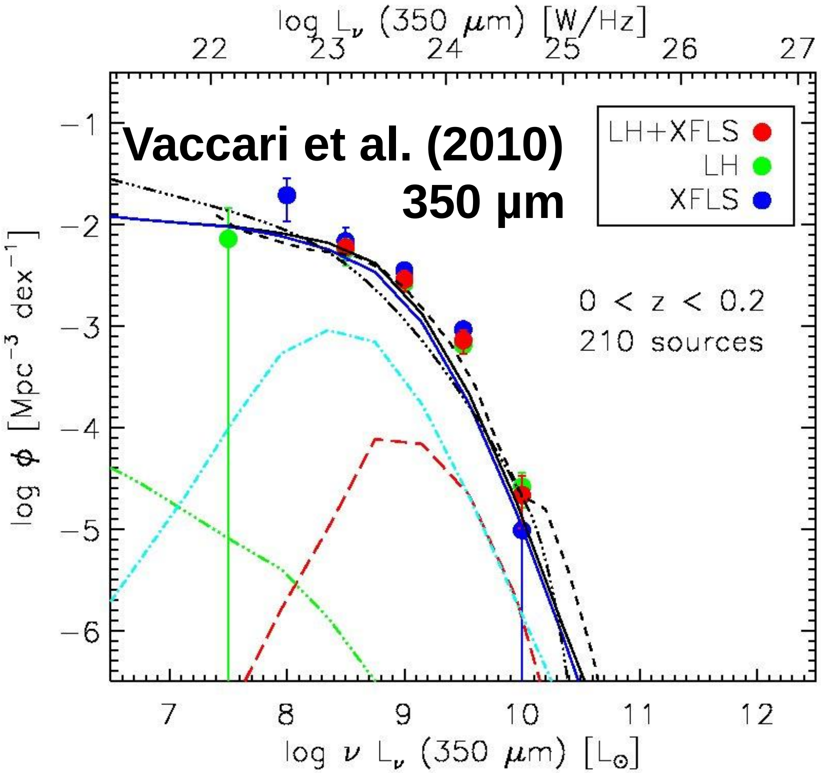
	median (P-H)/H		
	all	$S \leq 10\,\mathrm{Jy}$	$S > 10\,\mathrm{Jy}$
FLUX	-18.0%	-0.34%	-19.1%
PSFFLUX	-22.3%	4.4 %	-25.5%
GAUFLUX	-3.8%	17.0 %	-5.2%

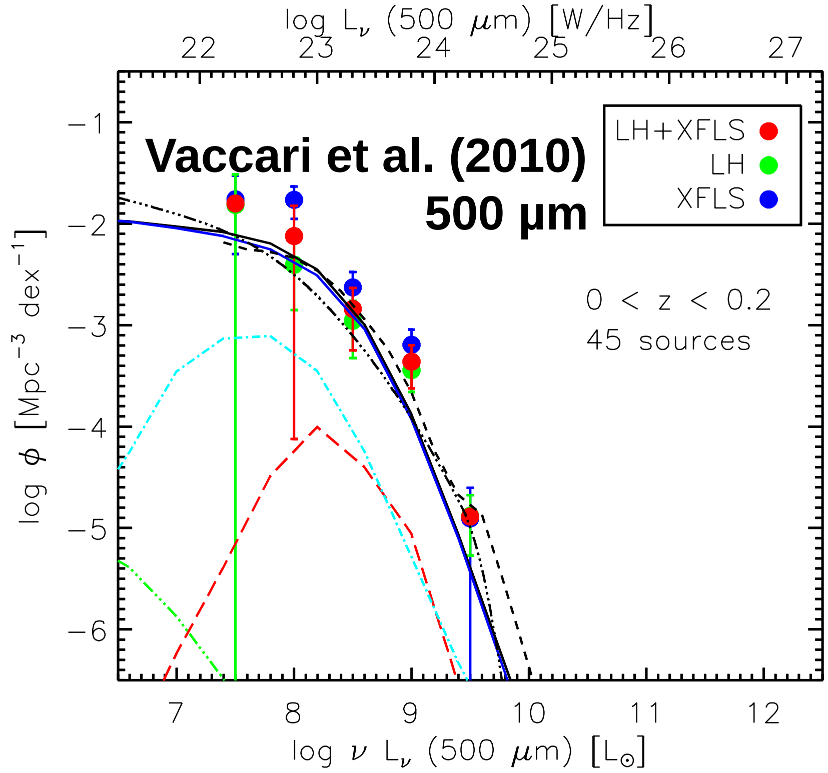
Redshift distribution of ERCSC sources

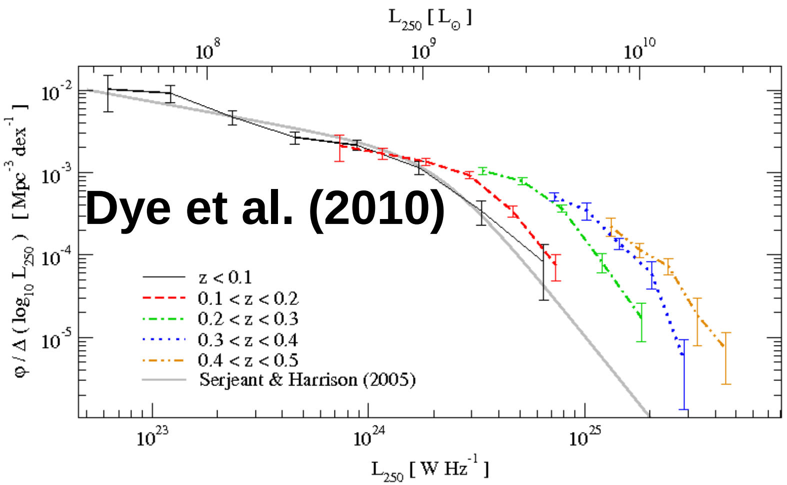


Courtesy of M. Clemens

Herschel sub-mm LLFs

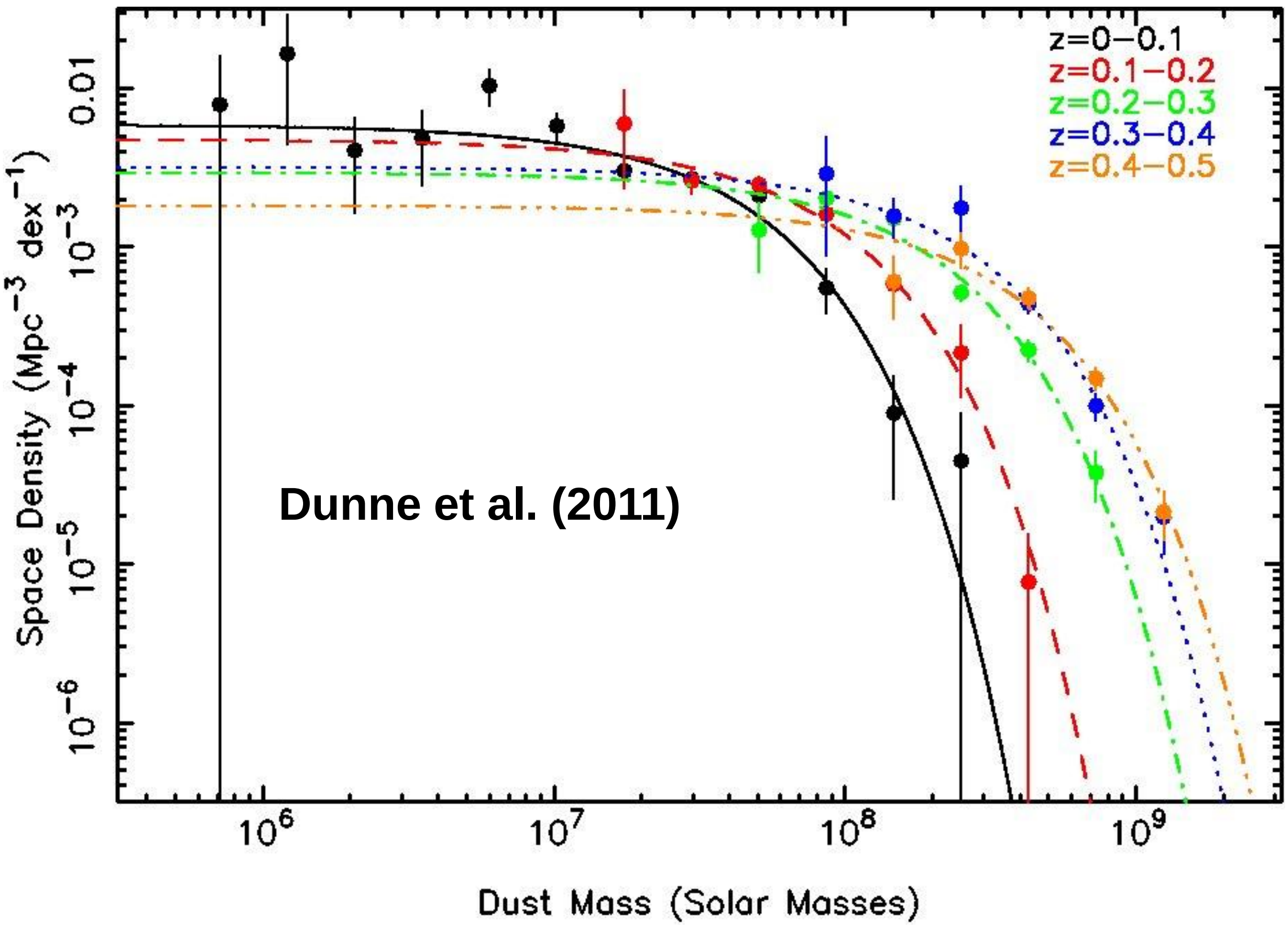






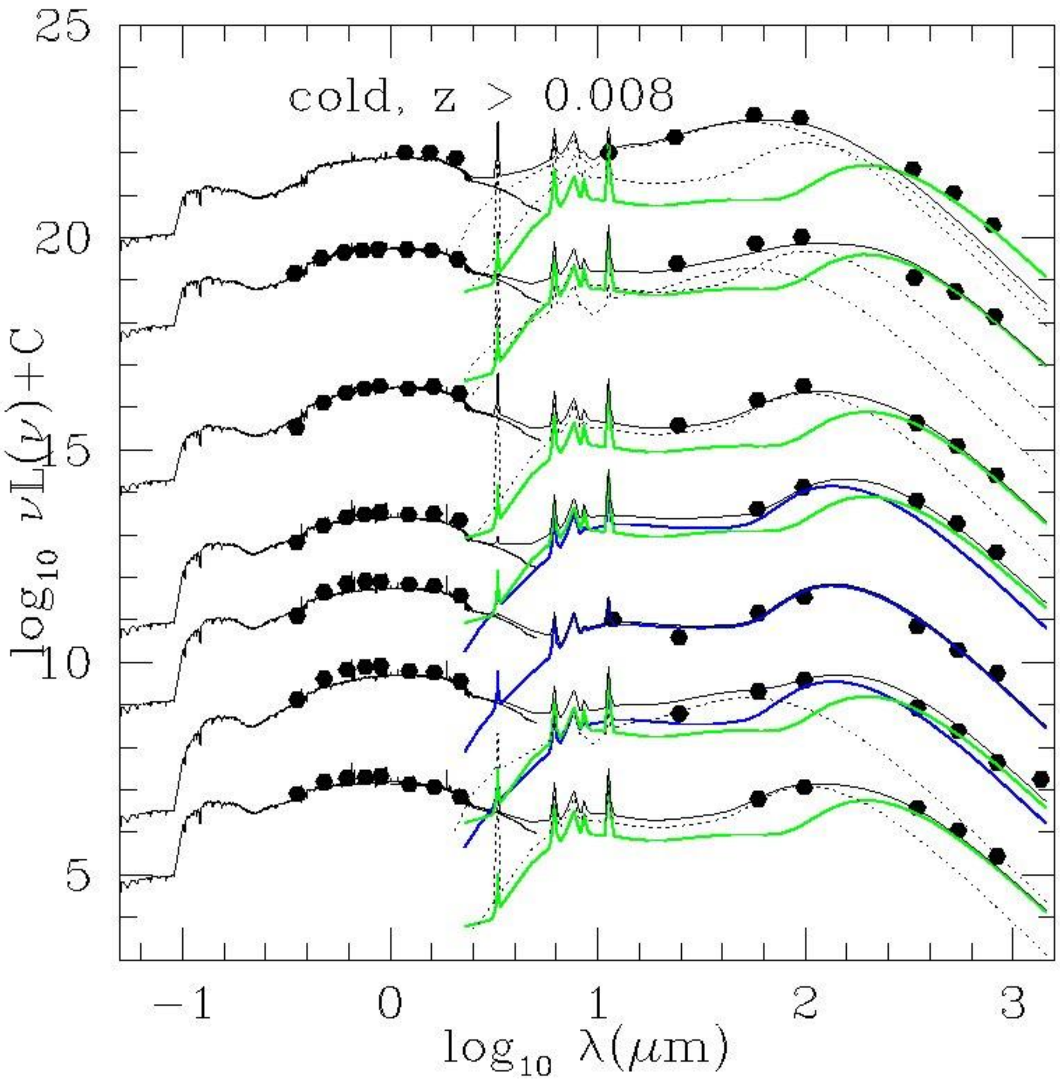
LLFs either extrapolated from IRAS (Serjeant & Harrison 2005) or need model dependent corrections for evolution. Planck provides truly local samples. Thanks to its all-sky coverage it has unique capabilities in sampling with good statistics the upper end of the LLF, hence of the SFR and of the dust mass function.

Dust mass function



From the Schechter fit one expects 0 galaxies with $M_{dust} > 10^9$ M_{sun} ($N(\geq 10^9\ M_{sun}) \sim 10^{-17}$ Mpc^{-3}), but a preliminary analysis (Planck early results. XVI.) finds at least 3 galaxies in this mass range

SEDs of dusty galaxies



Planck Collaboration. XVI. Planck provides information on the presence of colder dust than detectable by IRAS or AKARI all-sky surveys. While the SEDs of most galaxies can be fitted with two dust components at T_{cold}=16±4 K and T_{warm}=36±9 K, at least 13 galaxies were found with a dust component with temperatures as low as 10 K (green line).

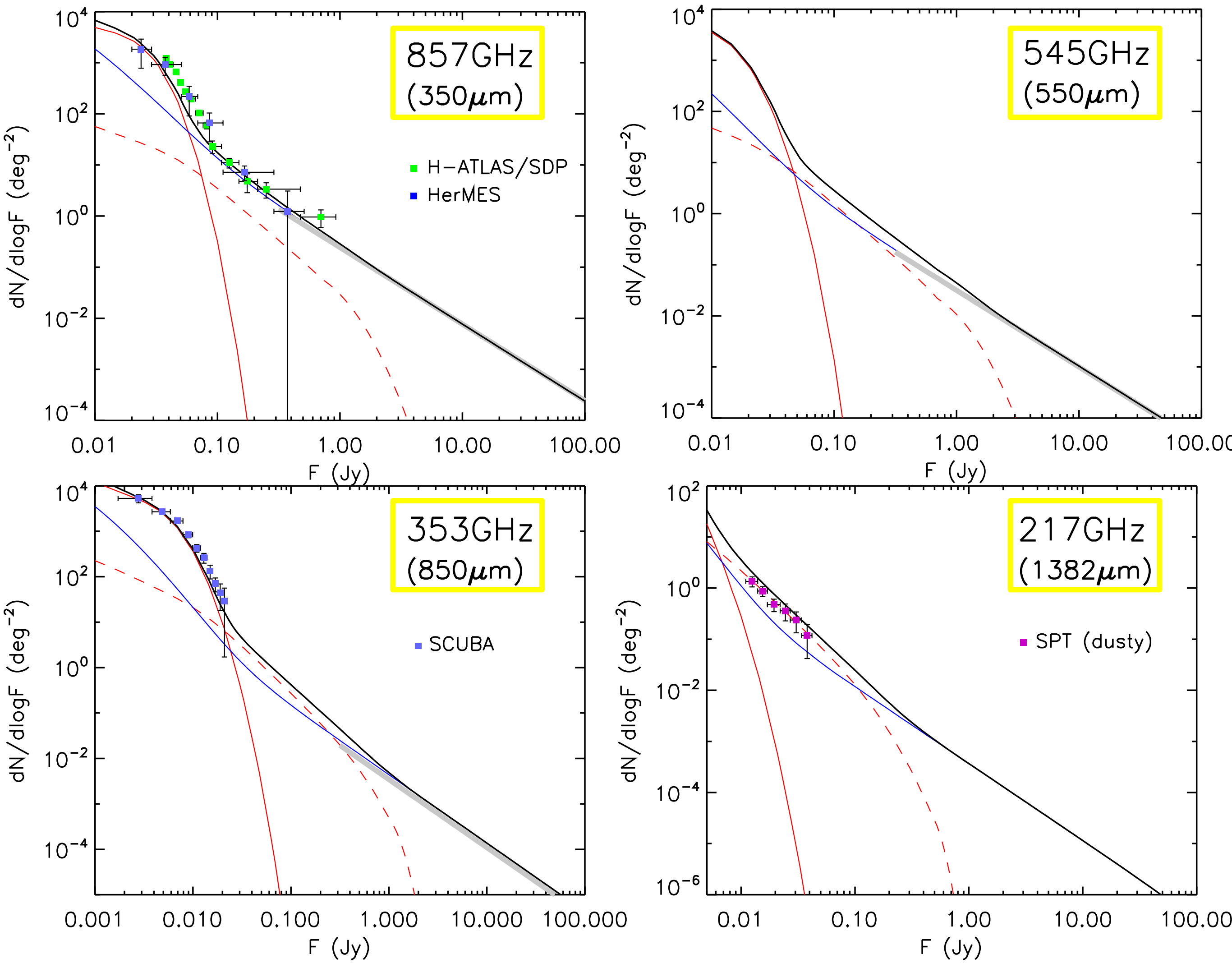
How abundant is the cold dust?

- Accurate flux density measurements and corrections CO contamination are crucial to answer this question.
- The Eddington bias and the CO contamination may lead to significant flux density overestimates. On the other hand, the FLUX estimator may lead to underestimates.
- More work is needed to assess whether indeed the Euclidean portion of the (sub-)mm counts of dusty galaxies is higher than expected based on previous knowledge of the SEDs, thus providing statistical evidence for the widespread presence of cold dust.

High-z dusty galaxies

- ERCSC dusty galaxies are at very low redshifts, as indeed expected on the basis of most models
- However, Planck surveys provide important and unique information also on high-z dusty galaxies and specifically on:
  - Strongly lensed galaxies
  - Proto-clusters of dusty galaxies
  - CIB fluctuations

Sub-mm/mm counts of **dusty galaxies**



Models

- un-lensed spheroids (Lapi et al. 2011)
- lensed spheroids (Negrello et al. 2007)
- late-type galaxies (Negrello et al. 2007)
- TOTAL

Planck detection limits tantalizingly close to expected detection of high-z strongly lensed galaxies

References:

- Serjeant & Harrison (2005)
- Clements et al. (2010)
- Oliver et al. (2010)
- Coppin et al. (2006)
- Vieira et al. (2010)

Courtesy of M. Negrello & A. Lapi

Proto-clusters of dusty galaxies

- Negrello et al. (2005) pointed out that, although individual high-z galaxies are generally too faint to be detectable by Planck, proto-clusters of dusty galaxies, unresolved by Planck, may show up as peaks on Planck maps. Examples may have already been found (see **Ludovic Montier**'s, **Dave Clements**', **Joaquin Gonzalez-Nuevo**'s talks)

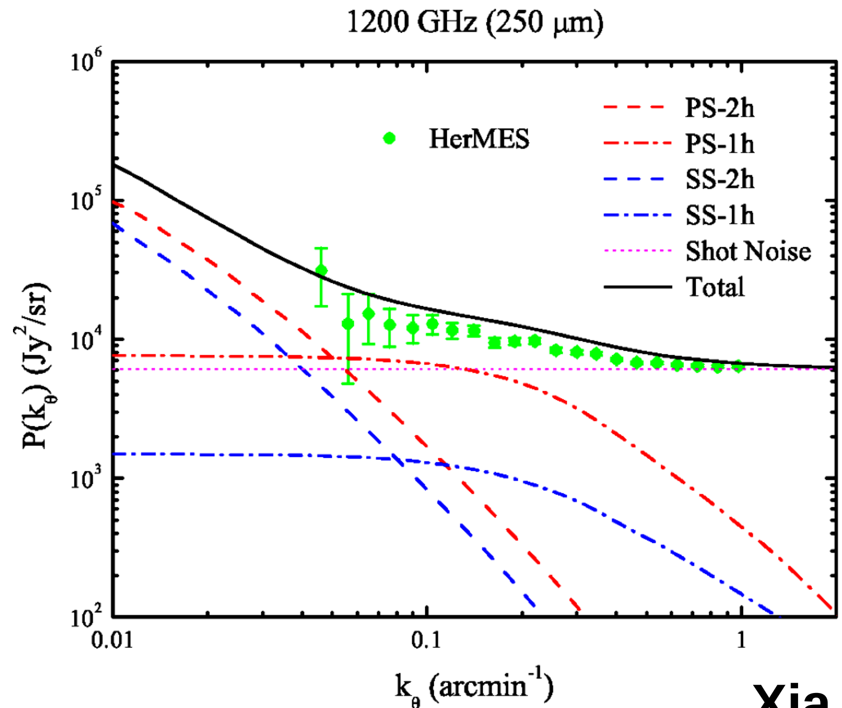
Power spectrum of CIB fluctuations - 1

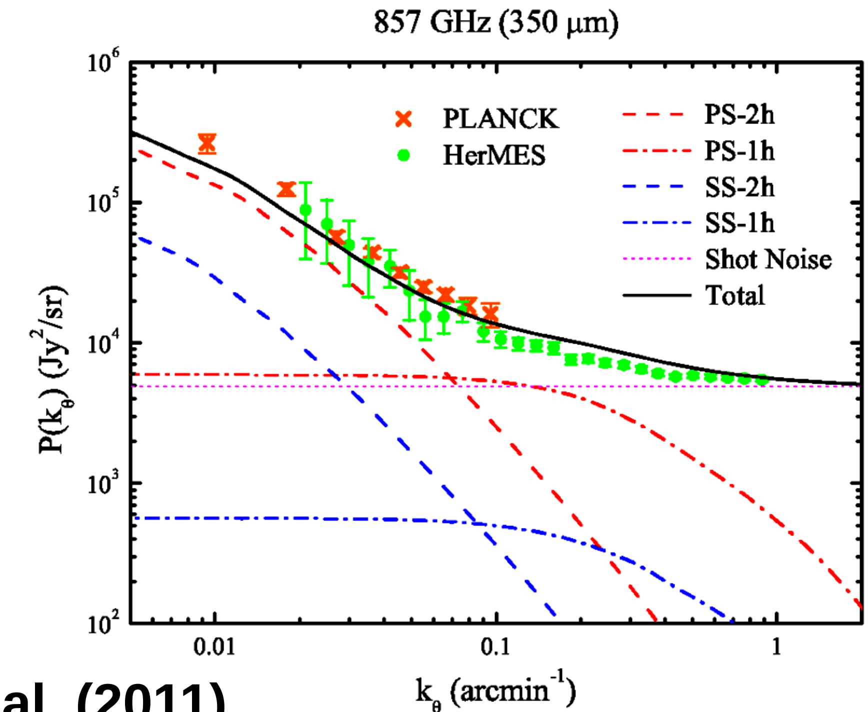
- To be discussed by **Jean-Loup Puget**. Only a few comments here.
- Well determined by Planck from multipole l=200 to l=2000 at 217, 353, 545 and 857 GHz (Planck Early Results. XVIII).
- Extension to higher multipoles thanks to higher resolution Herschel (Amblard et al. 2011), SPT (Hall et al. 2010; Shirokoff et al. 2011) and ACT (Dunkley et al. 2011; Das et al. 2011).

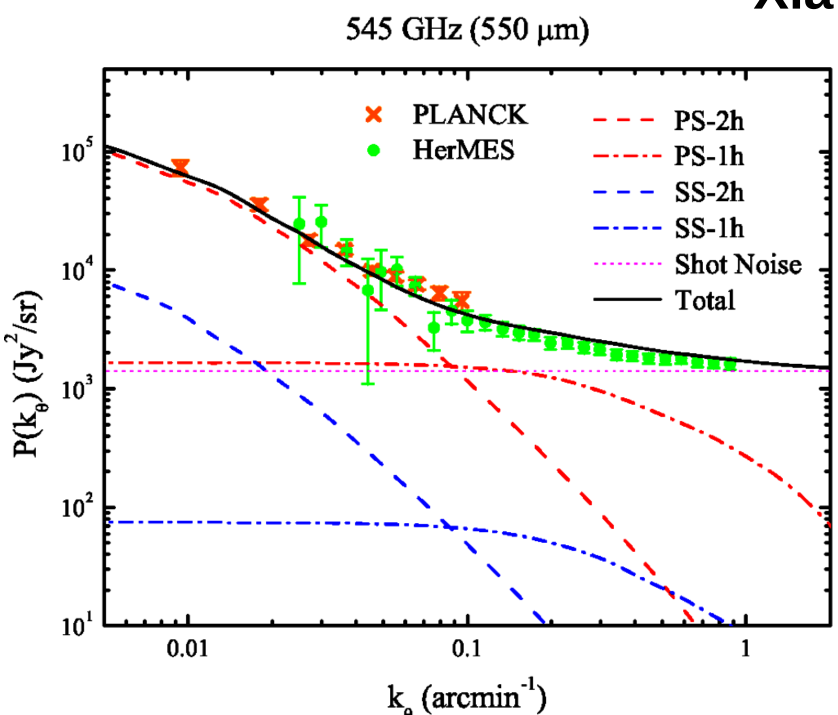
Power spectrum of CIB fluctuations - 2

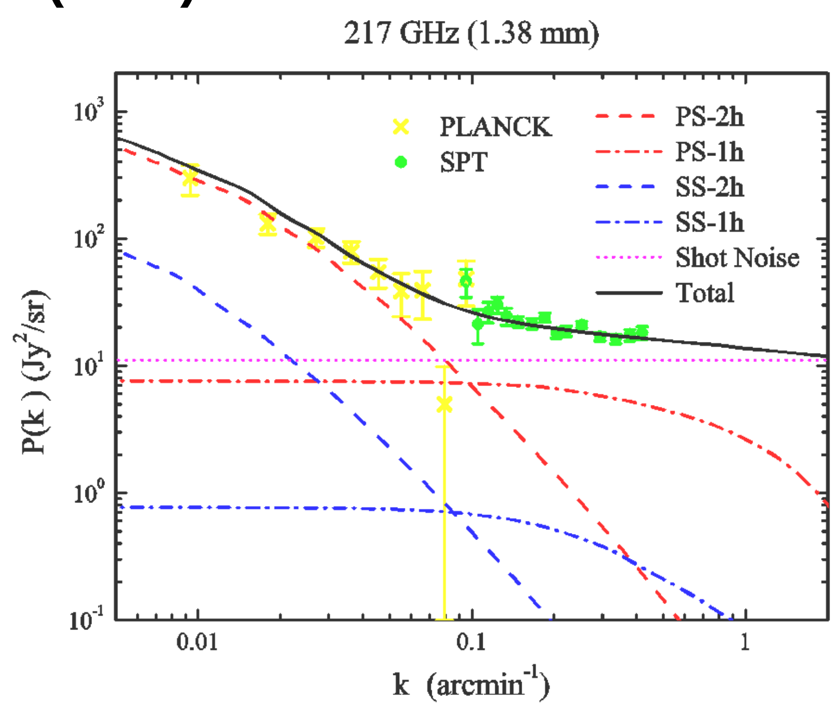
- Data well reproduced in the framework of the Halo Occupation Distribution Formalism (Planck Early Results. XVIII; Amblard et al. 2011; Pénin et al. 2011; Xia et al. 2011).
- Xia et al. (2011) find that all multifrequency data can be simultaneously reproduced in the framework of the Granato et al. (2004) model (see **Gigi Danese**'s talk) with only 2 free parameters, the minimum halo mass and the power-law index of the mean occupation function of galaxies.

Xia et al. (2011)









Power spectrum of CIB fluctuations - 3

- The *minimum* halo mass, $\log(M_{min}/M_{sun}) = 12.24 \pm 0.06$, derived by Xia et al. (2011), is higher but consistent within the errors, with the estimate by Amblard et al. (2011): $\log(M_{min}/M_{sun}) = 11.5$ (+0.7, -0.2). The corresponding *effective* halo mass at $z \approx 2$, i.e. at the peak of cosmic star formation, $\log(M_{eff}/M_{sun}) = 12.7$, is reassuringly close to that of the most efficient star-formers at that redshift (Tacconi et al. 2008) .
- A somewhat puzzling result, confirmed by independent analyses, is the implied presence of a substantial non-linear contributions at $z \geq 1$ on angular scales ≥10', corresponding to physical linear scales ≥ 5 Mpc, corresponding to mass scales ≥ several $\times 10^{13}$ M_{sun} to be compared with characteristic non linear masses of $\leq 2\times10^{11}$ M_{sun}

Conclusions: radio sources

- Planck is providing new insights into the SED of blazars in an essentially unexplored frequency region, close to the synchrotron peak, both directly and statistically (via source counts).
- Peak frequency uncorrelated with radio luminosity, at odds with the `blazar sequence' scenario. Results support the scenario proposed by Tucci et al. (2011)
- Some issues with sub-mm radio source counts need to be clarified

Conclusions: dusty galaxies - 1

- Planck yields the first determination of the Euclidean portion of sub-mm counts. Some models ruled out by Planck data alone.
- Issues with flux density estimates (optimal flux density estimator, CO contamination, amount of Eddington bias) still need to be fully sorted out
- Evidence of large cold dust masses in at least some galaxies.
- Indications of a strong excess (compared to Herschel-based estimates) in the high-mass tail of the dust mass function

Conclusions: dusty galaxies - 2

- Rare intensity peaks in Planck sub-mm maps dominated by high-z sources due to proto-clusters of dusty galaxies. Detection of high-z proto-clusters may be fostered if they act as gravitational lenses for background ULIRGs.
- Power spectra of CIB fluctuations consistent with being dominated by galaxies with halo masses ~ 5×10^{12} M_{sun} at z~2, independently found to be the most prolific star formers in the universe.
- Puzzling indications of non linear effects on scales ~ 10' yielded by sources thought to be at $z \geq 1$