High-frequency predictions for number counts of extragalactic radio sources and their impact on CMB experiments

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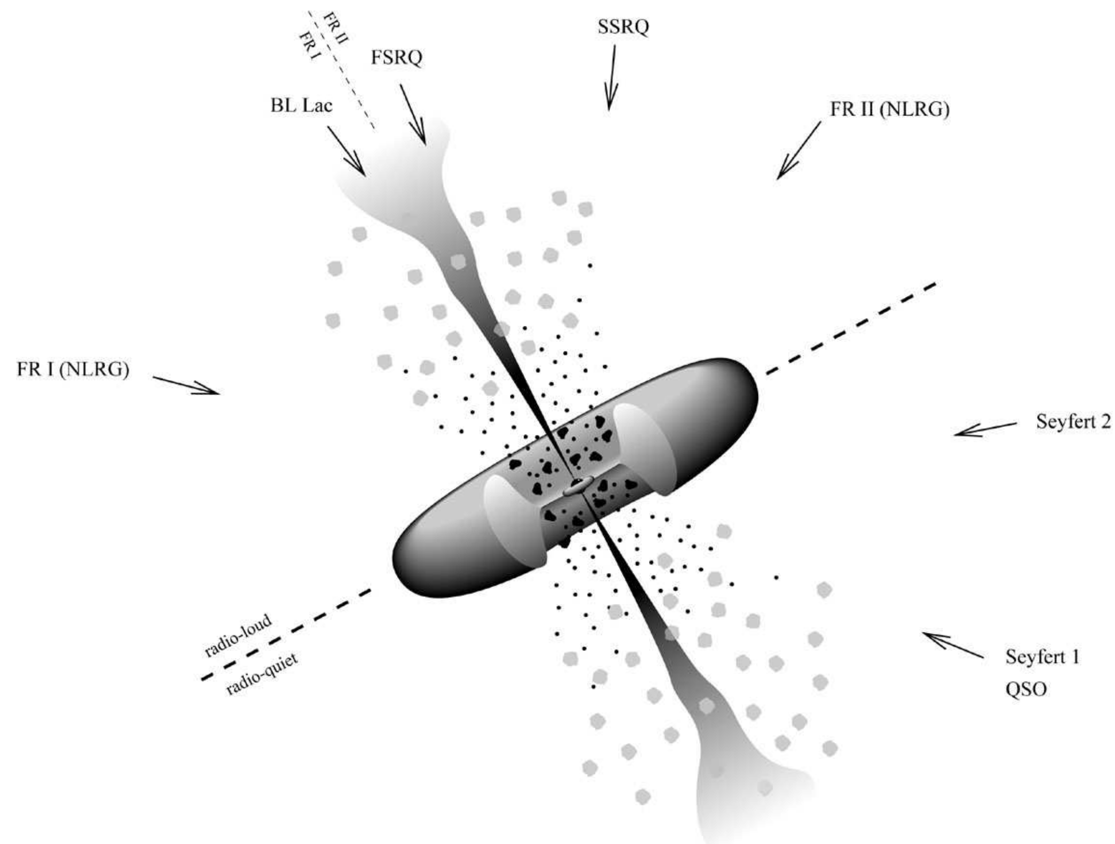
Basic classification of Extragalactic Radio Sources (ERS)

At flux densities of mJy–Jy, ERS are dominated by **AGN–powered** sources.

"Unification" scheme:
observed properties depend on the orientation of AGN jets relative to the observer.



Classification:
($S \propto \nu^{\alpha}$, at GHz frequencies)

$\alpha \geq -0.5 \longrightarrow$ **Blazars**
(flat–spectrum radio Quasars; BLLacs)

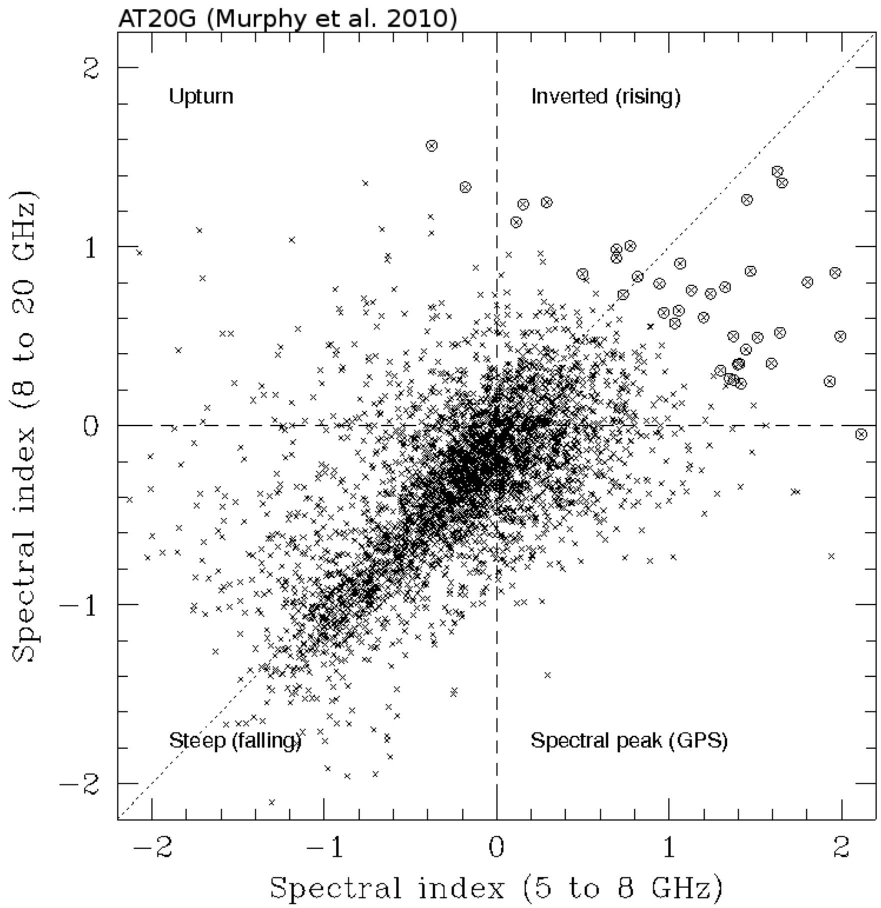
$\alpha < -0.5 \longrightarrow$ **Steep–Spectrum Sources**
(Quasars; radio galaxies)

ERS spectral behaviour at cm–mm wavelengths

ERS spectra can be approximated to a power law only in a small range of frequencies.

Different mechanisms are responsible for this:

- steepening due to high–energy electron ageing
- transition from optically thick to optically thin regimes
- at different wavelengths emission dominated by different components with different spectra



ERS number counts at high–frequencies

Two reference models: **Toffolatti et al. 1998 (T98); de Zotti et al. 2005 (dZ05)**

Determination of **epoch–dependent luminosity functions** for the different populations of ERS, by fitting available data on luminosity functions, redshift distributions, number counts.

- Simple power–law spectra for blazars: $\alpha_{flat} = -0.1$
- Good results for the total $n(S)$ at $\nu \lesssim 5\,\mathrm{GHz}$, but not for the single ERS populations
- Partially good results for the total $n(S)$ at $\nu > 5\,\mathrm{GHz}$, but:
  – **T98 scaled by** ~ 0.7 to match WMAP $n(S)$ ($\nu < 100\,\mathrm{GHz}$);
  – **dZ05 scaled by** ~ 0.5 to match *Planck*–HFI counts ($\nu \gtrsim 100\,\mathrm{GHz}$).

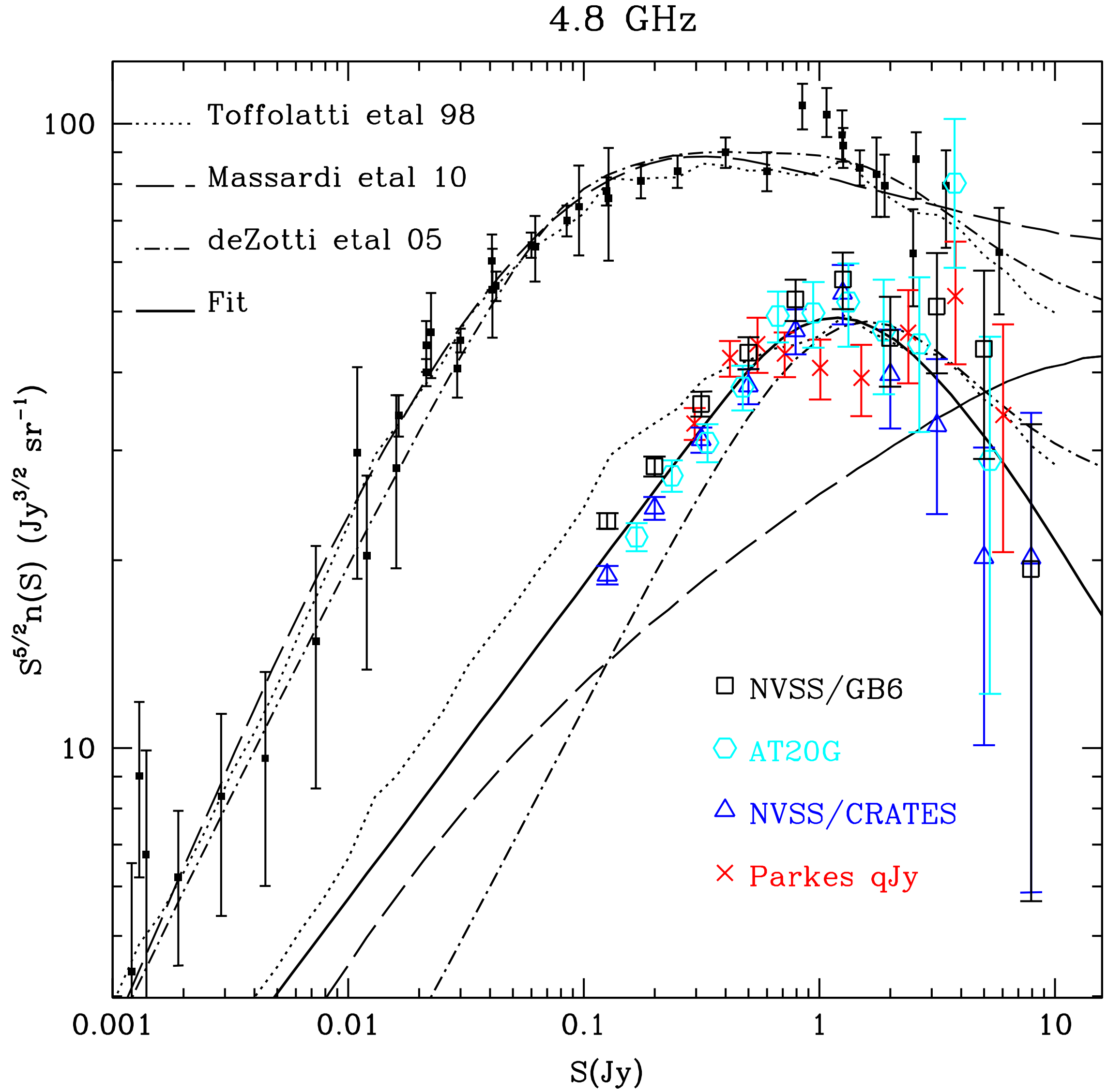
New model to estimate ERS number counts

(MT, L.Toffolatti, G.deZotti & E.Martinez–Gonzalez, 2011, A&A, 533, A57)

First step:

• **5–GHz number counts** for steep– and flat–spectrum sources.

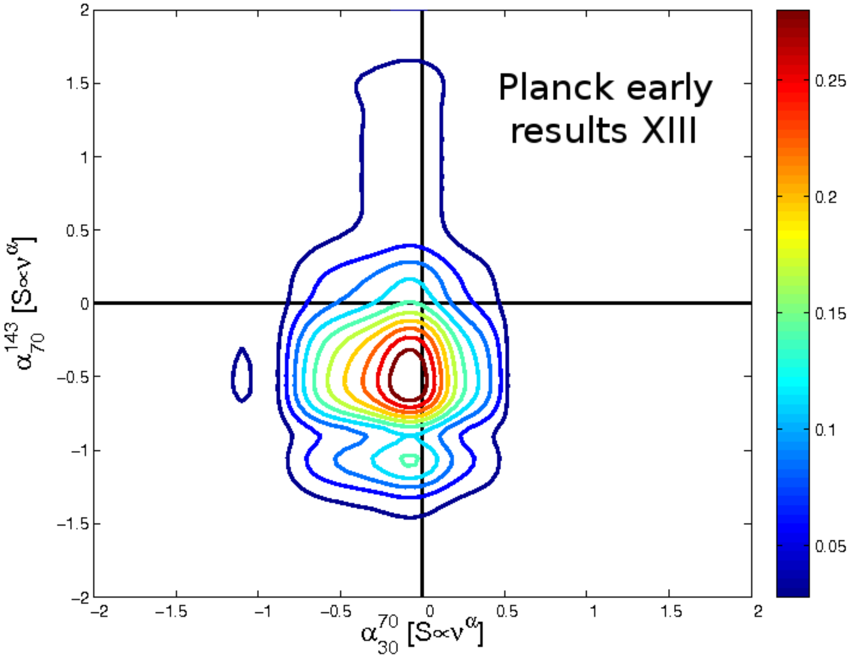
• **spectral index distribution** at 1.4–5 GHz using NVSS, GB6 surveys.



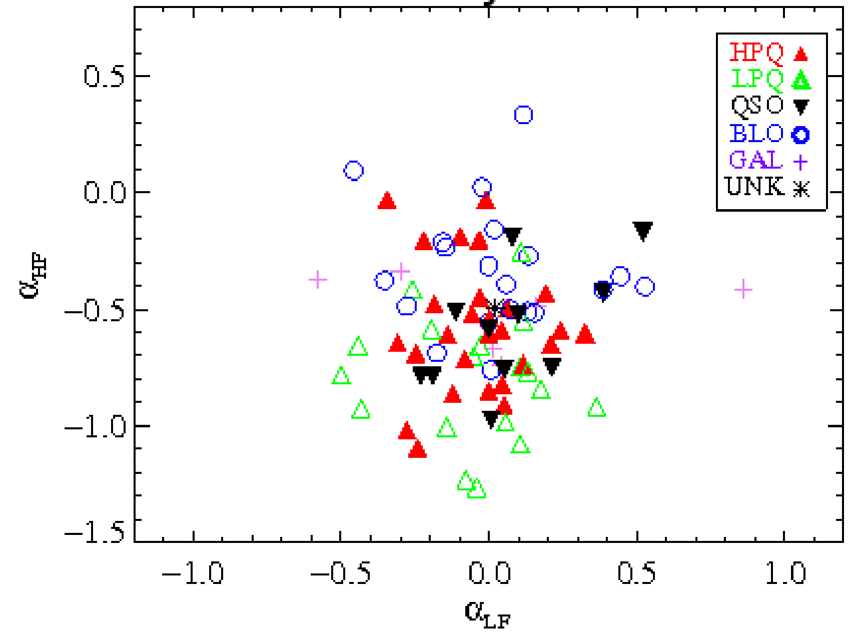
Second step: Extrapolation of 5–GHz flux densities to higher frequencies

- **Steep–spectrum sources**: average steepening of $\Delta\alpha = 0.3$ after 5 GHz (Bolton et al. 2004; Ricci et al. 2006; AT20G data)
- **Inverted–spectrum sources ($\alpha_1^5 > 0.3$)**: a broken power–law spectrum, with the peak at $\nu \lesssim 20$ GHz for most of them; few per cent are still inverted at $\nu > 40$ GHz.
- **Flat–spectrum sources (blazars)**: a break in the flat spectrum at ν_M

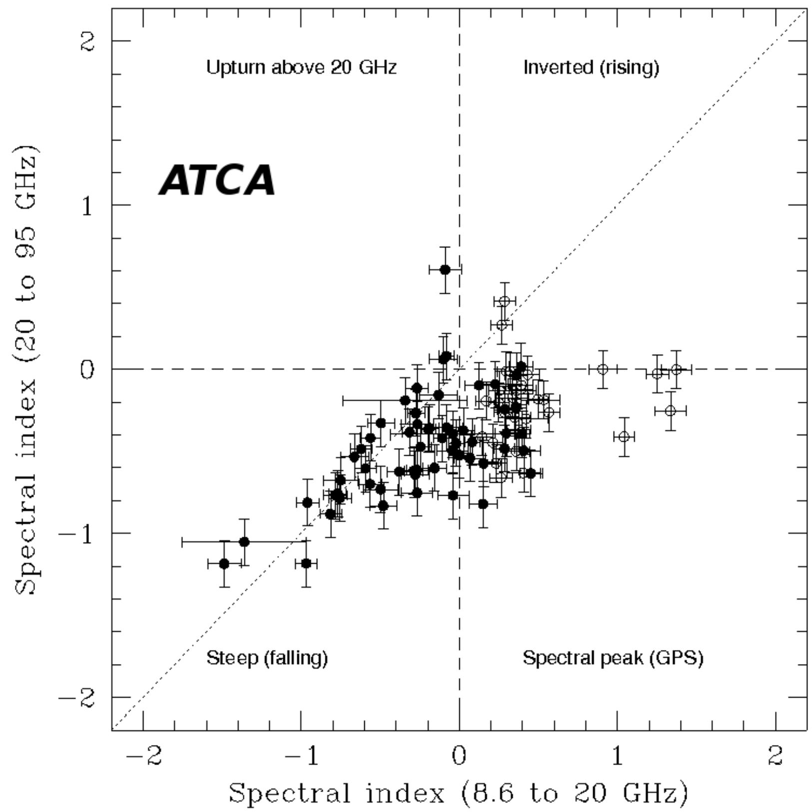
$$S(\nu) = \begin{cases} S(\nu_M)\,(\nu/\nu_M)^{\alpha_{fl}} & \text{if } \nu \le \nu_M \\ S(\nu_M)\,(\nu/\nu_M)^{\alpha_{st}} & \text{if } \nu \ge \nu_M \quad \alpha_{st} = -0.8 \pm 0.2 \end{cases}$$



Planck early results XV



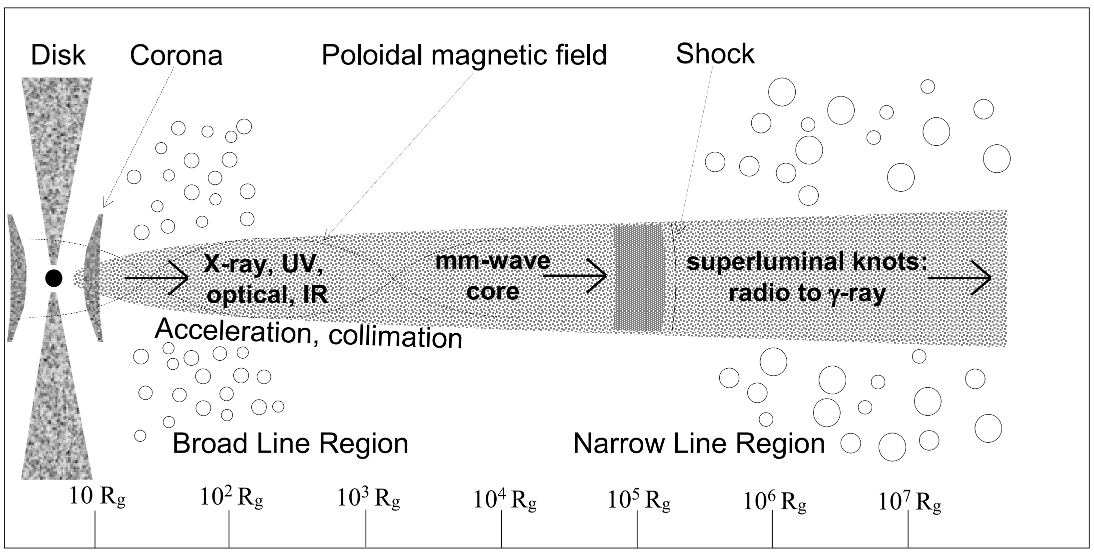
Massardi et al. 2010



Model of synchrotron emission from inhomogeneous relativistic jet

(Blandford&Konigl 1979; Marscher&Gear 1985; Valtaoja et al. 1992)

Flat spectra result from the **superposition of different components** of the inner parts of AGN relativistic jets (typically at 10^4–$10^5\ R_g$ from central AGN core), each with different self–absorption frequency.



$10^4\ R_g \sim 1\,\text{pc}$ for a Black Hole with 10^9 solar mass.

Two characteristic frequencies:

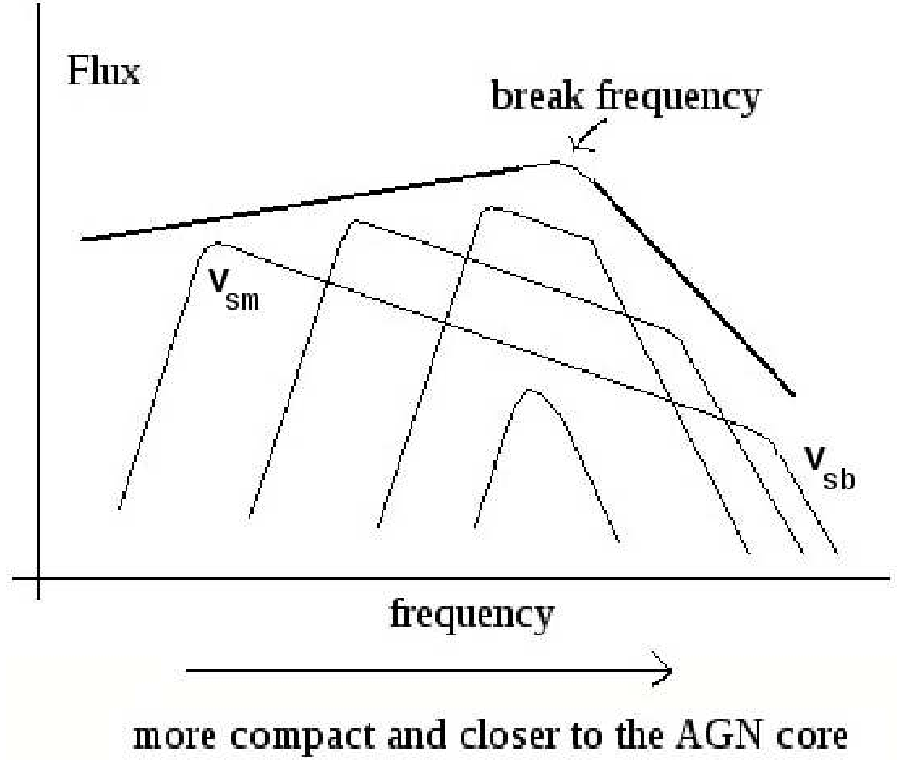
ν_{sm}

maximum in synchrotron spectrum

$$\nu_{sm} \propto r^{-1}$$

ν_{sb}

cutoff in the electrons energy distribution due to cooling ($\nu_{sb} \propto r$) (cooling time $\sim$ reacceleration time). Above this frequency spectra steepen.



There is a **radius** r_M at which $\nu_{sm} = \nu_{sb}$ (ν_M): the smallest radius from which self–absorbed synchrotron emission from the jet can be observed.

$\Longrightarrow$ **At** $\nu \geq \nu_M$**, jet emission dominated by optically–thin synchrotron from** $r \geq r_M$.

How to estimate of the Break Frequency

Homogeneous spherical model for a single emitting region

$$\nu_M \propto S_M^{2/5}\,\theta^{-4/5}\,H^{1/5}\,(1+z)^{1/5}\,\delta^{-1/5} \qquad\qquad \theta \simeq 2\frac{(1+z)^2}{D_L}\,r_M\,\phi$$

If we assume:

- Equipartition condition for magnetic and electron energy density
- $S_M = S_5(\nu_M/5)^{\alpha_{fl}}$
- power–law energy distribution $n_e(\gamma) = K\gamma^{2\alpha-1}$

the break frequency ν_M **is a function only of the parameters**: r_M, δ, z and of spectral indices (α_{fl}, α):

$$\nu_M \approx C(\alpha,\,\alpha_{fl})\,D_L\,(1+z)^{-1.5}\,\delta^{-0.5}\,r_M^{-1}$$

The key parameter is r_M: it defines the compactness of the emitting region at the ν_M frequency.

- (**C1**) $0.01 \leq r_M \leq 10\,\mathrm{pc}$
- stronger constraints:

BL Lacs

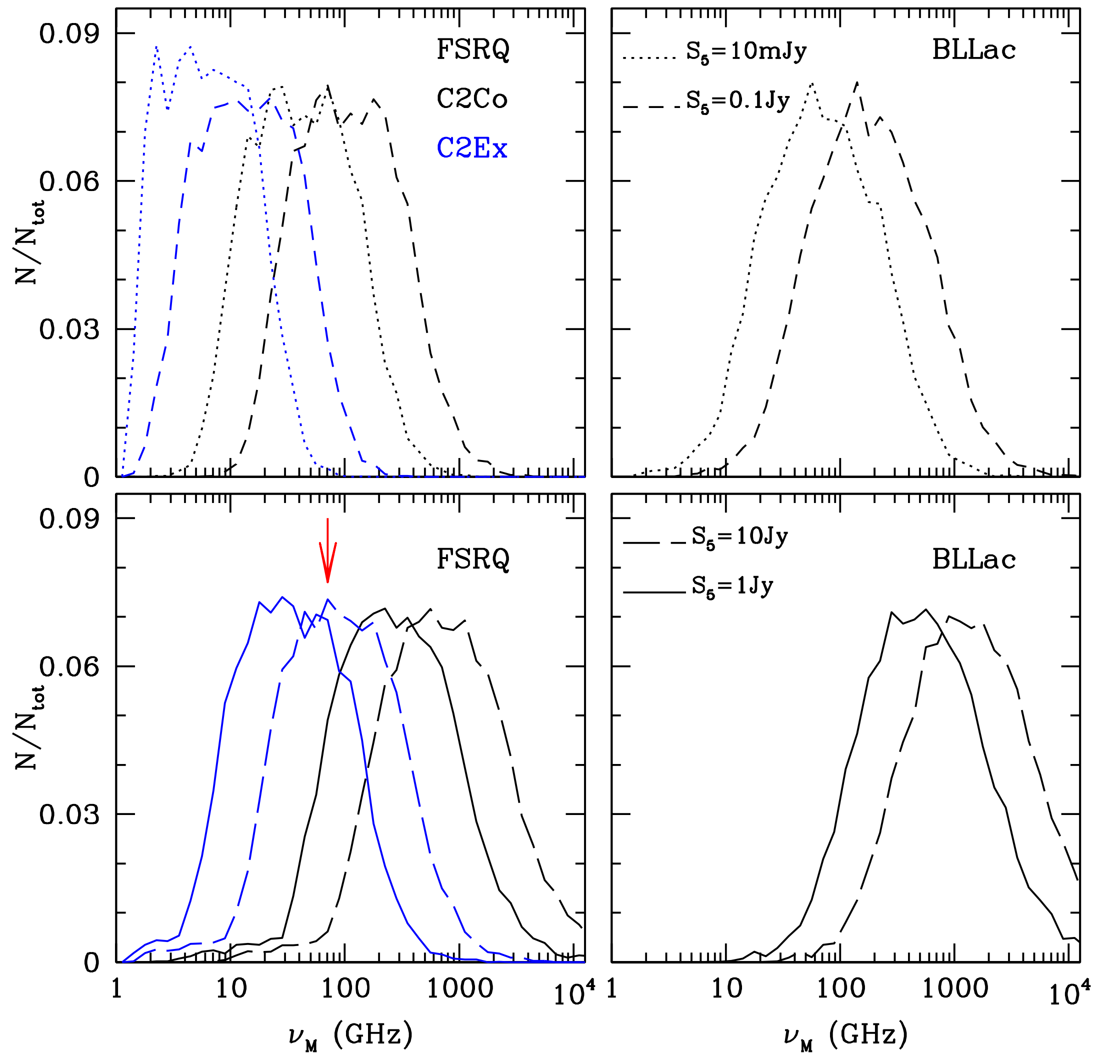
$$0.01 \leq r_M \leq 0.3\,\mathrm{pc}$$

FSRQ

(**C2Co**) $0.03 \leq r_M \leq 1\,\mathrm{pc}$

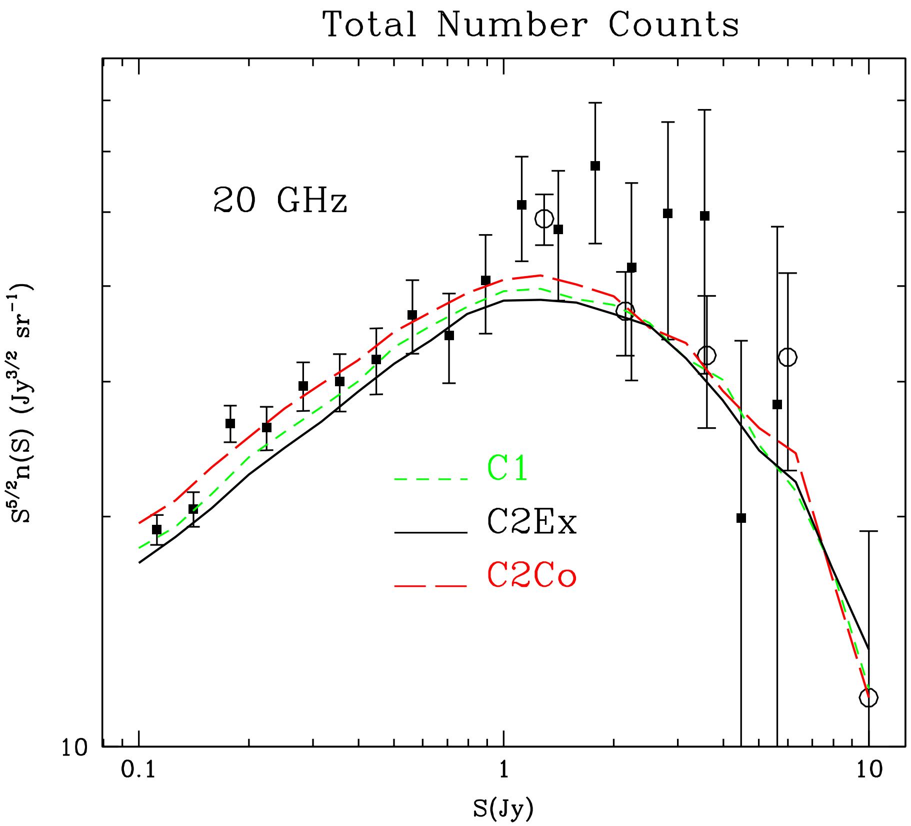
(**C2Ex**) $0.3 \leq r_M \leq 10\,\mathrm{pc}$

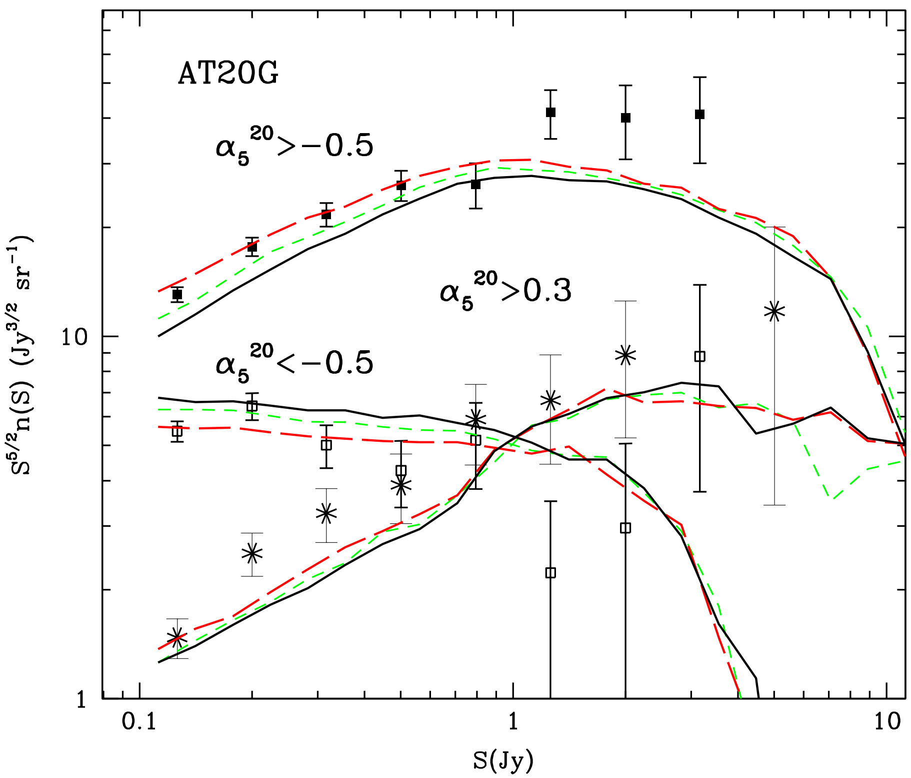
BL Lacs characterized by lower intrinsic power and by a weaker external radiation field $\Longrightarrow$ we expect **cooling less dramatic and more compact objects**.

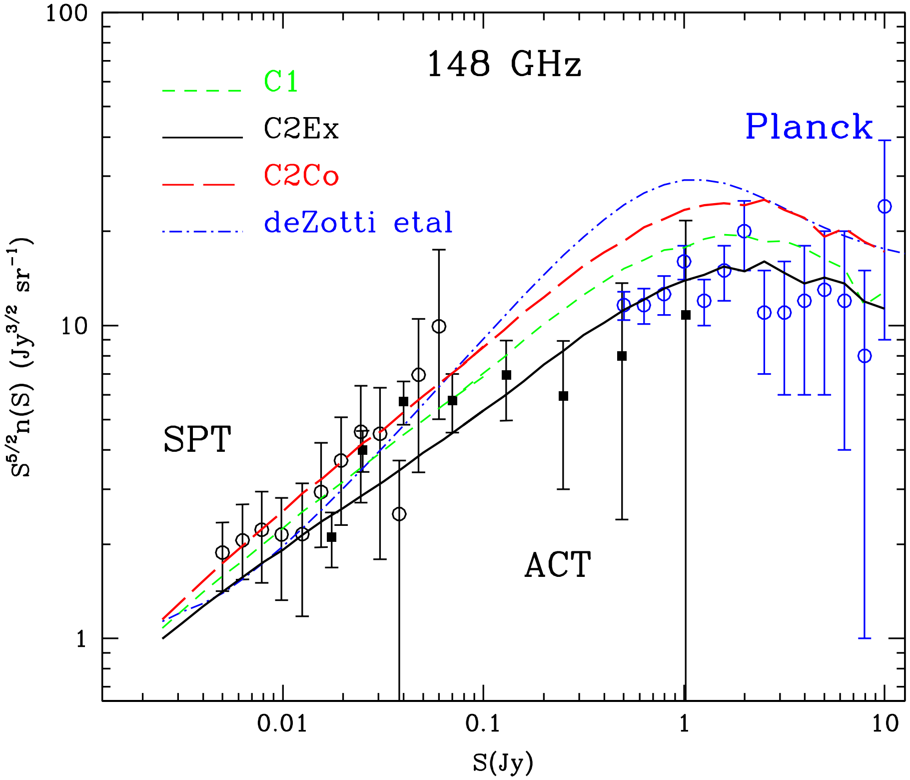


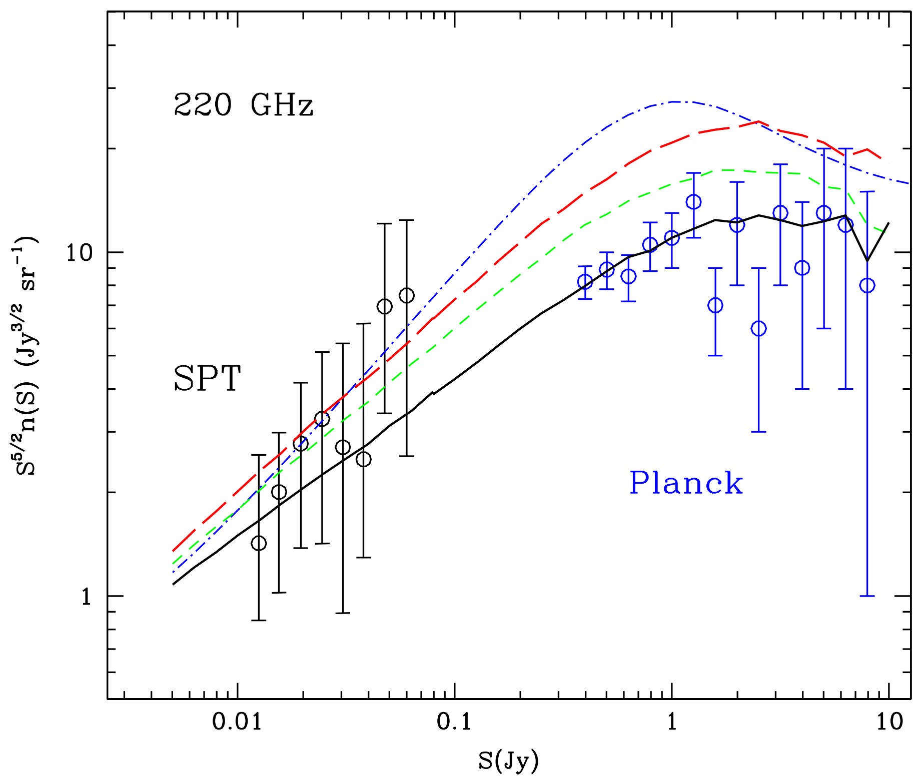
Model predictions vs observations

Number counts at 20 GHz from ATCA and WMAP







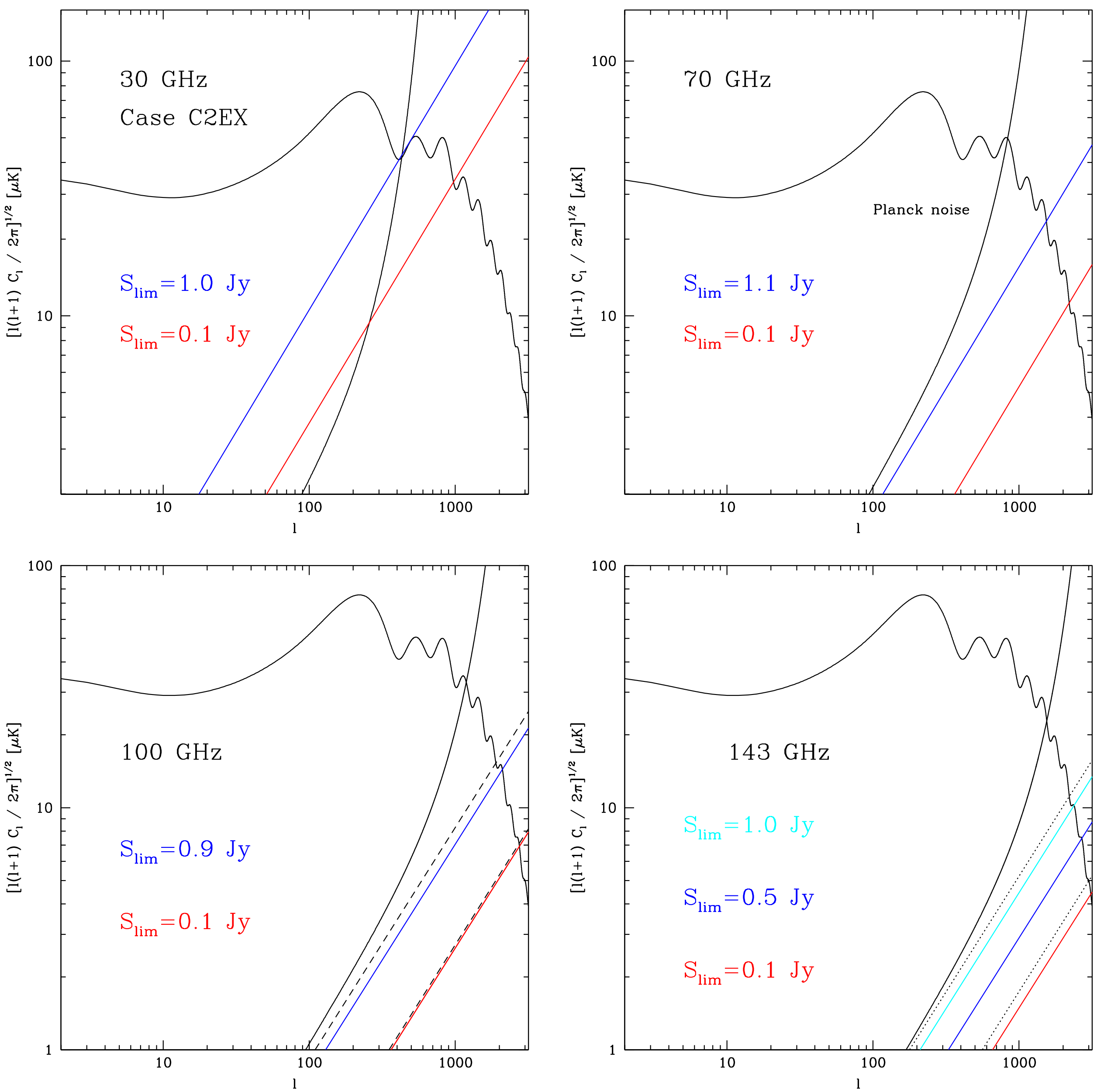


$\Longrightarrow$ **Best model (C2Ex)**: BL Lacs more compact than FSRQs. Break frequency is typically

$$10 \lesssim \nu_M \lesssim 100\,\mathrm{GHz} \text{ for FSRQs}$$
$$\nu_M \gtrsim 100\,\mathrm{GHz} \text{ for BL Lacs}$$

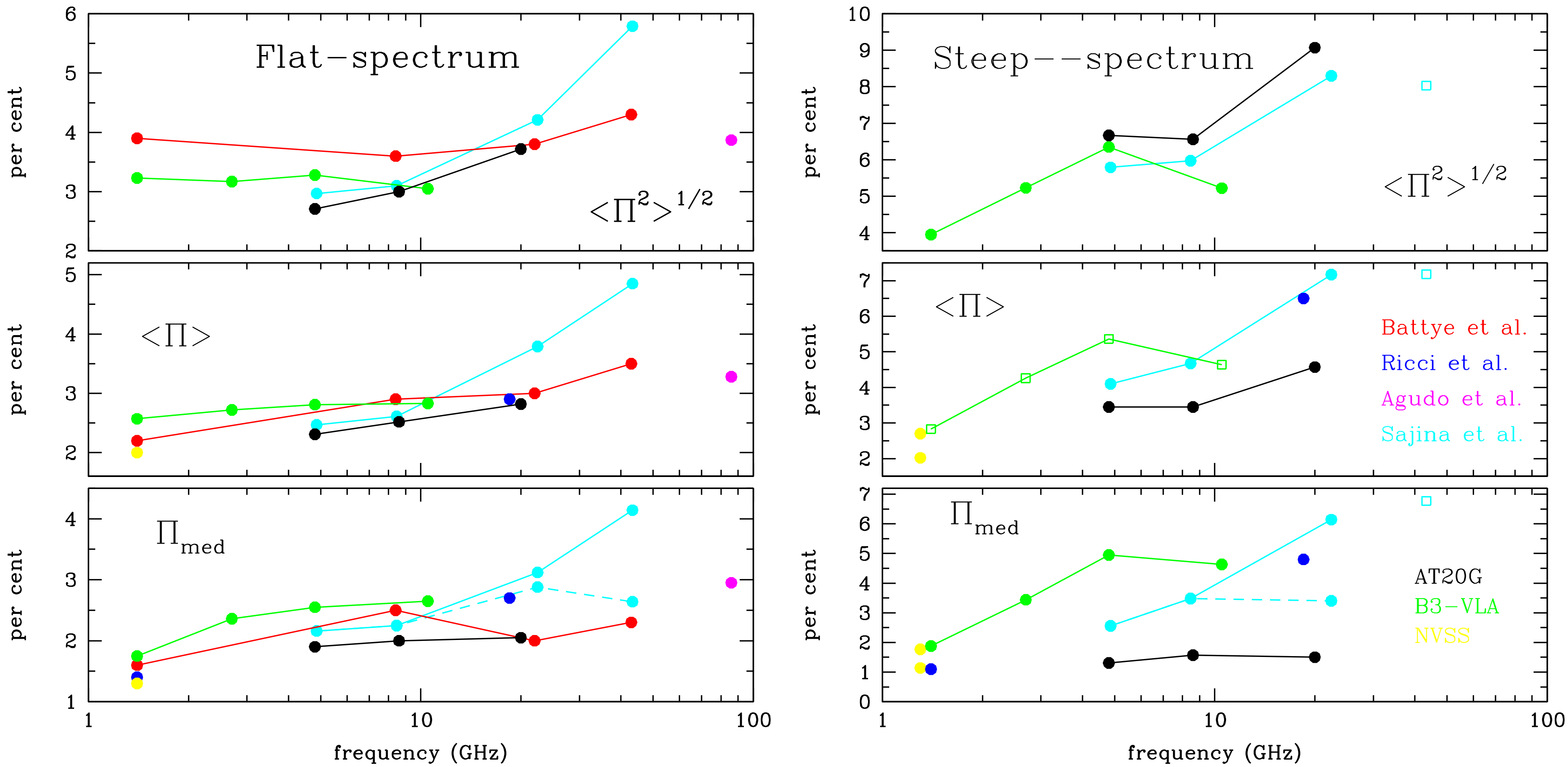
- **good agreement** with 353, 545 GHz *Planck* counts (see talk by H.Dole)

ERS vs CMB Power Spectrum

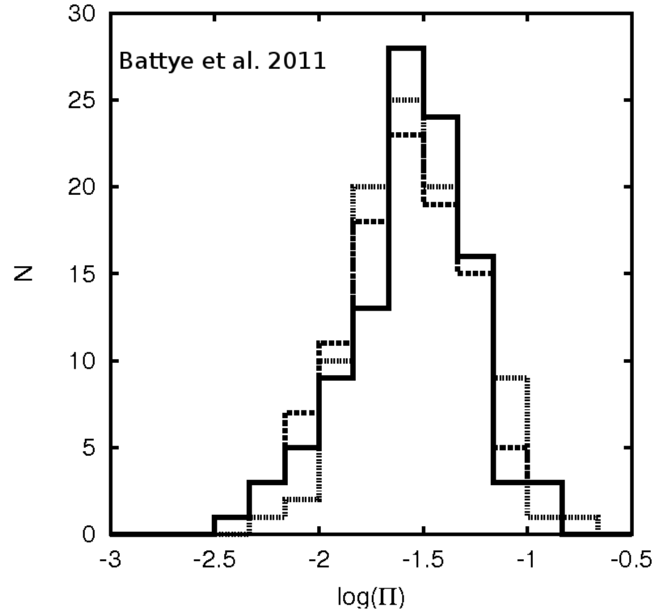


Polarization properties of ERS

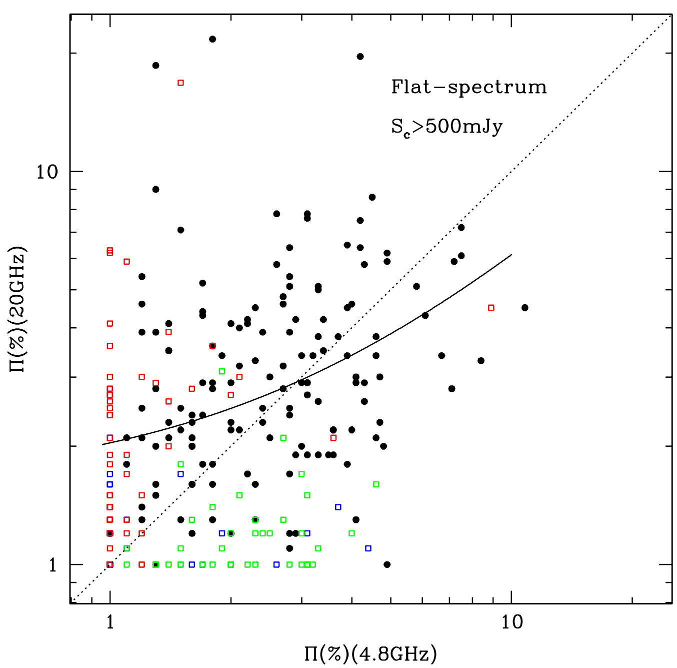
(MT & L.Toffolatti, Submitted to Advances in Astronomy)

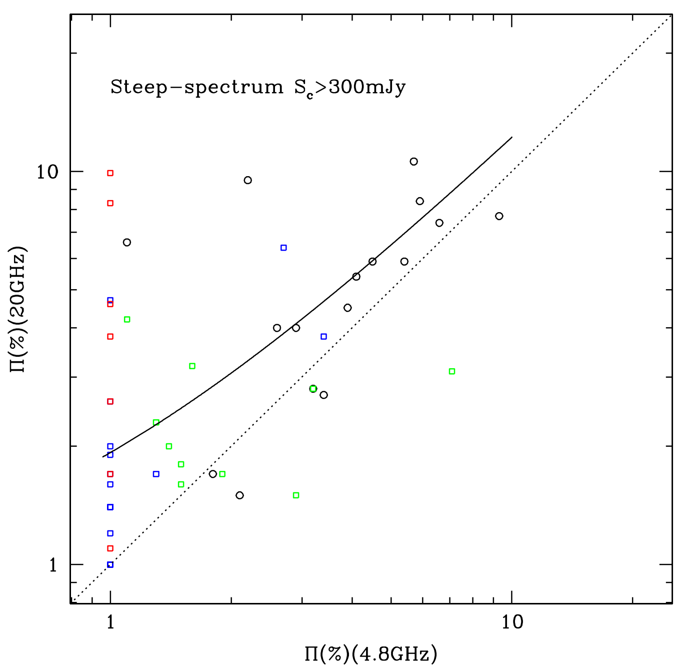


Histogram of Π at 8.4, 22 and 43 GHz of WMAP sources



Correlation between $\Pi(4.8GHz)$ and $\Pi(20GHz)$ for AT20G sources

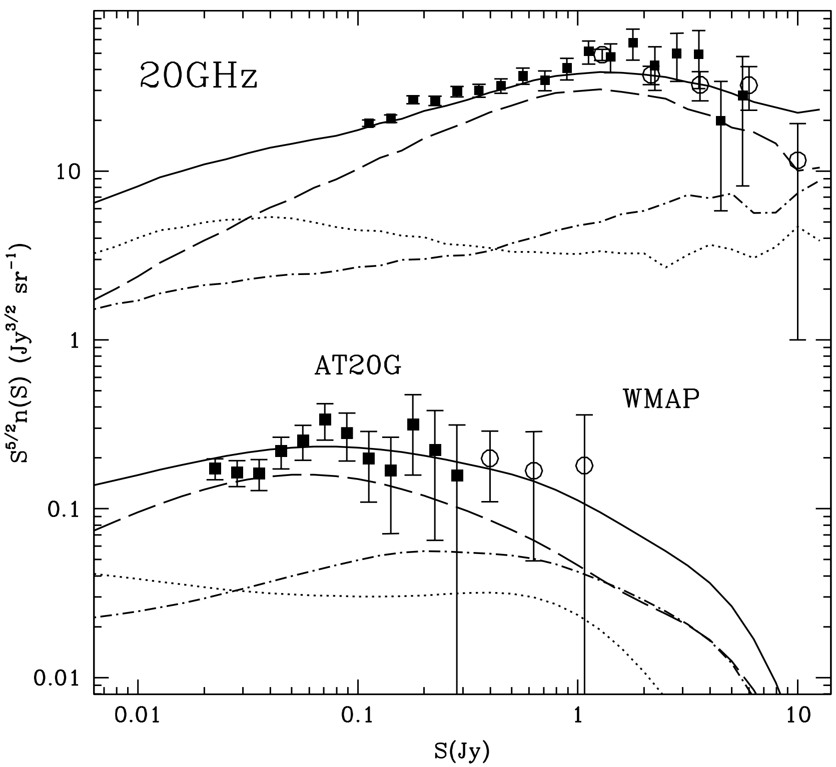


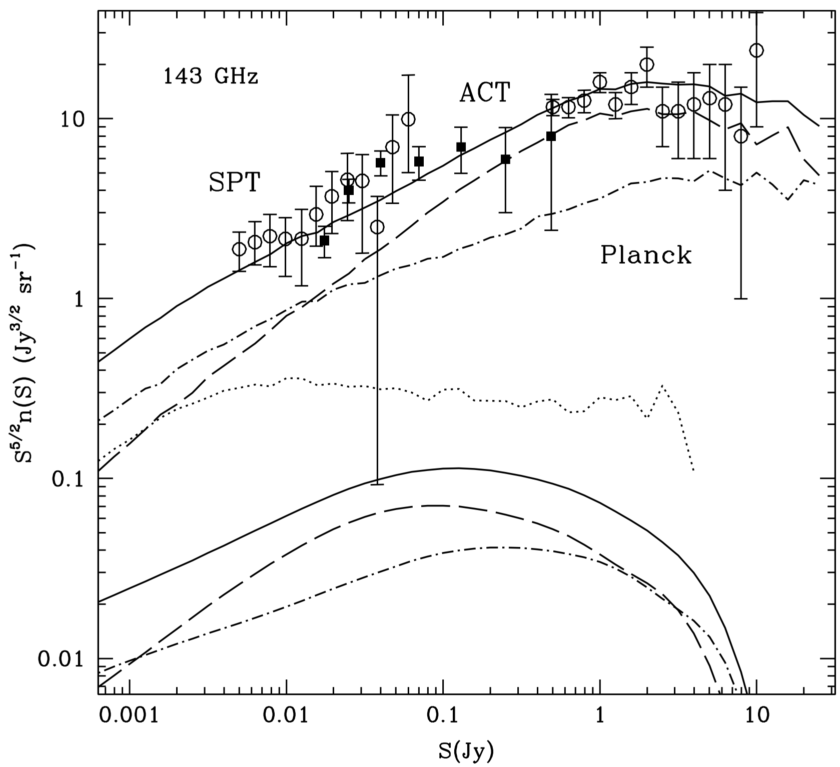


Number counts of polarized ERS

$\mathcal{P}(\Pi)$ modelled by a **log–normal distribution**:

		steep	FSRQ	BL Lac
Π_{med}	$=$	0.050	0.028	0.036
$\langle \Pi^2 \rangle^{1/2}$	$=$	0.070	0.038	0.045



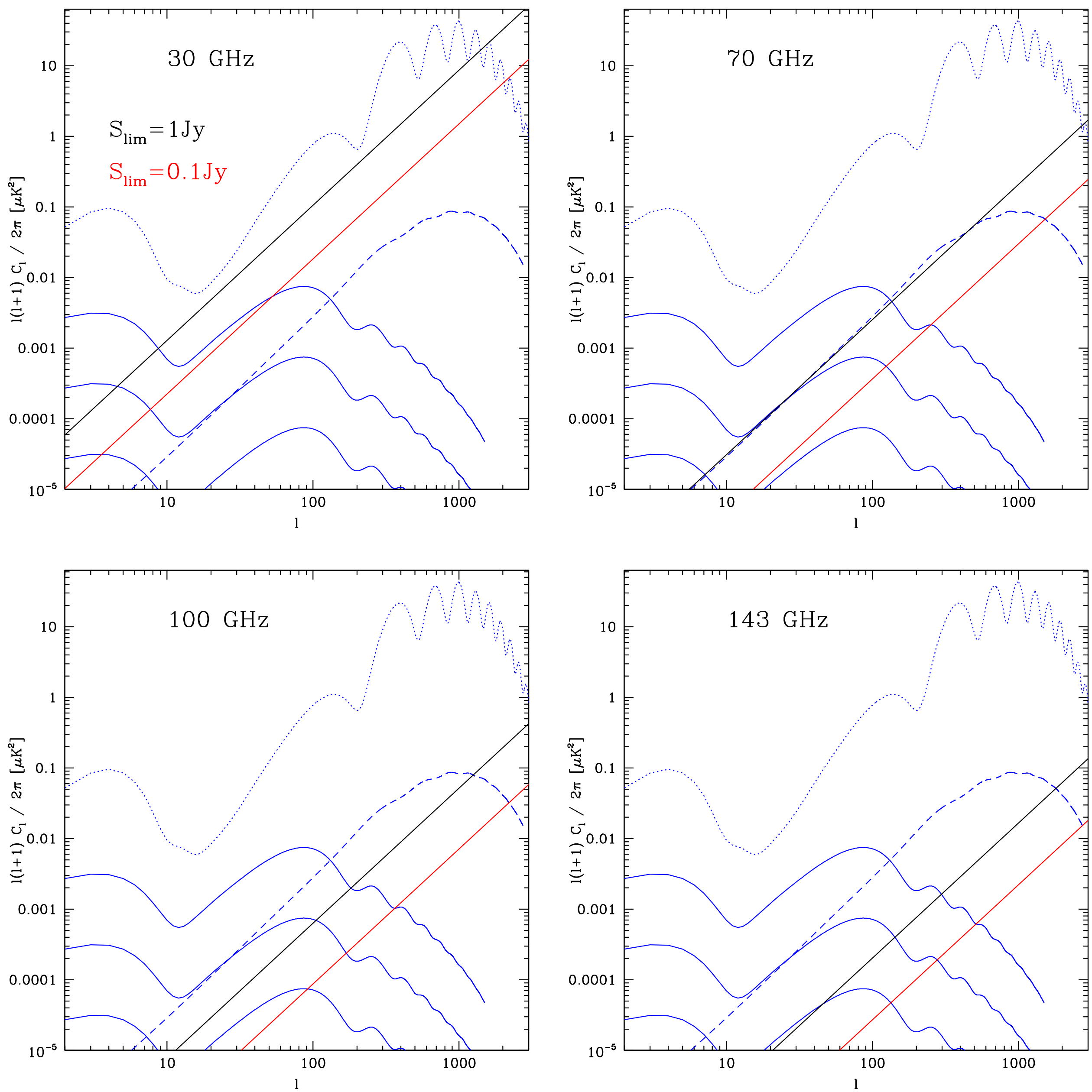


Integrated number counts of polarized sources

We expect **Planck** to be able to detect polarized sources (at a confidence level $\geq 95\%$) down to: $\sim$0.2 Jy at 30 GHz; $\lesssim$ 0.4 mJy at 44–70 GHz; something better at HFI frequencies.

P_{lim}	ν [GHz]						
[mJy]	30	44	70	100	143	217	353
80	78	66	54	47	40	34	28
100	54	46	38	**33**	**28**	**24**	**20**
200	**16**	**14**	**11**	**10**	**9**	**8**	**7**
400	4	**4**	**3**	3	3	3	2
WMAP	8	6	4	(# detected, $P_{lim} \sim 0.3$ Jy)			

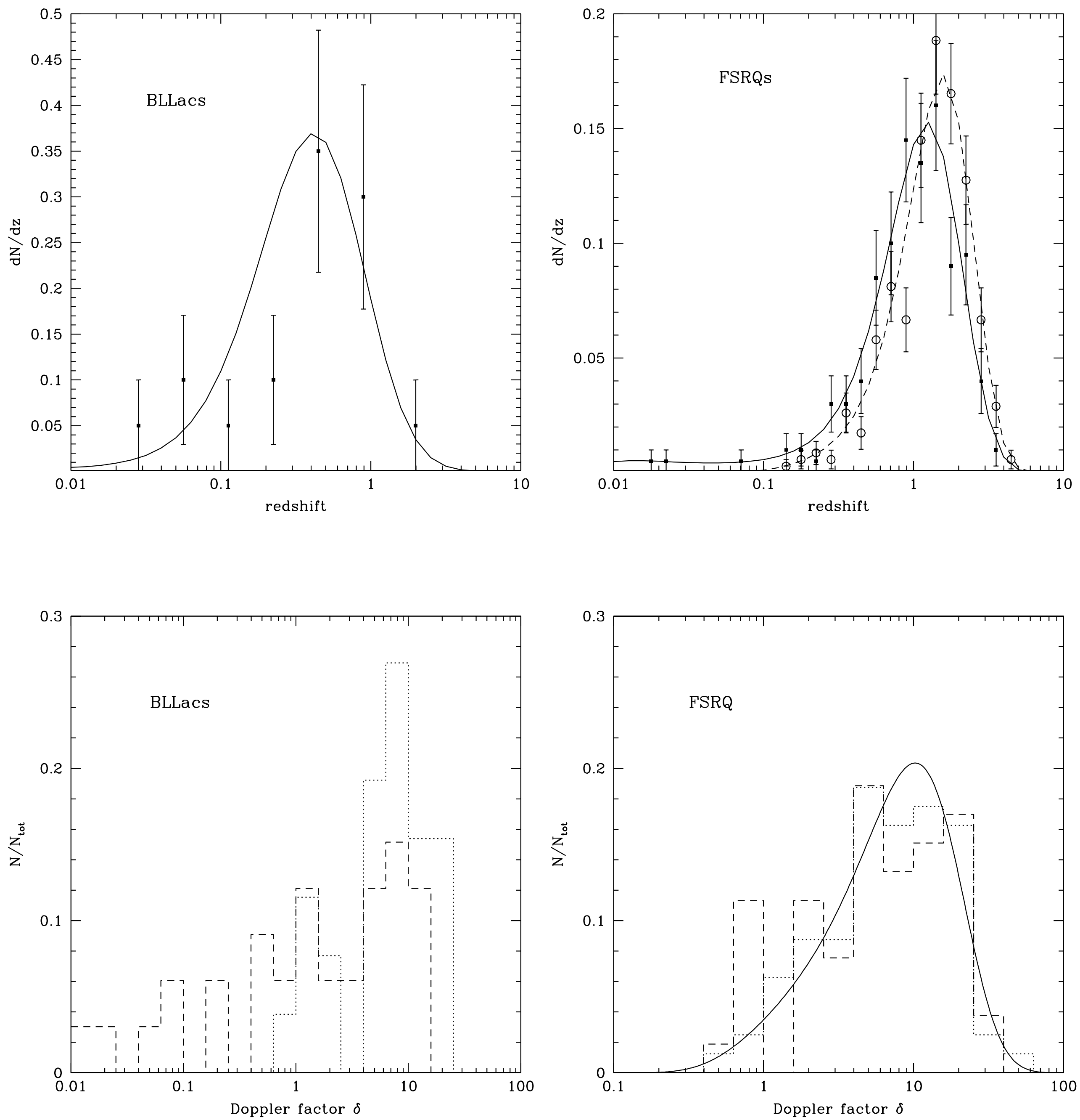
Polarization Power Spectra ($C_{E,B\ell} = 1/2 \langle \Pi^2 \rangle C_{T\ell}$)



Conclusions

- A first attempt to predict high–frequency counts of ERS using physically grounded recipes to describe spectra of blazars.
- Our best model provides estimates of the break frequency in blazar spectra, well in agreement with observations: ν_M **is typically between 10 and 100 GHz for FSRQs and** $\gtrsim 100$ **GHz for BL Lacs**.
- These results imply that r_M **is of parsec–scales**, at least for FSRQs. Values of $r_M \ll 1$ pc should be only typical for BL Lacs but rare for quasars.
- For *Planck*, ERS are not a strong contaminant for **CMB T, E power spectra** (enough removing or masking ERS with $S_{lim} \geq 1.0$ Jy).
- In **polarization**, we expect that *Planck* detect **dozen** (LFI channels) and maybe **few tens** (HFI channels) of ERS.
- ERS could be an important constraint for the detection of the cosmological **B–mode** if $r < 0.01$.

Redshift and Doppler factor for FSRQs and BL Lacs



Spectral properties of ERS

ν[GHz]	[5, 20]	[20, 148]	[5, 148]	[148, 220]
	ACT (median $\pm\sigma$)		SPT (mean $\pm\sigma$)	
	-0.07 ± 0.37	-0.39 ± 0.24	-0.13 ± 0.21	-0.50
model	ACT simulated sample		SPT simulated sample	
C2Co	-0.09 ± 0.31	-0.21 ± 0.28	-0.14 ± 0.30	-0.36 ± 0.39
C2Ex	**-0.09 ± 0.36**	**-0.35 ± 0.31**	**-0.22 ± 0.33**	**-0.50 ± 0.37**

ν[GHz]	44	70	100	143	217
median					
Planck	-0.06	-0.18	-0.28	-0.39	-0.37
C2Co	-0.13	-0.17	-0.19	-0.21	-0.24
C2Ex	**-0.22**	**-0.28**	**-0.34**	**-0.39**	**-0.44**