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Polarization properties of extragalactic radio sources and their contribution to microwave polarization fluctuations

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Abstract. We investigate the statistical properties of the polarized emission of extragalactic radio sources and estimate their contribution to the power spectrum of polarization fluctuations in the microwave region. The basic ingredients of our analysis are the NVSS polarization data, the multifrequency study of polarization properties of the B3-VLA sample (Mack et al. 2002) which has allowed us to quantify Faraday depolarization effects, and the 15 GHz survey by Taylor et al. (2001), which has provided strong constraints on the high-frequency spectral indices of sources. The polarization degree of both steep- and flat-spectrum sources at 1.4 GHz is found to be anti-correlated with the flux density. The median polarization degree at 1.4 GHz of both steep- and flat-spectrum sources brighter than $S(1.4\,\mathrm{GHz}) = 80$ mJy is $\simeq$2.2%. The data by Mack et al. (2002) indicate a substantial mean Faraday depolarization at 1.4 GHz for steep spectrum sources, while the depolarization is undetermined for most flat/inverted-spectrum sources. Exploiting this complex of information we have estimated the power spectrum of polarization fluctuations due to extragalactic radio sources at microwave frequencies. We confirm that extragalactic sources are expected to be the main contaminant of Cosmic Microwave Background (CMB) polarization maps on small angular scales. At frequencies <30 GHz the amplitude of their power spectrum is expected to be comparable to that of the *E*-mode of the CMB. At higher frequencies, however, the CMB dominates.

Key words. radio continuum: galaxies – polarization – cosmic microwave background

1. Introduction

Polarization measurements provide crucial information on the physics of radio sources. At high enough frequencies for Faraday rotation to be negligible we can reliably assume that the magnetic field direction lies perpendicular to the observed polarization position angle. On the other hand, determinations of the Faraday rotation measures (*RM*s) are informative on the magneto-ionic properties of the medium embedding the emitting region or along its line-of sight.

Another very important use of polarization measurements of large samples of radio sources is to quantify the contamination by these sources of polarization maps of the Cosmic Microwave Background (CMB). The astonishing advances in our understanding of the basic properties of the Universe and in precision determinations of its fundamental parameters made possible by the recent accurate measurements of acoustic peaks of the Cosmic Microwave Background (CMB) anisotropy power spectrum by the TOCO (Miller et al. 1999), BOOMERanG (de Bernardis et al. 2002), MAXIMA (Lee et al. 2001), DASI (Halverson et al. 2002), and CBI (Pearson et al. 2002) experiments, have put further impetus in experimental efforts to exploit the extraordinary wealth of cosmological information carried by the CMB.

A Gaussian CMB fluctuation field is fully characterized by four power spectra, C_ℓ^{TT}, C_ℓ^{EE}, C_ℓ^{BB}, C_ℓ^{TE}, where T stands for "temperature", while E and B are rotationally invariant fields, which are linear, but non-local, combinations of the Stokes parameters Q and U (Seljak 1997; Kamionkowski et al. 1997; Zaldarriaga & Seljak 1997). It is then clear that polarization measurements are crucial to fully exploit the CMB information content. In particular, detection of CMB polarization is

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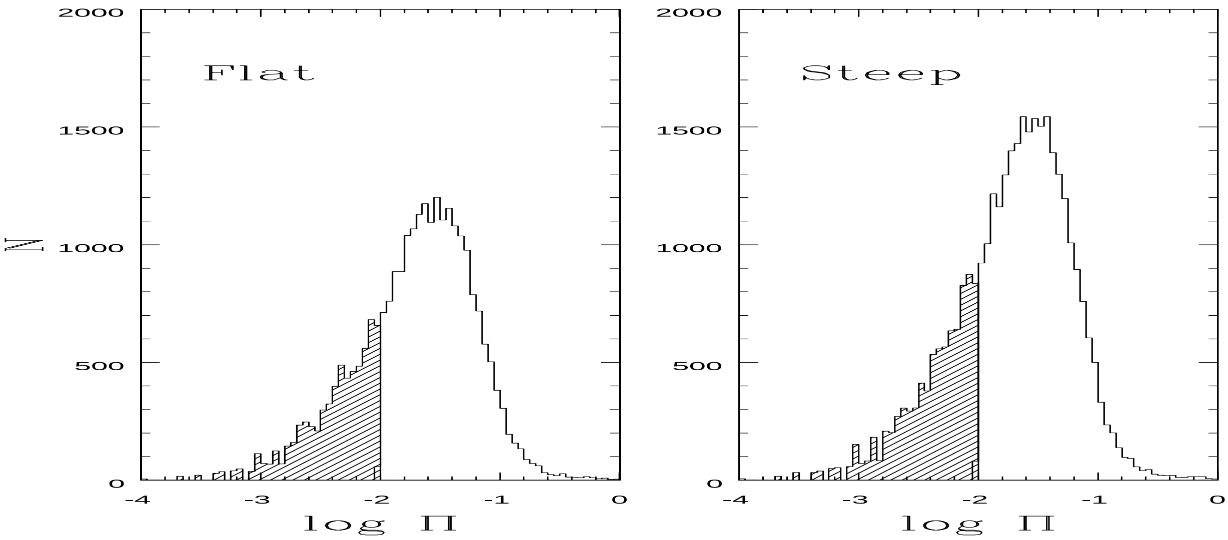

Fig. 1. Polarization degree distributions of flat/inverted- (left) and steep-spectrum (right) NVSS sources brighter than 80 mJy. The hatched areas correspond to values seriously contaminated by instrumental polarization (see text). The median polarization degree is 2.2%, for both populations.

critical for tests of Planck-scale physics (Hu & White 1997; Kamionkowski & Kosowski 1999; Hu & Dodelson 2002). This has motivated experimental efforts by many groups (see Staggs et al. 1999; Cecchini et al. 2002; De Zotti 2002). Although these measurements are very challenging because of the weakness of the expected signal (at, or below, several μK level), recent upper limits (Hedman et al. 2001; Keating et al. 2001) have already got close to it, and a detection may be achieved in the next few years.

It is not yet clear, however, whether the ultimate limit to our ability of measuring the CMB polarization will be set by detector sensitivity or by foregrounds, because the latter are still very poorly understood. On small angular scales, foreground intensity fluctuations at cm and mm wavelengths are dominated by extragalactic radio sources (Toffolatti et al. 1998, 1999), which are significantly polarized and are therefore expected to dominate also foreground polarization fluctuations up to at least ~100 GHz. Preliminary investigations have been carried out by Sahzin & Korölev (1985) and De Zotti et al. (1999). These works assumed a constant mean polarization degree for all classes of radio sources (estimated from rather small samples), a Poisson space distribution, and adopted mean values of the spectral indices to extrapolate to high frequencies.

The NRAO VLA Sky Survey (NVSS, Condon et al. 1998), covering ≃82% of the sky to a flux density limit of ≃2.5 mJy at 1.4 GHz and containing data on Stokes I, U, and Q parameters for almost 2×10^6 sources, has provided an extensive data base for a statistical investigation of the polarization properties of extragalactic sources. Important complementary information comes from the multifrequency study of over 100 sources drawn from the B3-VLA sample (Mack et al. 2002), which allows us to get insight into the effect of Faraday depolarization, which strongly affects polarization measurements at 1.4 GHz. Our analysis is presented in Sect. 2. The data by Condon et al. (1998) and Mack et al. (2002) also allow us to considerably improve on the available estimates of polarization fluctuations due to extragalactic sources in the microwave region. The new analysis, presented in Sect. 3, exploits the real space distribution of NVSS sources, which covers the flux density range relevant for CMB experiments, the true 1.4–5.85 GHz spectral index distribution of sources, obtained combining NVSS and GB6 (Gregory et al. 1996) data, the polarization degree distribution at 1.4 GHz, and the correction for Faraday depolarization, based on the data by Mack et al. (2002). The new constraints on the high frequency spectral indices set by the 15 GHz survey by Taylor et al. (2001) are also taken into account. Our main conclusions are summarized and discussed in Sect. 4.

2. Polarization properties of extragalactic radio sources

The 1.4–4.85 GHz spectral indices α ($S_\nu \propto \nu^{-\alpha}$) of a complete sub-set of NVSS sources were obtained via a cross-correlation with the Green Bank 4.85 GHz catalogue (GB6, Gregory et al. 1996) covering 6.07 sr (48.3% of the sky) to a flux limit of $S_{4.85} = 18$ mJy and comprising 75, 162 sources[1]. The distribution of the polarization degree $\Pi = (U^2 + Q^2)^{1/2}/I$ at 1.4 GHz for a complete sub-sample of NVSS sources brighter than $S(1.4\,\mathrm{GHz}) = 80$ mJy is shown in Fig. 1 for steep- ($\alpha > 0.5$) and flat/inverted-spectrum ($\alpha \leq 0.5$) sources separately. Note that the the low–Π tail of the distribution is contaminated by the residual instrumental polarization which is estimated to be ~0.3% (Condon et al. 1998). For this reason, in investigating correlations, sources for which the NVSS catalog yields a polarization degree $\Pi \leq 1\%$ are attributed an upper limit of 1%.

[1] The cross-correlation was made using the DIRA2 database and software (Nanni & Tinarelli 1993; Battistini et al. 1994) developed by the Astronet Database Group – Italy, available at the Institute of Radio Astronomy (IRA) of the National Research Council (CNR). DIRA2 is at `http://www.ira.bo.cnr.it/dira2/`

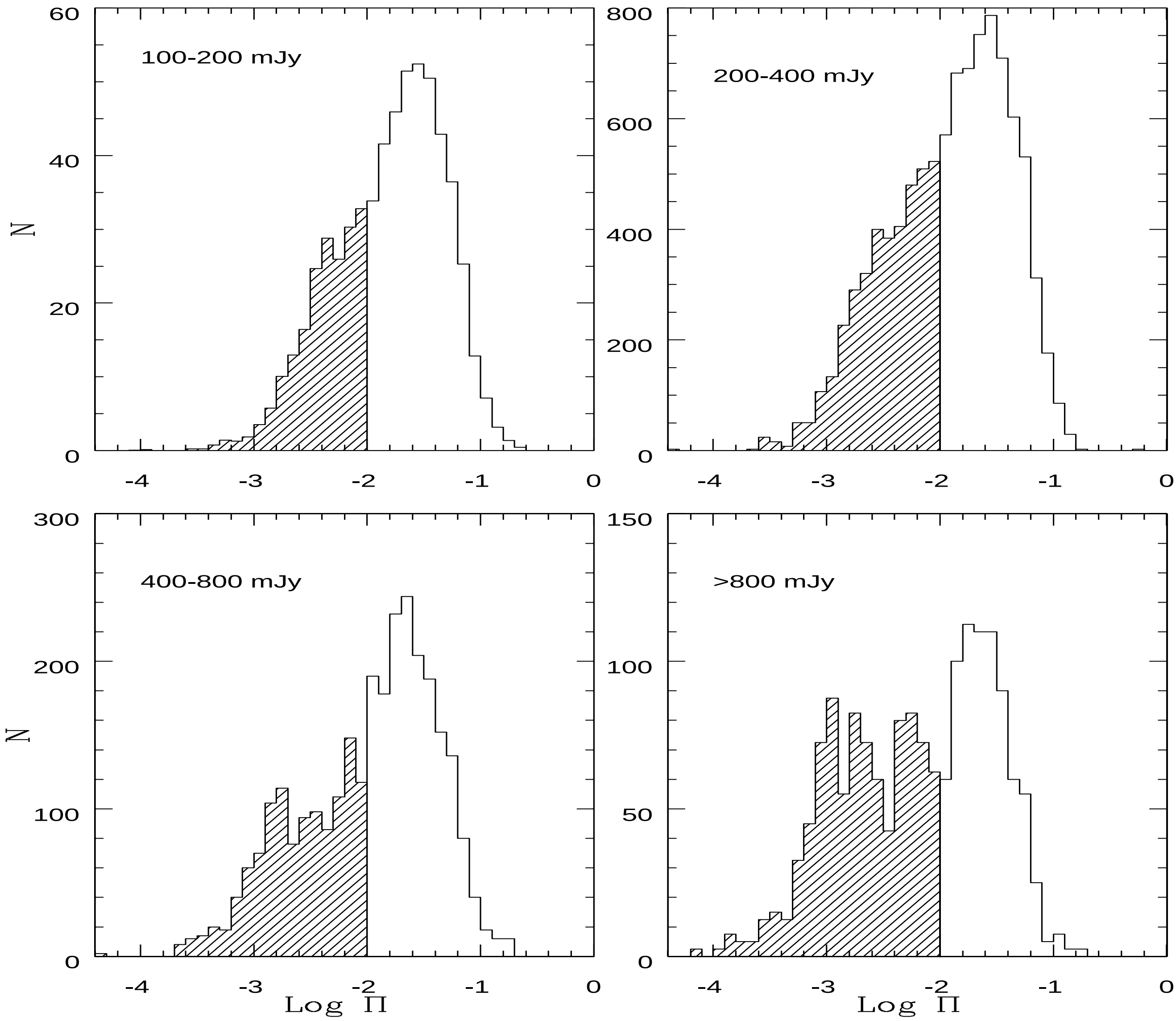

Fig. 2. Polarization degree distribution of steep-spectrum NVSS sources for several flux density intervals: 100–200 mJy (8032 sources; median value: 1.82%), 200–400 mJy (3700 sources; median value: 1.45%), 400–800 mJy (1438 sources; median value: 1.37%), >800 mJy (660 sources; median value <1%, formal median value: 0.74%). The hatched areas have the same meaning as in the previous figure.

As illustrated by Figs. 2 and 3, the mean polarization degree is anti-correlated with the flux density, especially in the case of steep-spectrum sources. The median Π steadily decreases from 1.8% for the 100–200 mJy bin (both for steep- and flat-spectrum sources) to <1%, for steep-spectrum sources, or to 1.05% for flat-spectrum sources, at flux densities >800 mJy.

We have tested the statistical significance of the correlation using the computer package ASURV Rev 1.2, developed by Isobe, La Valley & Feigelson (La Valley et al. 1992), which implements the methods presented in Feigelson & Nelson (1985) and in Isobe et al. (1986). For sources with $S(1.4\ \mathrm{GHz}) \geq 80$ mJy the test by Cox proportional hazard model yields a global χ^2, with one degree of freedom, of 573 for flat-spectrum and of 800 for steep-spectrum sources. In both cases the null hypothesis is rejected to a very high level of significance (probability $\ll 10^{-5}$).

The origin of this correlation is unclear. One possibility is that it may come from a change in the composition of the source population with decreasing flux density. In fact, Snellen et al. (2002) find that the fraction of flat-spectrum radio sources identified with point sources (i.e. quasars) in APM scans decreases, compared to the fraction of extended objects (i.e. galaxies), with decreasing radio flux density. But the distributions (see Fig. 4) of the polarization degrees of NVSS compact and extended sources with $S(1.4\ \mathrm{GHz}) \geq 500$ mJy in the sample by Snellen et al. (2002) show that extended sources tend to be less polarized than the compact ones, and therefore their effect goes in the direction opposite to the observed anti-correlation. We caution however that the situation may be different for steep-spectrum sources.

As a second attempt, we exploited the redshift data determined by Sadler et al. (2002) by cross-matching the NVSS with the first 210 fields observed in the 2dF Galaxy Redshift Survey, covering an effective area of 325 square degrees. There is an indication that the sources with the highest radio power tend to be less polarized at 1.4 GHz (see Fig. 5). The standard

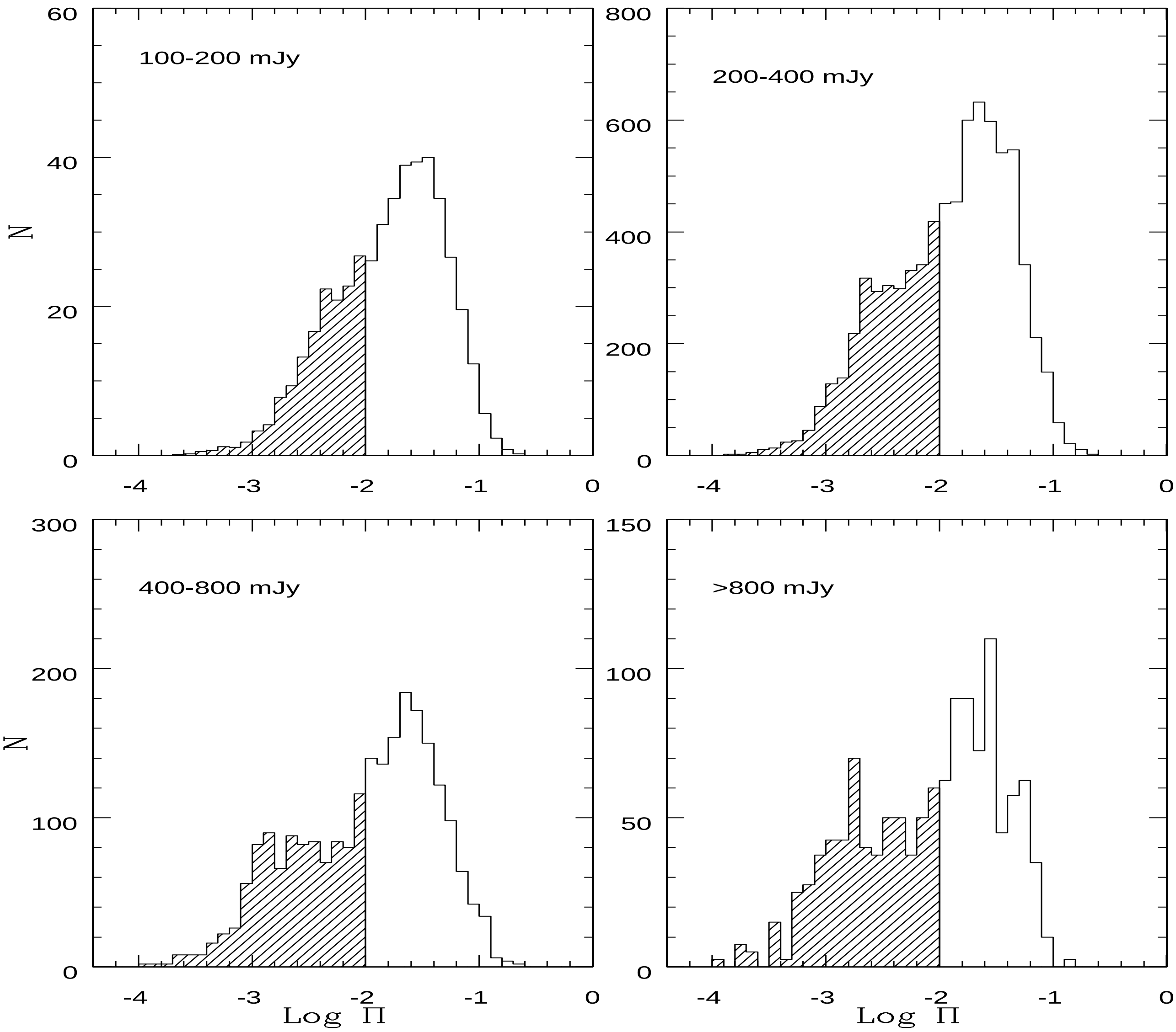

Fig. 3. Polarization degree distribution of flat/inverted-spectrum NVSS sources for several flux density intervals: 100–200 mJy (6198 sources; median value: 1.84%), 200–400 mJy (2859 sources; median value: 1.50%), 400–800 mJy (1150 sources; median value: 1.32%), >800 mJy (496 sources; median value: 1.05%). The hatched areas correspond to values seriously contaminated by instrumental polarization (see text).

statistical tests, taking into account upper limits, do not detect, however, a significant correlation between polarization degree and luminosity. On the other hand, as will be seen in the next section, there are clear evidences of substantial Faraday depolarization at 1.4 GHz, at least for steep-spectrum sources. But if the *intrinsic* polarization is uncorrelated with radio luminosity, we would expect a positive correlation between *observed* polarization and luminosity, since the more luminous sources are, on average, at higher redshifts and the Faraday rotation measures (RM) are proportional to $(1 + z)^{-2}$. Thus, the null result may be indicative of an anti-correlation between the *intrinsic* polarization degree and radio luminosity or of an increase of the intrinsic RM with z compensating the decrease due to the cosmological shift of frequencies to the red. Evidences in favour of the latter possibility have been reported by Pentericci et al. (2000). In the case of galaxies with intense star-formation activity we may expect higher depolarization at higher luminosities as the effect of both more chaotic magnetic fields and of higher RMs, due to a higher abundance of ionized gas and stronger magnetic fields.

If, on the other hand, the polarization degree is uncorrelated with luminosity, the observed anti-correlation of the polarization degree with flux density might be interpreted in terms of a decreasing effect of Faraday depolarization if the average redshift of sources increases with decreasing flux density.

3. Faraday depolarization

The exploitation of the NVSS data to estimate the contamination of CMB polarization maps by radio sources requires the extrapolation of 1.4 GHz polarized fluxes to high frequencies ($\nu \geq 20$ GHz) as used for CMB polarization experiments. At the latter frequencies the Faraday depolarization is probably small or negligible, while it is generally important at 1.4 GHz.

An extensive multifrequency study of the linear polarization properties of a representative sub-sample, comprising

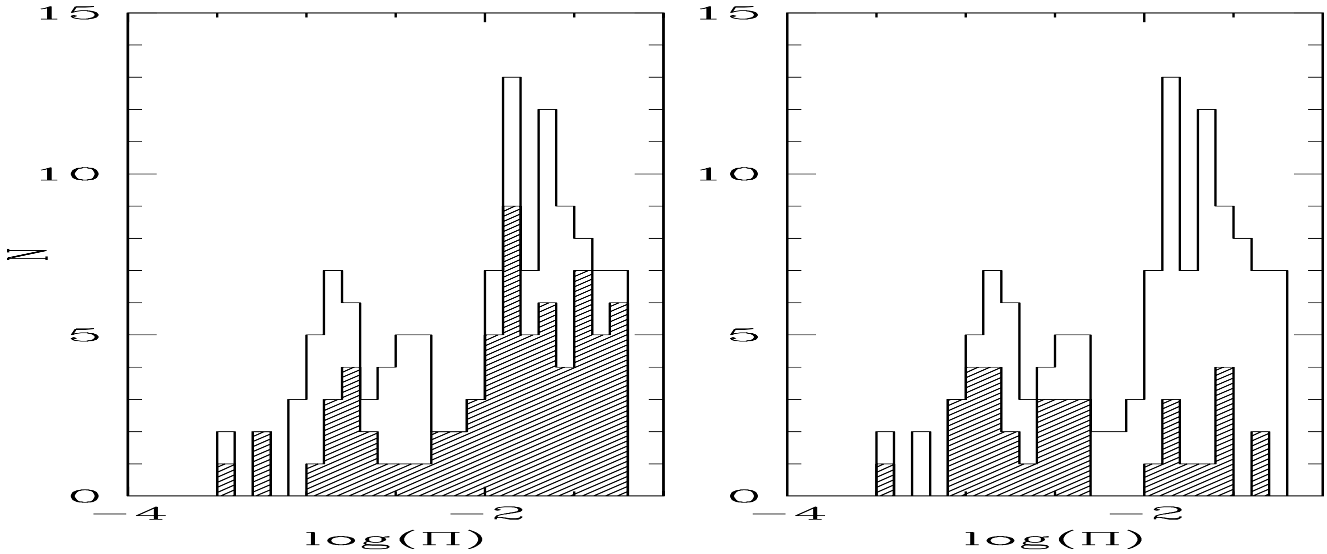

Fig. 4. Polarization degree distribution of flat/inverted-spectrum NVSS sources with $S(1.4\ \mathrm{GHz}) \geq 500$ mJy optically identified by Snellen et al. (2002). The hatched area in the left panel shows the distribution of stellar sources, the one in the right panel, the distribution of extended sources.

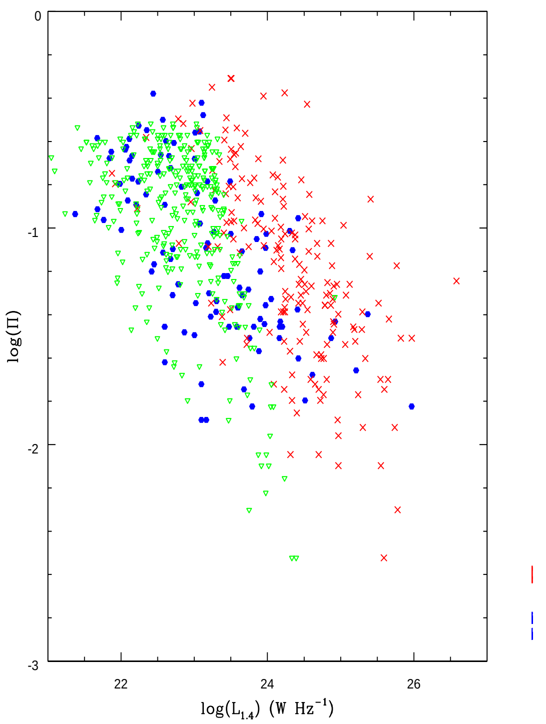

Fig. 5. Observed polarization degree versus radio luminosity for NVSS galaxies in the sample by Sadler et al. (2002). Crosses are AGNs, filled hexagons are star-forming galaxies. Sources whose polarization is either not measured to better than 3σ or is <1% (and therefore substantially contaminated by instrumental polarization) have been attributed an upper limit equal to the maximum between 3σ and 1%. These upper limits are shown as triangles. An Einstein-de Sitter universe with $H_0 = 50$ has been adopted.

192 sources, of the B3 VLA survey (Vigotti et al. 1989) has been recently carried out by Mack et al. (2002), using the Effelsberg 100-m telescope. They made polarization measurements at 2.695 and 4.85 GHz of sources they had earlier detected in polarization at 10.6 GHz. All sources in this sample were observed with a resolution larger than their angular extension, which was found to be always significantly smaller than 60″, while the Effelsberg beam-widths are 69″ at 10.6 GHz, 143″ at 4.85 GHz and 261″ at 2.7 GHz; this excludes any frequency-dependent differential depolarization. Their data, combined with the NVSS data at 1.4 GHz, have allowed them to estimate the rotation measures for 143 sources.

As illustrated by Fig. 6, the distribution of polarization degrees of steep-spectrum sources shifts to increasingly higher values as the frequency increases, as expected in the presence of substantial Faraday depolarization at 1.4 GHz. For such sources we have $\langle\Pi\rangle = 2.93\%$, 4.68%, 6.04%, and 8.65% at 1.4, 2.7, 4.85, and 10.6 GHz, respectively. This frequency dependence of $\langle\Pi\rangle$ is consistent with depolarization in uniform slabs with effective rotation measure $RM \simeq 260$, implying that the Faraday depolarization is small at ≥10 GHz. The mean polarization degree at 1.4 GHz of these sources is significantly higher than found for the full NVSS sample in the same flux density interval, reflecting the selection criterion requiring sources to have detected polarization at 10 GHz. On the other hand, since there is no significant correlation between the ratio $\Pi(10.4\ \mathrm{GHz})/\Pi(1.4\ \mathrm{GHz})$ and flux density at either frequency, we assume that the mean ratio between the polarization degrees at the two frequencies, $\langle\Pi(10.4\ \mathrm{GHz})/\Pi(1.4\ \mathrm{GHz})\rangle \simeq 3$, is representative of the mean correction for Faraday depolarization.

The standard statistical tests applied to the 99 sources with measured or estimated redshift detect a highly significant correlation between *intrinsic RM*s (i.e. observed $RM \times (1+z)^2$) and radio luminosity (see Fig. 7): Cox's proportional hazard model gives $\chi^2 = 29$ for 1 degree of freedom; Kendall's and Spearman's correlation tests give a z-value of 4.5 and $\rho = 0.44$, respectively. According to each test the null hypothesis (no correlation) has a probability $\ll 10^{-5}$. The correlation remains highly significant ($\chi^2 = 16$, probability of no

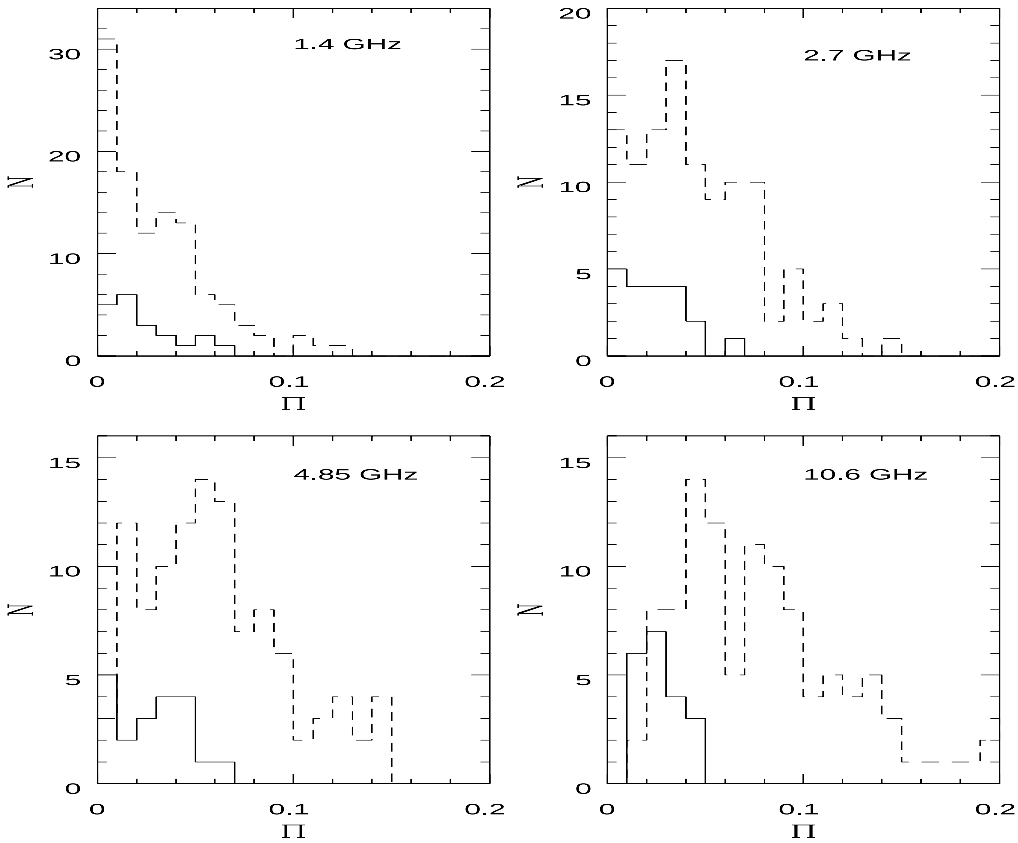

Fig. 6. Polarization degree distributions of sources flat- (solid) and steep-spectrum (dashed) sources in the sample by Mack et al. (2002) at 4 frequencies.

correlation $\simeq 10^{-4}$) even if we remove the point in the lower left-hand corner of Fig. 7.

In the case of flat-spectrum sources we have, for the same frequencies, $\langle \Pi \rangle$ = 1.66%, 2.19%, 2.63%, and 2.66%, respectively, consistent with the Faraday depolarization being relatively small, for most sources of this type, already at 1.4 GHz. This result is in agreement with earlier multifrequency polarization studies of compact flat-spectrum sources (Jones et al. 1985; Rudnick et al. 1985), which found a median value of polarization ~2.5% between 1.4 and 90 GHz, independent of frequency, although some sources do show a systematic increase of polarization with frequency (see Fig. 6 and Rudnick et al. 1978). It should be noted, however, that Mack et al. (2002) could not determine reliable *RM*s for flat-spectrum sources. On the other hand, the mm/sub-mm polarization survey of flat-spectrum radio sources by Nartallo et al. (1998) has yielded significantly higher polarization degrees. If for each object we take the mean of measurements made at different epochs, we find that the median polarization degree at 1.1 mm of High Polarization Quasars (10 objects) is 7.3%, that of Low Polarization Quasars (4 objects) is 4.3%, and that of BL Lacs (11 objects) is 6.3%. For comparison, the median polarization degrees given by the NVSS for the same objects are 2.4% for HPQs, <1% for LPQs, and 1.9% for BL Lacs. Only the 3 flat-spectrum radio-galaxies in the sample by Nartallo et al. (1998) have a polarization degree at 1.1 mm comparable or lower than that measured by the NVSS. The median 1.1 mm polarization for the full sample by Nartallo et al. (1998) is 5.5%; at 1.4 GHz its median polarization is 2%. This would again suggest a factor of 3 increase of the polarization degree from 1.4 GHz to high frequencies.

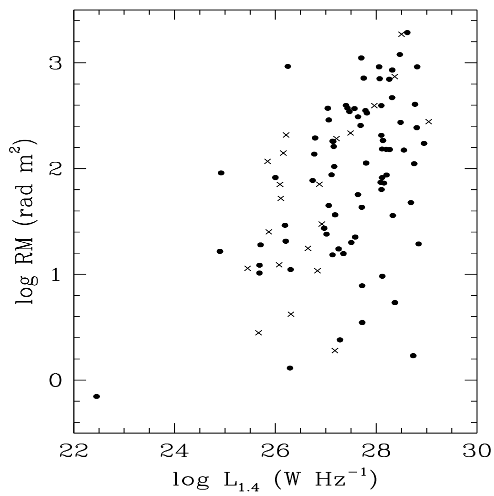

Fig. 7. Rotation measures as a function of the 1.4 GHz luminosity for steep-spectrum sources in the sample by Mack et al. (2002) with spectroscopic (filled circles) or photometric redshift (crosses). An Einstein-de Sitter universe with H_0 = 50 has been adopted.

4. Power spectrum estimates

As mentioned above, we aim at estimating the power spectrum of polarization fluctuations due to extragalactic radio sources at the high frequencies ($\gtrsim$20 GHz) at which CMB polarization experiments are carried out. We will make reference, in particular, to the frequencies of the Low Frequency Instrument (LFI) of ESA's PLANCK mission (30, 44, 70, and 100 GHz), which span a range similar to that covered by NASA's Microwave Anisotropy Probe (MAP) mission (22, 30, 40, 60, 90 GHz).

Based on the discussion in the previous section, we assume that the polarization degree of steep-spectrum sources increases, on average, by a factor of 3 from 1.4 to 10 GHz and stays constant at still higher frequencies. As for flat-spectrum sources, we consider two possibilities: their polarization degree is either frequency-independent, or increases, on average, by a factor of 3 at high frequencies, as is the case for sources in the sample by Nartallo et al. (1998). In the latter case, we assume that the increase applies to frequencies $\nu \geq 30$ GHz.

A second issue is the extrapolation of source spectra. Adoption of the 1.4–4.85 spectral indices up to high frequencies leads to over-predicting the surface density of inverted- ($\alpha < 0$), flat- ($0 \leq \alpha \leq 0.5$), and steep-spectrum sources brighter than 30 mJy at 15 GHz by a factor of 9.2, 2.2, and 1.2, respectively, compared to the findings by Taylor et al. (2001). This indicates average steepenings above 4.8 GHz of $\Delta\alpha_{\rm steep} \simeq 0.12$, $\Delta\alpha_{\rm flat} \simeq 0.47$, and $\Delta\alpha_{\rm inverted} \simeq 1.35$, that we incorporate in our flux density extrapolations.

In estimating the power spectra we assume that sources above the detection limits estimated by Toffolatti et al. (1998) for the PLANCK channels, namely 650, 480, 330, and 350 mJy at 30, 44, 70, and 100 GHz, respectively, are removed.

We have selected the portion of the sky region covered by both the NVSS and the GB6 survey at $b > 10°$ (area of 16 726 square degrees). The power spectrum has been computed using the HEALPix package (Górski et al. 1999). An analysis of the NVSS data alone (which reach lower fluxes and therefore allow us to derive the power spectrum for a broader range of angular scales) shows no evidence for departures from Poisson noise (which produces a simple white noise power spectrum, with the same power in all multipoles). The same conclusion was reached by Tegmark & Efstathiou (1996) from an analysis of a point-source catalogue (Becker et al. 1995) from the VLA FIRST survey. This is not in conflict with the evidences for clustering of radio-sources in the GB6 (Kooiman et al. 1995) and in the FIRST (Cress et al. 1996) survey. In fact, as shown by Toffolatti et al. (1999), the contribution of the observed clustering to the power spectrum of the source distribution is small in comparison with the Poisson contribution, not surprisingly in view of strong dilution of the clustering signal, due to the broad redshift distribution of radio sources. The same conclusion holds for steep- and flat- plus inverted-spectrum sources separately, although in this case the range of scales that can be investigated is more limited, due to the higher flux limit of the GB6 survey.

The power spectrum of fluctuations due to a Poisson distribution of sources whose differential source count per steradian, as a function of the flux density S, is $n(S)$, writes (Tegmark & Efstathiou 1996):

$$C_\ell = \int_0^{S_{\rm c}} n(S)\, S^2\, {\rm d}S, \tag{1}$$

where $S_{\rm c}$ is the minimum flux density of sources that can be individually detected and removed. Clearly we can derive only a lower limit to C_ℓ because we can estimate the high frequency counts only for sources brighter than $S_{4.85\,\rm GHz} \geq 18$ mJy, and we are therefore missing the contribution of fainter sources. However, since the slope of $n(S)$ in the relevant flux density range is $\beta = -{\rm d}\log n/{\rm d}\log S \simeq 2$ (Taylor et al. 2001), the underestimate of C_ℓ is probably no more than $\sim$10%. We have tested this by attributing to NVSS sources not detected at 4.85 GHz a spectral index drawn at random from the spectral index distribution of sources also present in GB6 catalogue, after having checked that no dependence of such a distribution on flux density is indicated by the (very limited) data on sources down to $S(1.4\,\rm GHz) \gtrsim 1$ mJy (Fomalont et al. 1984; Donnelly et al. 1987). This implies extending the high-frequency counts of "flat"-spectrum sources downwards in flux by a factor $\simeq$7 (and by a factor of $\simeq$20 those of the steep-spectrum ones, which however yield a smaller contribution to fluctuations at high frequencies). As expected, the C_ℓ's increased by only a few percent. We also investigated the effect of missing polarization measurements by attributing to sources whose polarization was not measured a polarization degree and a polarization angle drawn at random from the observed distributions. Again, the derived power spectra did not change appreciably.

As expected (Seljak 1997), sources yield essentially identical contributions to E- and B-mode power spectra; therefore only the E-mode is plotted in Fig. 8. We have also checked that the TE (T representing temperature fluctuations) power spectrum vanishes, as expected due to the random distribution of polarization position angles of sources.

5. Discussion and conclusions

Until adequate high frequency "blind" polarization surveys will become available, estimates of the contamination of CMB polarization maps by extragalactic sources will require delicate extrapolations of data from low-frequency surveys.

The main strength of the present analysis, compared with previous ones, is the use of a far more extended data-base. The NVSS survey has yielded polarization data for a very large, complete sample of extragalactic sources, allowing a direct observational determination of the power spectrum of polarization fluctuations due to them at 1.4 GHz. The data also show a previously unnoticed anti-correlation of the polarization degree with flux density, which deserves further investigation.

Furthermore, coupling NVSS with GB6 data made possible to separately determine the contributions of steep and "flat"-spectrum sources. The median polarization degree of the two populations for $S(1.4\,\rm GHz) \geq 80$ mJy turns out to be essentially equal (at the level of 2.2%) and shows a similar decrease with increasing flux density.

The data by Mack et al. (2002) have allowed us to investigate how the polarization properties of sources vary with

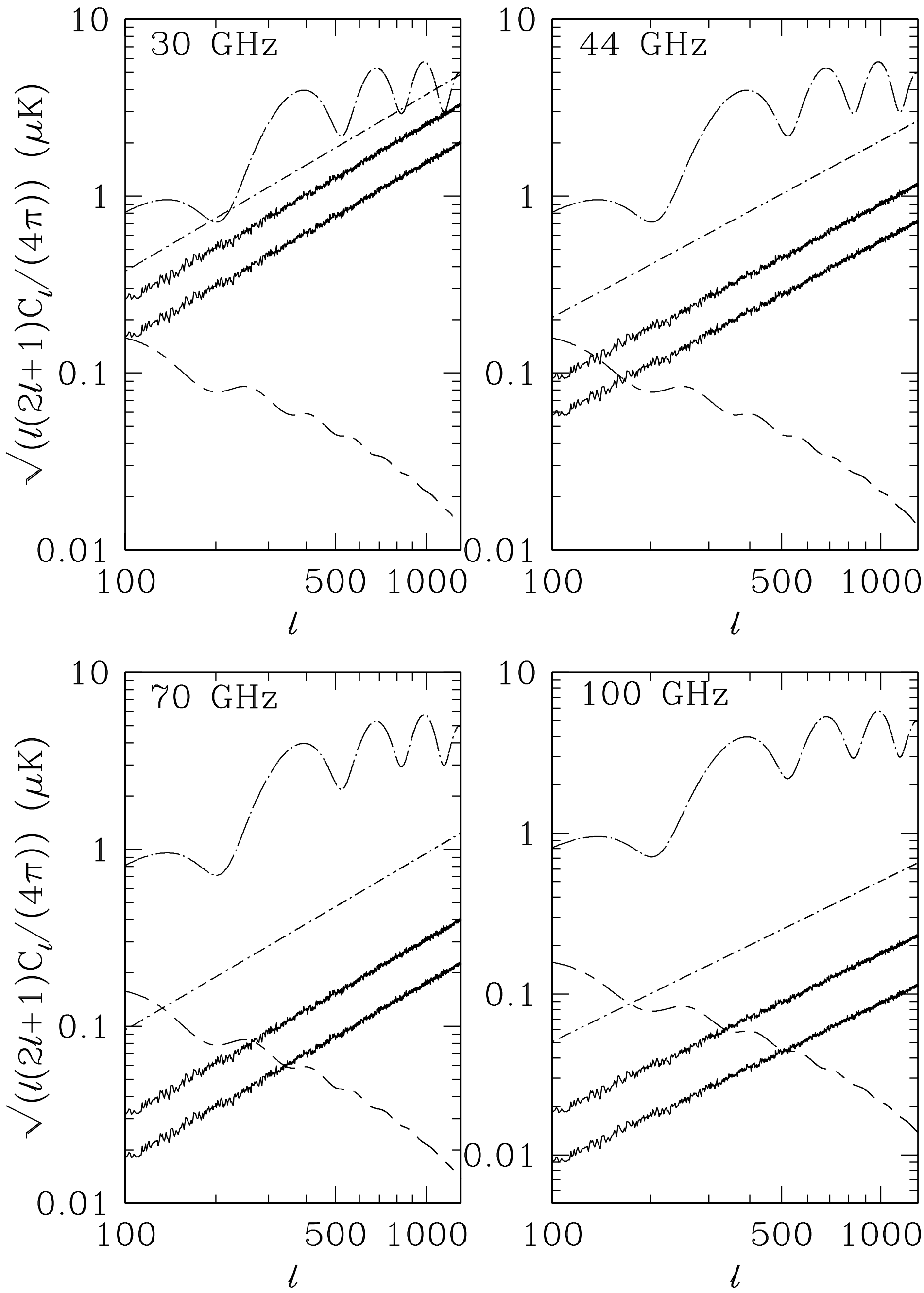

Fig. 8. Power spectrum of polarization fluctuations due to extragalactic radio sources (irregular lines; E- and B-modes are indistinguishable) at Planck-LFI frequencies: 30 GHz (upper left-hand panel), 44 GHz (upper right-hand panel), 70 GHz (lower right-hand panel), and 100 GHz (lower right-hand panel). The lower irregular lines correspond to the case of a frequency-independent polarization degree for flat- and inverted spectrum sources, while the upper ones correspond to a factor of 3 increase of the mean polarization degree at Planck frequencies, compared to NVSS measurements. In both cases the mean polarization degree of steep-spectrum sources measured by the NVSS survey has been corrected upwards by a factor of 3. The dot-dashed straight line shows the preliminary estimate by De Zotti et al. (1999). Also shown, for comparison, are the CMB E- (dot-dashed curve) and B-mode (long-short dashes) power spectra for a flat CDM cosmological model with $\Omega_\Lambda = 0.7$, $\Omega_{\rm darkmatter} = 0.25$, $\Omega_{\rm baryon} = 0.05$, $H_0 = 70\,{\rm km\,s^{-1}\,Mpc^{-1}}$, and a tensor contribution to the temperature quadrupole equal to 30% of that of scalar perturbations. The CMB power spectra were computed with CMBFAST (Seljak & Zaldarriaga 1996).

frequency. For steep-spectrum sources we found clear evidence of Faraday depolarization corresponding to an effective value of the rotation measure $RM \simeq 260$ rad m^{-2}. The average intrinsic polarization degree of these sources, observed at $\nu \gtrsim 10$ GHz, is estimated to be, on average, 3 times higher than at 1.4 GHz.

On the other hand, the mean polarization degree of flat-/inverted-spectrum sources increases only weakly from 1.4 to 10.6 GHz, suggesting that these sources have either small or really extreme RMs. Of course, polarization properties of radio sources may change with frequency not only by Faraday rotation but also for other reasons, such as the appearance of new emission components with different polarization properties. Only high-frequency polarization surveys may resolve this issue. We have considered two possibilities: either the mean polarization degree is frequency-independent, as indicated by the multifrequency studies by Jones et al. (1985) and Rudnick et al. (1985), or it increases, at high frequencies, by a factor ≃3 compared to 1.4 GHz, as is the case for the sample of Nartallo et al. (1998).

Another critical issue is the extrapolation in frequency of the observed flux densities. Adoption of the observed 1.4–4.85 GHz spectral indices leads to over-predicting the 15 GHz counts by a factor ≃3, compared with results of the survey by Taylor et al. (2001). Predictions of the most commonly used evolutionary models (Dunlop & Peacock 1990; Toffolatti et al. 1998), accounting for existing source counts up to 8.4 GHz and for the associated redshift/luminosity distributions, yield 15 GHz counts in excess by similar factors. Therefore, to extrapolate the 1.4 GHz flux densities we have exploited the observed spectral indices only up to 5 GHz. Above this frequency we have adopted the average spectral steepenings necessary to ensure, for each population (steep-, flat- and inverted-spectrum sources), consistency with the results by Taylor et al. (2001).

An estimate of the power spectrum of polarization fluctuations at Planck frequencies obtained extrapolating the 1.4 GHz fluxes as described in Sect. 2, with an upper flux-density cut-off corresponding to the source detection limit in each Planck channel as estimated by Toffolatti et al. (1998) and applying the average correction for Faraday depolarization derived in Sect. 3, is shown in Fig. 8. The present estimates are significantly below those by De Zotti et al. (1999), mostly due to the substantial steepening of the source spectra between 5 and 15 GHz implied by the results of the survey by Taylor et al. (2001). As illustrated by Fig. 8, extragalactic radio sources are not expected to be a serious hindrance for measurements of the CMB E-mode power spectrum at $\nu \geq 30$ GHz. They are even less of a problem for measurements of the temperature-E-mode correlation since their TE power spectrum vanishes, owing to the random distribution of their polarization position angles.

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