A new model for the cosmological evolution of low frequency extragalactic radio sources

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Abstract. We present a new evolutionary model for the population properties of radio sources at frequencies <5 GHz, thus complementing the De Zotti et al. (2005) model, holding at higher frequencies. We find that simple analytic luminosity evolution is still sufficient to fit the wealth of available data on local luminosity functions, multi-frequency source counts, and redshift distributions. However, the fit requires a luminosity-dependent decline of source luminosities at high redshifts, at least for steep-spectrum sources, thus confirming earlier indications of a "downsizing" also for radio sources. The upturn of source counts at sub-mJy levels is accounted for by a straightforward extrapolation, using the empirical far-IR/radio correlation, of evolutionary models matching the far-IR counts and redshift distributions of star-forming galaxies. We also discuss the implications for source counts and populations for surveys to be performed with SKA and its pathfinders.

Reasons for a new model

The still most widely used evolutionary models for radio sources at ν < 5 GHz date back to the 1990's (Dunlop & Peacock1990; Toffolatti et al.1998). Although these models proved to be very useful benchmarks even today, *several of their building blocks need to be updated*, starting from the underlying cosmology.

Meanwhile, *large amounts of new data have been accumulating since then*, including new deep/large area surveys (see De Zotti et al. 2009 for a review and references), identifications of sub-mJy sources at 1.4GHz, accurate determinations of the local luminosity function, redshift distributions for complete samples.

Many key scientific issues in this field are still open. What is the nature of evolution? Is it luminosity dependent? Is there a clear evidence for a decline of the comoving space density of radio sources at high redshifts? Are flat- and steep- spectrum sources obeying the same evolution laws, as expected in the framework of 'unification'schemes? Which sources are responsible for the upturn of differential sourcecounts at sub-mJy levels?

For this reasons *we have parametrized the evolving luminosity functions of AGN-powered radio sources and fitted the model to a bunch of new datasets, looking for the overall best fit.*

Fig 2: Source counts

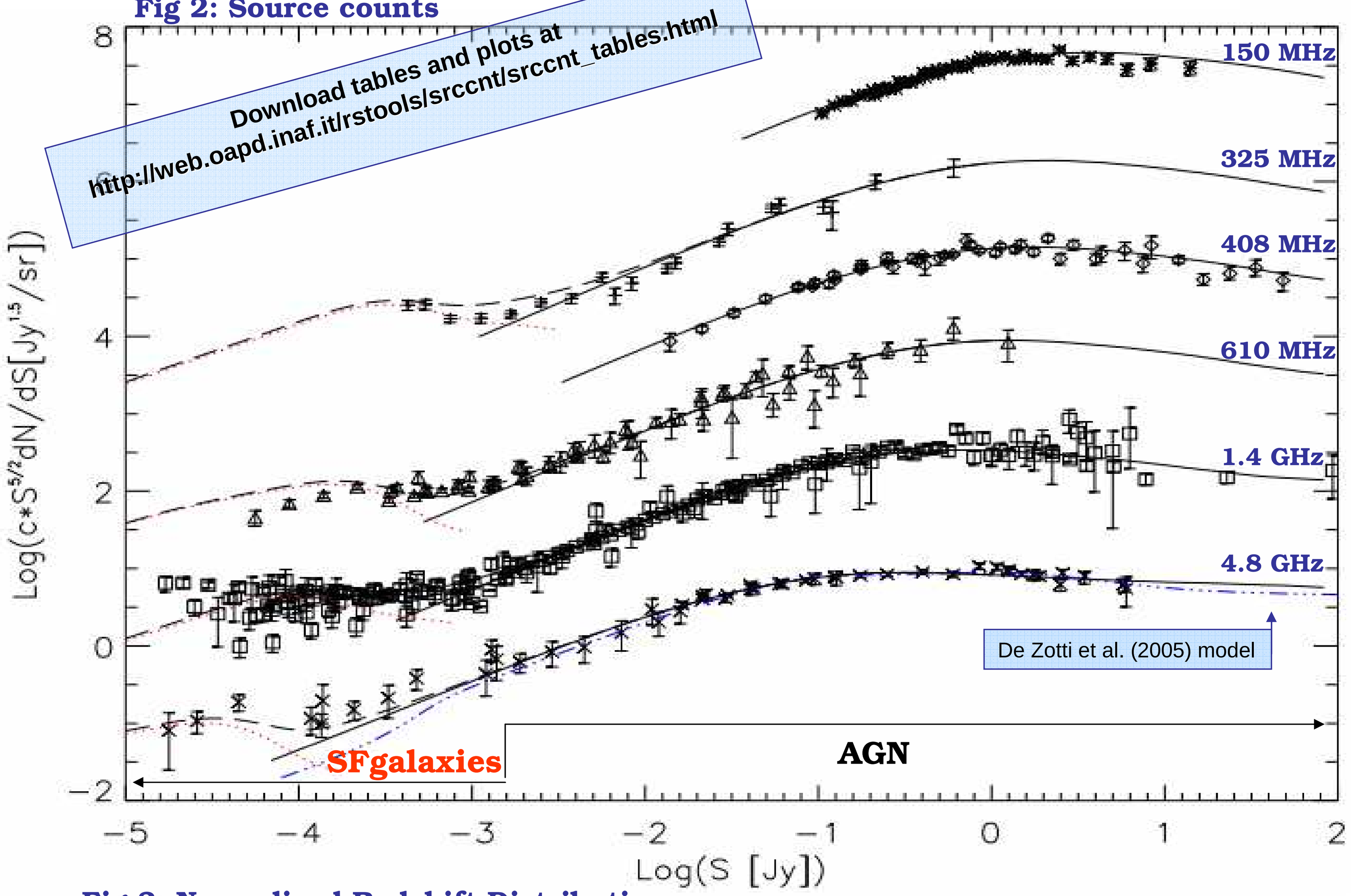


Fig.3: Normalized Redshift Distributions

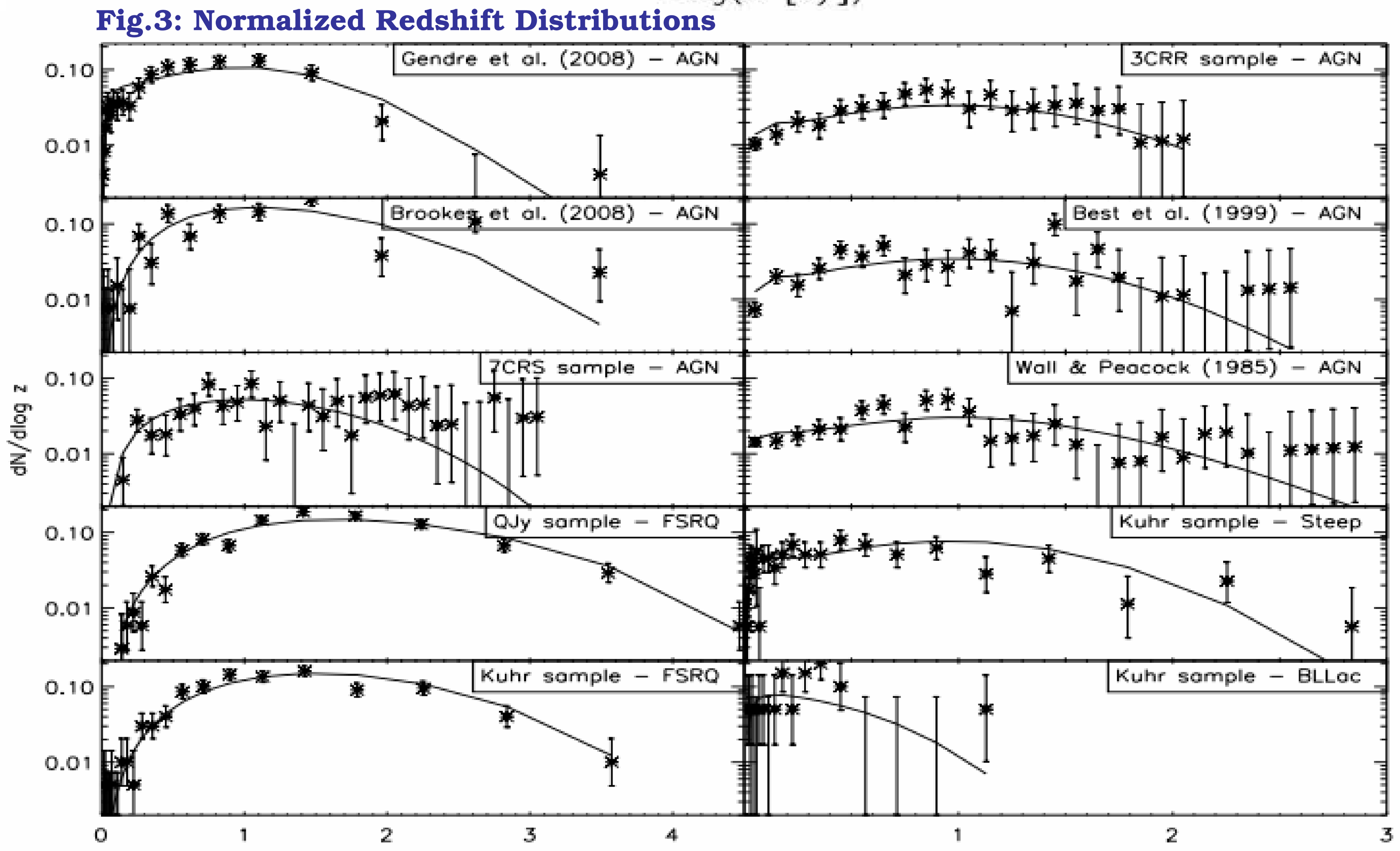
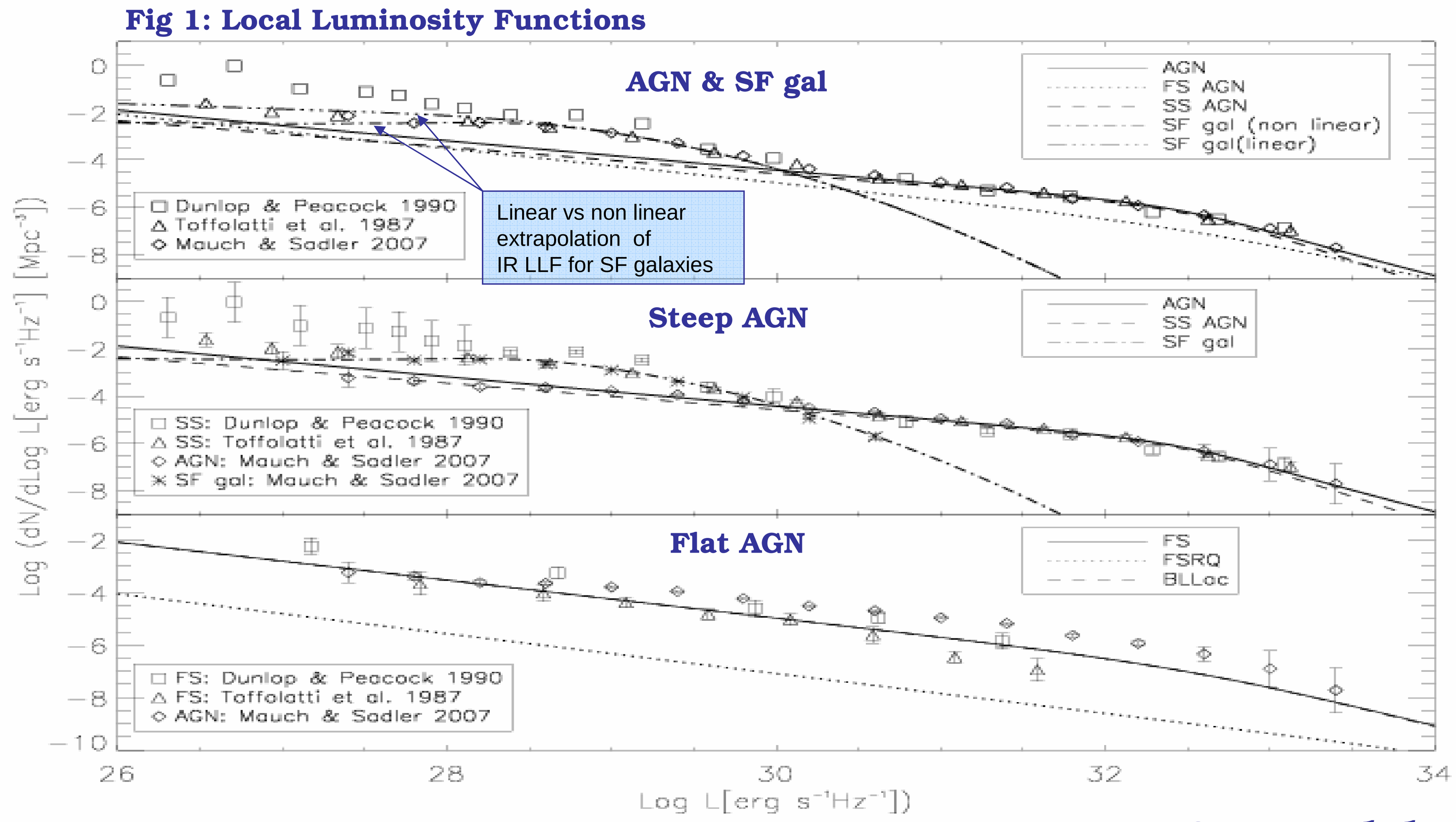


Fig 1: Local Luminosity Functions



Our model

Our model includes *two flat-spectrum populations with different evolutionary properties (FSRQs, and BLLacs) and a single steep-spectrum population*. For each population we adopt a simple power-law spectrum, $S \propto \nu^{\alpha}$,with $\alpha_{FSRQ} = \alpha_{BLLac} = 0.1$,and $\alpha_{steep} = 0.8$.

The epoch-dependent comoving luminosity functions is

$$\Phi(L,z) = \frac{n_0}{(L/L_\star)^a + (L/L_\star)^b}$$

Standard luminosity evolution models without a high-z decline of the comoving luminosity function, did not yield any acceptable fit to the data on steep-spectrum AGNs and on FSRQs. For these source populations *we have adopted a more complex luminosity evolution law for all the populations, allowing also the redshift cutoff to vary with L (similar to "downsizing") for FSRQs and steep spectrum objects*:

$$L_\star(z) = L_\star(0)\,\mathrm{dex}\left[k_{evo} z\left(2z_{top} - 2z^{m_{ev}} z_{top}^{(1-m_{ev})}/(1+m_{ev})\right)\right] \qquad |m_{ev}|<1$$

$$z_{top} = z_{top,0} + \frac{\delta z_{top}}{1 + L_\star(0)/L}.$$

We have simultaneously fitted all the datasets in Fig. 1, 2, 3 and minimized the sum of χ^2 obtaining the values of the parameter in the table.

The model fits local and non local luminosity functions, source counts between 0.15 and 5 GHz, and redshift distribuions.

Table 1: Model parameters

Parameters	FSRQ	BLLac	SS-AGNs
a	0.760	0.723	0.559
b	2.508	1.618	2.261
$\log n_0$	-10.382	-6.879	-5.970
$\log L_\star(0)$	34.323	32.638	32.490
k_{evo}	-0.996	0.208	1.226
$z_{top,0}$	1.882	1.282	0.977
δz_{top}	0.018	-	0.842
m_{ev}	-0.166	1	0.262

We found that: 1) *luminosity evolution is still sufficient to fit the wealth of available data on radio AGNs*; 2) the *fit requires a luminosity-dependent decline of space densities of steep-spectrum sources at high redshifts*, with positive evolution continuing up to higher redshifts for the more luminous sources confirming *indications of a "downsizing" also for radio sources; 3) data do not require a similar behaviour for FSRQs*; 4) the *redshift at which the evolution peaks is found to be substantially higher for FSRQs than for the lower luminosity BLLac objects*, again consistent with "downsizing".

The upturn of sourcecounts at sub-mJy levels is accounted for by a straightforward extrapolation, exploiting the well established correlation between far-IR and radio luminosities, of evolutionary models accounting for the far-IR counts and redshift distributions of star-forming galaxies. A comparison of radio and 60 μm local luminosity functions indicates deviations from a linear relation at low luminosities (upper panel of Fig. 1). A simple analytic expression describes the correlation over the full luminosity range:

$$L_{1.4\mathrm{GHz}} = \frac{1.16\times10^{-2} L_b}{(L_b/L_\nu(60\mu m))^{3.1} + L_b/L_\nu(60\mu m)} \qquad L_b = 8.8\times10^{29}\,\mathrm{erg\,s^{-1}\,Hz^{-1}}$$

The currently available surveys are not deep enough to provide an independent test of the deviations from linearity, but surveys with the SKA and its pathfinders will.

Radio Background and large area surveys

According to our model the directly counted sources already account for most of the extragalactic background intensity determined by means of the classical T–T plot method (Fig. 4). The dominant contribution comes from radio AGNs; the contribution of starforming galaxies is higher at the lowest frequencies where it reaches 39.5%.

The new model has been also used to interpret data on large-scale clustering of radio sources on the basis of the NVSS survey (Blake & Wall 2002).

Predictions for EMU

Table 2 (and Fig. 6) shows the contribution of the different populations to the total counts at 1.4 GHz. Below 0.4 mJy (see Fig. 7) the starforming population (including proto-spheroidal forming galaxies, starburst and early-type spiral galaxies) becomes the dominant population.

The AGN populations are dominated by steep-spectrum objects, which, at low flux levels are dominant up to high redshifts.

Fig 4: Radio Background

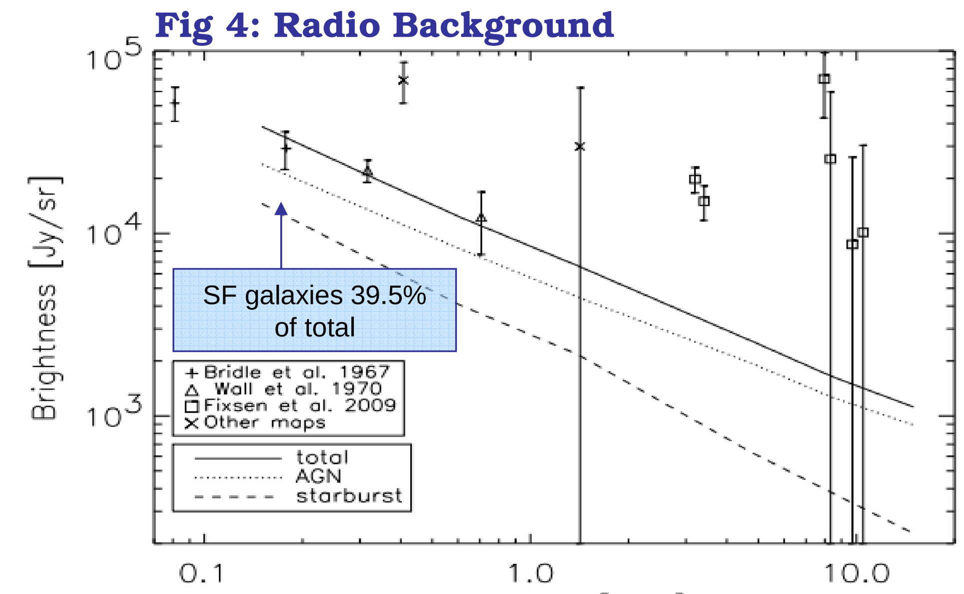


Fig 5: 1.4 GHz 2-point correlation function

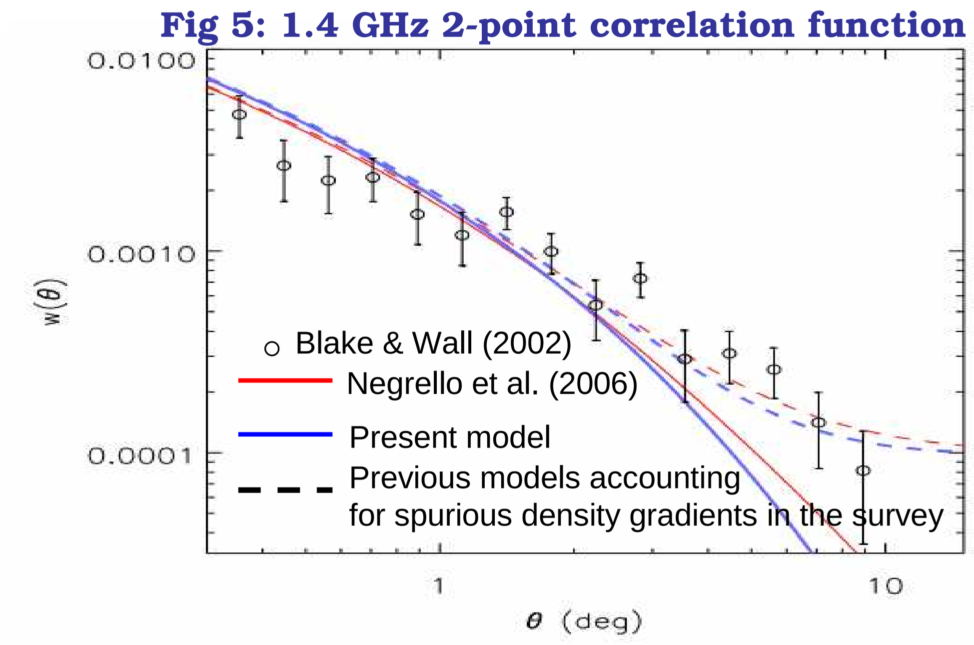


Fig 6: 1.4 GHz redshift distribution and source counts for AGNs

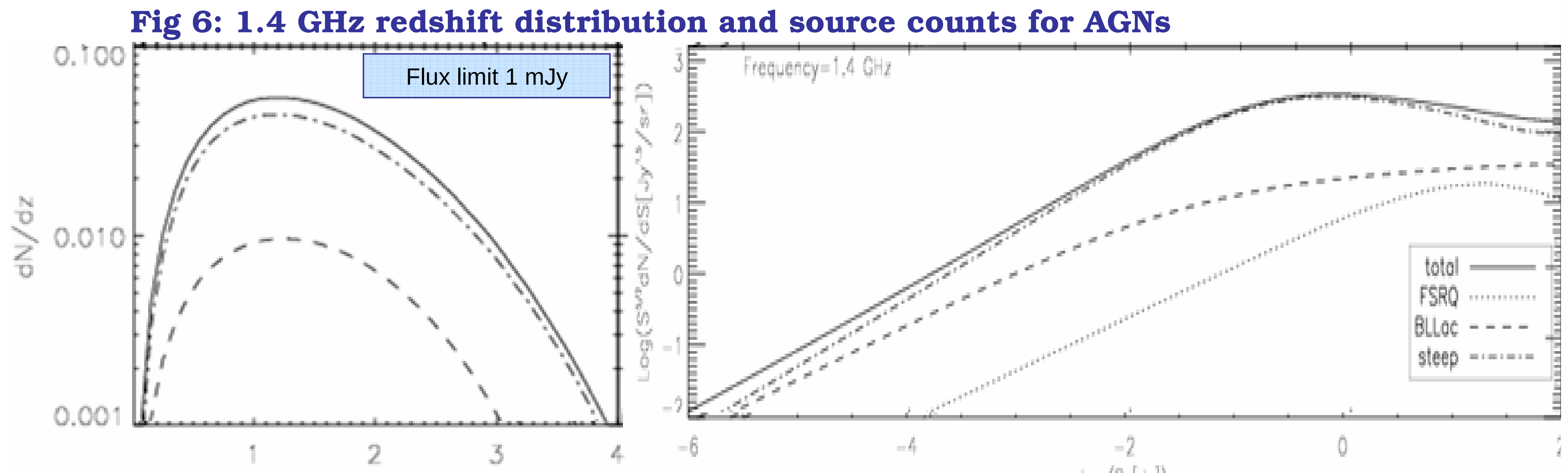


Fig 7: Faint-end of the 1.4 GHz source counts

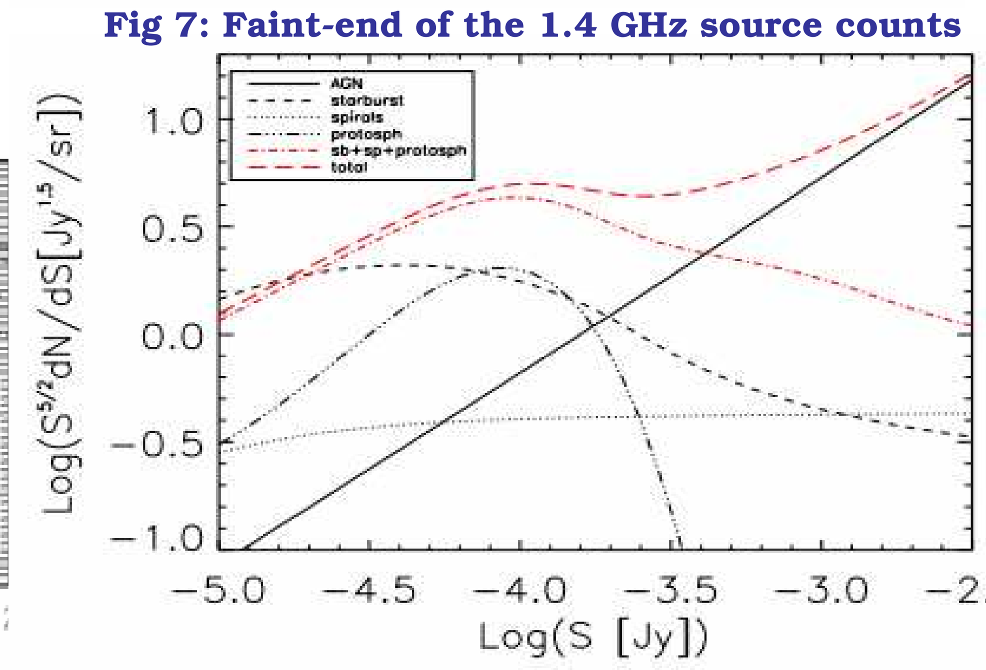


Table 2: 1.4 GHz population fractions

Flux limit	10 μJy	50 μJy	400 μJy
AGN total	3%	6%	50%
AGN flat (FSRQ+BLLac)	1+32%	1+28%	1+18%
AGN steep	67%	71%	81%
SF galaxies	23%	16%	6%
Protospheroids	74%	78%	44%

For further details and a complete list of references see Massardi et al. (2010), accepted for publication on MNRAS (arXiv:1001.1069)