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Optical Identification/Flux Density Relationship for Radio Galaxies

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SUMMARY

Optical identification statistics have been summarized over a flux-density range of about 1000:1 at 408 MHz for identifications of galaxies made on the Palomar Sky Survey (PSS) prints from the 3CR, Ooty-occultation, Bologna and 5C surveys. The percentage identification of galaxies seen on PSS, PI(S), decreases from about 60% for a flux density of about 15 Jy at 408 MHz to about 15% at 1 Jy and ∿ 10% at 25 mJy. The observed PI(S) relation is compared with the predictions of theoretical models of radio luminosity function derived by Wall et al. (1977) and Robertson (1980) based on radio source counts and luminosity distribution of strong radio sources. Rather than assuming a standard optical luminosity for all radio galaxies, we have taken into account the available information on their bivariate radio-optical luminosity function. It is found that the observed PI(S) data do not support model 5 of Wall et al. in spite of its consistency with radio source counts, implying that there occurs no evolution of radio sources for luminosities $<10^{25}$ W Hz^{-1} sr^{-1} at 408 MHz. The observations of PI(S) are in reasonable agreement with model 4(b) of Wall et al. and with the free-form model of Robertson but indicate that the local luminosity function at 408 MHz in the range of about 10^{23-25} W Hz^{-1} sr^{-1} is lower by a factor of about two than that assumed by them.

Key words: radio galaxies - optical identification - radio luminosity function - cosmology

1. - INTRODUCTION

Optical identifications are now available for a large number of radio sources with a wide range of flux-densities. Since the redshift data for a sufficient number of radio galaxies are unlikely to be available for a long time, it is worthwhile using the identification statistics at various flux-densities for verifying the predictions of several models, that assume a steep evolution with cosmic epoch, as proposed in literature. This requires, however, a knowledge of the radio-optical bivariate luminosity function about which some information is now available for galaxies (Auriemma et al. 1977; Meier et al. 1979; Hummel 1980).

In this paper, we first present a summary of the optical identifications of 494 sources outside the galactic plane ($|b|>20^0$) with flux-densities $S_{327} \gtrsim 0.3$ Jy, whose lunar occultations have been observed at 327 MHz which the Ooty radio telescope (Swarup et al. 1971). We then examine the variation of percentage identification with flux-density, PI(S), defined as the percentage of radio sources of a given flux-density S which are identified with galaxies brighter than a limiting magnitude. For this purpose, we have combined the Ooty data with the available identification statistics of sources from complete samples for $S_{408} > 20$ mJy for the optical identifications based on Palomar Sky Survey (PSS). These observations are compared with theoretical estimates based on a model consistent with available information on the bivariate luminosity function of radio galaxies.

2. - OPTICAL IDENTIFICATIONS OF OOTY RADIO SOURCES

Of over 1200 lunar occultation observations made with the Ooty radio telescope so far, results on accurate positions, structure and optical identifications have been catalogued for 714 radio sources (Subrahmanya and Gopal-Krishna 1979 and references therein; Singal et al. 1979; Venkatakrishna and Swarup 1979; Joshi and Singal 1980). Of these, 494 sources have galactic latitudes $|b| > 20°$ and constitute the Ooty sample for the present study. It may be noted that effective resolution attainable from lunar occultations depends on the observational signal-to-noise ratio (Scheuer 1962). The resolution achieved for Ooty occultations is generally about 1 to 4 arcsec for the comparatively stronger sources with $S_{327} > 1.5$ Jy and about 6 to 15 arc sec for $S_{327} > 0.5$ Jy. It is found that over 80 per cent of the sources of $S_{327} > 1.5$ Jy have been well resolved in the Ooty catalogues (Venkatakrishna and Swarup 1979). However, a majority of the sources in the range 0.3-1 Jy have only been partially resolved since the resolution achieved till the recent improvement in the sensitivity of the Ooty telescope was generally of the same order as the median angular size of 8-10 arc sec for these sources.

Optical identifications available for the Ooty sources are all based on PSS. The observed angular sizes of most of these radio sources are less than 30 arc sec. A search was made for optical objects lying within about 1 arc min from the radio source. However, a radio source was generally considered identified only if the optical object was within a rectangular area defined by the size of the radio source and positional errors. Positions of optical objects in the vicinity of the radio sources are determined to an accuracy of about 0.5 arc sec using a Zeiss coordinate measuring machine (Kapahi et al. 1973). The uncertainties in the radio positions of most of these sources are within 1 arc sec in each coordinate, implying a low rate of misidentification due to chance coincidence. For instance, since the average density of background objects on PSS for $|b| \gtrsim 20°$ is about

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4×10^{-4} obj/arc sec^2 (Willis and de Ruiter 1977), the probability of a chance occurrence of a PSS object within 2 arc sec of the radio centroid is only about 0.5 per cent. Further, the reliability of the identifications of Ooty sources is enhanced by the availability of brightness profiles derived from the occultation curves.

An examination of the radio-optical separations of the identified Ooty sources shows that in one-third of the cases, the separations are > 4 arc sec, appreciably larger than the measurement errors since the latter are mostly within 1.5 arc sec. There may thus be many cases with genuine displacements between the radio centroid and the associated optical object. However, for 80 per cent of the identified double sources, such displacements are within 0.2 times the overall angular size. This can be compared with a similar result for relatively low-luminosity radio sources associated with nearby galaxies, for which Bridle and Fomalont (1978) find that 80 per cent of such displacements are within 0.15 times the overall size. A detailed investigation of the angular separation and flux-density ratios of the two components of the double radio sources is presented elsewhere (Swarup and Banhatti 1981).

Among the 494 Ooty sources, 142 are optically identified with objects on PSS, of which 68 are galaxies, 50 are BSOs including 14 confirmed QSOs and a BL Lac object, 13 are either red or neutral stellar objects and the remaining objects are too faint to be classified. The median angular size of the Ooty sources is about 20 arc sec for the galaxies, 5 arc sec for the quasars and 11 arc sec for the unidentified objects. This suggests that most of the unidentified objects may be distant radio galaxies.

For the purpose of PI(S), the Ooty sources have been divided into 4 ranges of flux-density, with S_{327} in the range 0.3-0.6, 0.6-1.2, 1.2-2.4 and 2.4-4.8 Jy containing respectively 166, 173, 100 and 38 sources. While comparing the PI(S) of these sources with that of sources from other catalogues defined at 408 MHz, the median S_{327} was transformed to S_{408} assuming a spectral index of 0.75.

3. - IDENTIFICATION STATISTICS FROM OTHER CATALOGUES

In order to obtain PI(S) over a wide range of S, the Ooty data have been supplemented with the published data on the identification statistics of sources from 5 low-frequency catalogues: 3CR, B2, 5C3, 5C7 and 5C12. For the sake of uniformity of data, we have restricted our analysis to sources outside the galactic plane ($|b| > 20°$) and used the identification based on PSS. Although deeper identifications are available for some of these sources, they have not been considered here since they are not uniformly available for all the sources in these catalogues. Also, since the luminosity function of quasars is poorly defined in literature compared to that of radio galaxies, the present paper has been confined to the PI(S) of radio galaxies seen on PSS at estimated redshifts of $\lesssim 0.5$.

At high flux-densities, we have chosen the sources with $|b| > 20°$ from the 3CR complete sample of 166 sources (Jenkins et al. 1977). These sources have been divided into 3 bins with S_{178} in the range 10-10$\sqrt{2}$ Jy, 10$\sqrt{2}$-20 Jy and $\geq$ 20 Jy consisting of 71, 34 and 30 sources respectively. The optical identifications for these sources have been taken from the compilation of Smith et al. (1976), ignoring the data based on deep identifications. After obtaining the percentages of identification, the median flux-densities in these ranges have been converted to 408 MHz using $\alpha = 0.75$.

In the intermediate ranges of S, we have used a complete sample of sources with $S_{408} \geq 0.9$ Jy, $|b| > 20°$ from the Bologna B2 catalogue (Grueff and Vigotti 1972, 1973). The optical identifications of these sources are generally based on improved declination measurements at 5 GHz. These sources have been divided into 5 bins for PI(S), with S_{408} in the range 0.9-0.9$\sqrt{2}$, 0.9$\sqrt{2}$-1.8, 1.8-1.8$\sqrt{2}$, 1.8$\sqrt{2}$-3.6$\sqrt{2}$ and $\geq$3.6$\sqrt{2}$ Jy containing respectively 246, 129, 80, 65 and 34 sources.

At lower flux-densities we have firstly used the data on sources from the 5C3 survey, for which optical identifications have been attempted by Richter (1975) in terms of a 'reliability' of associating the radio sources with probable identification candidates in the vicinity of the sources. From these sources, we have defined two bins with S_{408} in the range 15-45 mJy and 45-135 mJy comprising respectively of 44 and 45 sources. For PI(S), we have assumed that the total number of identifications with PSS objects is given by the sum of the individual reliabilities (denoted as r_3 by Richter) of the objects in the relevant range of S.

Perryman (1979) has made a detailed investigation of optical identifications of radio sources in the 5C7 survey using deep plates taken with the Palomar 48-inch Schmidt telescope with a limiting V magnitude of about 22. After correcting for chance coincidences, the total identification rate at 408 MHz for both galaxies and quasars is estimated by him as about 20 per cent up to V magnitude of about 22. Only 24 out of 79 possible identification candidates in table 6 of Perryman (1979) are associated with galaxies or probable galaxies brighter than 20 magnitude which may be visible on PSS. Hence, the estimated identification for radio galaxies on PSS for the 5C7 sources is about 24/79 x 20%. For making another estimate, we may consider sources only of RA error class 1, 2 and 3 arc sec in his paper for which chance coincidence is small. From table 5 and 6 of the paper, it is seen that only 9 out of 92 radio sources are associated with galaxies brighter than 20 magnitude, including 1 expected by chance. Thus, it is estimated that the percentage identification on PSS for a median flux density of about 30 mJy at 408 MHz is about 8±3%.

Recently R.C. Benn (Private Communication) of Cambridge has made deep identifications of 5C12 field which is located at a high galactic latitude and for which more accurate radio positions are available than for the 5C7 survey. The total identification rate for both galaxies and QSOs up to the limiting magnitude of 23.5^m in blue is estimated to be about 32% (after correction for contamination by chance coincidence) with an estimated identification content for galaxies and probable galaxies of about 13±2% up to 21^m in blue (limits of PSS).

The PI(S) thus obtained for galaxies identifiable from PSS is given in Table I and plotted in Fig. 1 against the median S_{408}. The flux-densities of B2 sources overlap with those of Ooty sources, and the observed PI(S) is seen to be in good agreement with each other for these two catalogues. It may also be noted that at the highest flux-densities, the PI(S) of 3CR sources is in good agreement with that of sources sources from the larger, all-sky catalogue of Robertson

Table I - Percentage of identifications of radio galaxies

Sample	Freq (MHz)	S-range (Jy)	$S_{med}(408)$ (Jy)	% identified	
3CR	178	$10 - 10\sqrt{2}$	6.38	29.6 ±	7.3
		$10\sqrt{2} - 20$	9.03	47.1	14.3
		$\geqslant 20$	16	63.3	18.6
B2	408	$0.9 - 0.9\sqrt{2}$	1.07	17.1	3
		$0.9\sqrt{2} - 1.8$	1.51	16.3	3.8
		$1.8 - 1.8\sqrt{2}$	2.14	25.0	6.2
		$1.8\sqrt{2} - 3.6\sqrt{2}$	3.60	32.3	8.1
		$\geqslant 3.6\sqrt{2}$	7.2	52.9	15
OTL	327	0.3 - 0.6	0.36	14.5	3.2
		0.6 - 1.2	0.72	15.6	3.2
		1.2 - 2.4	1.44	17.0	4.5
		2.4 - 4.8	2.88	26.3	9.4
5C6	408	0.015-0.045	0.026	10.6	5.2
		0.045-0.135	0.078	6.1	3.4

(1973) for $S_{408} > 10$ Jy (not included in the present study). The error bars shown in the Fig. 1 are only typical and estimated simply as $100\ [p(1-p)/N]^{1/2}$, where $p = PI/100$ is the fraction of identified galaxies in a sample of N radio sources. The theoretical curves will be explained later.

4. THEORETICAL PREDICTIONS

A theoretical estimate of PI(S) from an assumed world model requires a specification of radio-optical bivariate luminosity function (BLF) which consists of two parts: a) the overall radio luminosity function (RLF), defined as the volume density of radio sources of a given range of log P at a given epoch z, and b) the distribution of absolute optical magnitudes (M) of radio sources of various luminosities at each epoch. An observational determination of these properties involves the formidable task of complete identifications and redshift measurements of radio sources contained in a reasonably large volume of the sky. Although this is unlikely to be accomplished in the near future, there have been some attempts in the recent literature to derive the BLF of radio galaxies from nearby samples (Auriemma et al. 1977; Meier et al. 1979; Hummel 1980). Hence, as a first approximation, it is worthwhile predicting PI(S) from a simple empirical model consistent with these observations. In the following sections, we will attempt to formulate such a simple model and verify its predictions against the observed PI(S) of galaxies identified on PSS. The exact geometry used in the calculations is irrelevant at this stage, but we have used the Einstein de-Sitter geometry ($q_0=0.5$) with $H_0 = 50$ kms^{-1}/Mpc. Also, we refer all luminosities to a constant observed frequency of 408 MHz and express them in W Hz^{-1} sr^{-1}.

4.1 - REDSHIFT-LIMITS FOR IDENTIFICATIONS USING PSS

Before predicting PI(S) from an assumed model, it is necessary to convert the limiting apparent magnitude of PSS to the redshift limits corresponding to the various possible values of the absolute magnitudes of radio galaxies. For this, one has to correct the observed apparent magnitude limit for galactic absorption, apply K-correction and then convert it to the scale of M used in BLF through an appropriate colour relation. For convenience, we use the P magnitudes (M_p) of the Zwicky system of photographic blue magnitudes since it was chosen for the BLF derived by Auriemma et al. (1977) and Meier et al. (1979). This roughly corresponds to the effective filter used for the blue plates of PSS, but is fainter than the

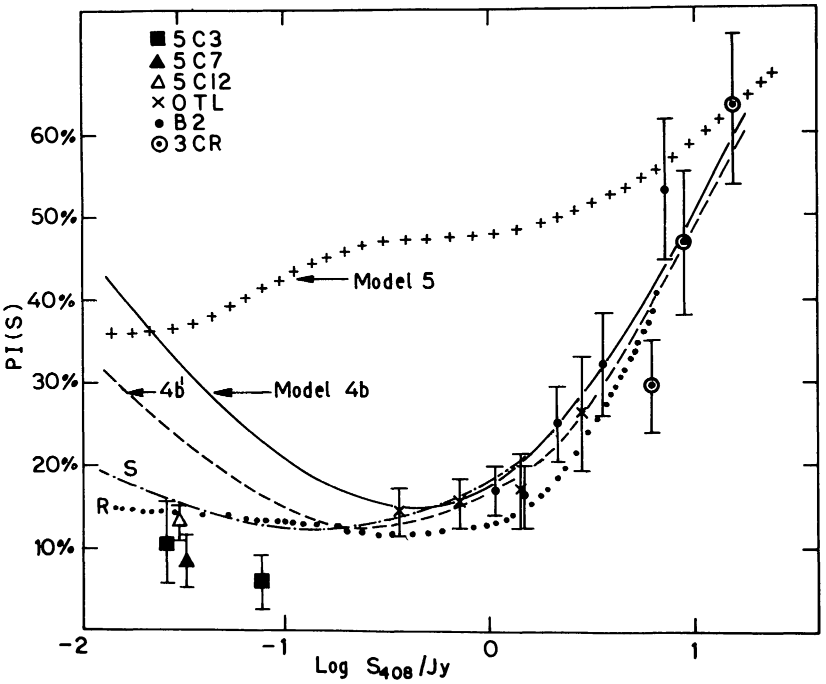

Figure 1: Percentage identification versus flux-density, PI(S), for identifications of radio galaxies using Sky Survey Prints. The curves denote predictions for a limiting red magnitude of 19.5 corresponding to the theoretical models: 4b(solid curve), 4b'(- - -), R(. . .) and S(-· - · -).

standard photoelectric blue (B) magnitude scale by about 0.25 mag. The red filter used in PSS is somewhat similar to the standard R filter, but is a little narrower and has a slightly lower mean wavelength than that of the R-filter. The majority of radio galaxies are ellipticals with colour relations approximated by: B-V = 0.9 (Pence 1976; Auriemma et al. 1977) and V-R = 0.8 (Oke 1971; Kristian et al. 1978), where V corresponds to the photovisual scale. The spirals are generally bluer than ellipticals and have B-V typically in the range 0.5 to 0.7 mag (e.g., Motz and Duveen 1977). However, since the uncertainties in the BLF are much larger for spirals than for ellipticals, and also their contribution to radio sources of S > 20 mJy is much smaller than that of the ellipticals, we will ignore the differences between their colours for simplicity. Thus, in the following paragraphs, we will assume a constant value of $m_p - m_r = 1.7$ for both spirals and ellipticals, where m_r is the apparent magnitude corresponding to the red PSS.

The limiting magnitude of PSS is 20 mag for the red and 21 mag for the blue plates and slightly lower for the prints. In view of the above colour relation, it can be seen that red plates of PSS are more suited for optical identifications of radio galaxies than the blue plates and hence the limiting magnitude of PSS should be taken as that corresponding to the red plates. The sensitivity of PSS depends somewhat on the region of survey and also on the type of object. Hence, we have chosen a nominal average value of $m_r = 19.5$ as the limiting magnitude for the identifications based on PSS. We have further applied a uniform correction of 0.2 mag for absorption. For K-correction, we used the results of Katgert et al. (1979) which are based on the work of Pence (1976). With these corrections, the range of magnitudes M_p between -19.5 and -23.5 used below correspond to redshift limits between 0.18 and 0.65.

4.2 - THE RADIO LUMINOSITY FUNCTION

The RLF is generally written as the product of a local luminosity function (LLF) and an evolution function (EF). A self-consistent scheme for its determination was described by Wall et al. (1977, 1980; hereafter referred to as WPL) based on the source counts for $S_{408} > 10$ mJy and the luminosity distribution of a complete sample of strong sources with $S_{408} > 10$ Jy. They introduced the EF in terms of a few parameters which were to be optimised to fit the observed source counts and also to closely reproduce the assumed luminosity distribution of strong sources. By trying several feasible schemes, they have concluded that these observations can be satisfied by two widely different models labelled by them as 4b and 5. A 'free-form' model also fitting into the above scheme was derived by Robertson (1980). We have attempted the prediction of PI(S) for all these models of EF, which will be denoted by 4b, 5 and R where 4b, 5 correspond to the models 4b, 5 of WPL and R corresponds to the 'standard free-form' model of Robertson (1980) whose EF was kindly supplied to us by the author.

It may be noted that the requirement of an exact agreement with a specified luminosity distribution introducesa dependence of LLF on the choice of EF. However, for the luminosity distribution of the strong sources used in the above models, this dependence is not pronounced for $P < 10^{26}$ W Hz^{-1} sr^{-1}. This portion of LLF is plotted in Fig. 2 (solid curve) for model 4b of WPL and we refer to the original references for the LLF corresponding to the three models of EF used by us.

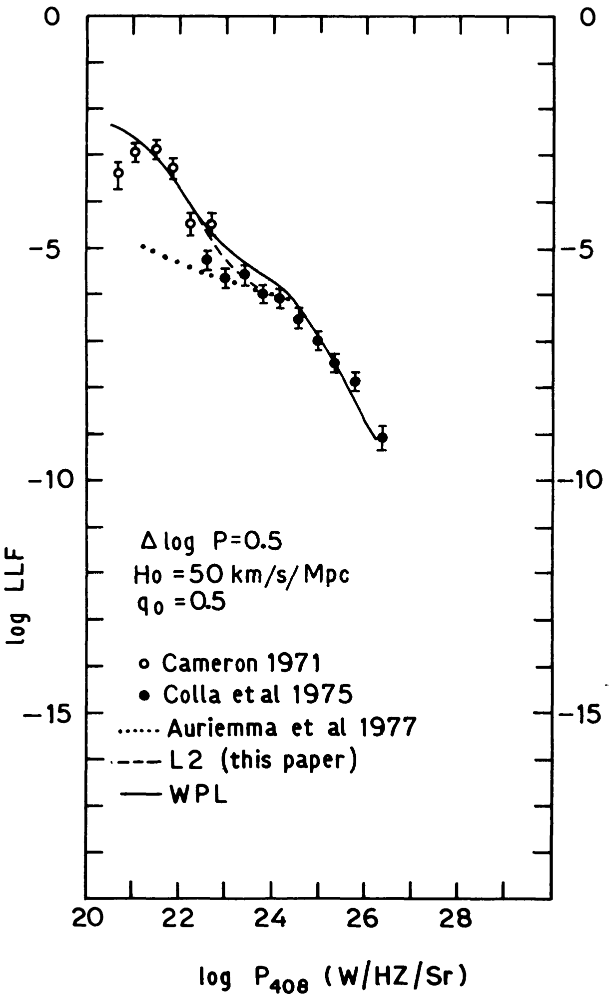

Figure 2: Local Luminosity Function for low luminosities. Ordinate denotes the logarithm of LLF(/Mpc^3) for Δ log P = 0.5. L2 is the revision in LLF which leads to an improved prediction of PI(S) at low S, as discussed in the text.

Also shown in Fig.2 are the observational determinations of the LLF of spirals by Comeron (1971) and of ellipticals by Colla et al. (1975) and Auriemma et al. (1977). These data have been taken from Fanti and Perola (1977) and are consistent with the more recent determination for the ellipticals by Meier et al.(1979). It can be seen from Fig. 2 that the LLF assumed in the above models is appreciably higher than the observed LLF of ellipticals in the region of P ∿ 10^{23-24} W Hz^{-1} sr^{-1}, where the various observational determinations are in good agreement with each other, but the discrepancy is appreciably larger than that expected from the observational errors. Hence if the WPL model for LLF in the above luminosity range is correct, it would imply that a good fraction fo the corresponding radio sources would be spirals. But, hardly any spirals are found to have P > 10^{23} W Hz^{-1} sr^{-1}. In anticipation of the results presented in a later section, we wish to remark that our observations of PI(S) also indicate that the true LLF may be appreciably lower than that used by WPL for these luminosities and hence closer to the above observational estimates for ellipticals.

4.3 - THE FRACTIONAL BIVARIATE LUMINOSITY FUNCTION

In making theoretical predictions of percentage identifications, the previous workers have only considered a simple model in which all radio galaxies are assumed to be a standard candle with the same optical absolute magnitude. However, the observed absolute magnitudes M_p of radio galaxies range from about -19.5 to -23.5 with the corresponding redshift limits on PSS ranging from $z = 0.2$ to 0.65 ($H_o = 50$). Further, the standard candle model is justified only for galaxies fo high radio luminosities, which does hold for a majority of radio sources seen in a flux-limited sample, but there is an appreciable difference between the luminosity functions of different M for $P < 10^{24.5}$ W Hz^{-1} sr^{-1} (Auriemma et al. 1977; Meier et al. 1979). Hence a proper prediction of PI(S) should be based on the existing determinations of BLF. At this stage, we find it convenient to introduce the term 'fractional bivariate luminosity function' (FBLF) representing the fraction of radio sources in the unit value of a given range of luminosity which have M_p in a specified range. Since the present paper will be concerned only with the identifications of galaxies, we will henceforth restrict FBLF to radio galaxies alone. Thus, in each range of luminosity, the sum of FBLF for all M_p should represent the total fraction of galaxies in the radio sources of that luminosity-range. An inference of such a fraction from the existing literature is likely to be much more reliable than the actual volume densities of the sources of different types. Thus, we can write the BLF of galaxies as the product of RLF and FBLF.

The information available on the BLF of radio sources is all based on relatively nearby samples ($z < 0.2$) of radio galaxies of luminosities $P < 10^{26}$ W Hz^{-1} sr^{-1} for which evolutionary effects are negligible (Auriemma et al. 1977; Meier et al. 1979; Hummel 1980). For simplicity, we will assume that the effects of cosmological evolution are contained in RLF and negligible in FBLF at least upto the limit of PSS. Observationally, there is some evidence that the evolutionary effects are not important for $z < 0.3$ (Katgert et al. 1979) and most of the galaxies identified through PSS are expected to have redshifts within about 0.5. Further, at high flux-densities when the contribution of sources with $P \gtrsim 10^{26}$ becomes important at these low values of redshifts, it is necessary to assume the fraction of expected quasars. We have assumed that the quasars account for 10% of radio sources in the luminosity-range $10^{25.5-26.3}$ W Hz^{-1} sr^{-1}, 20% in $P \sim 10^{26.3-27.1}$ and 50% for $P > 10^{27.1}$. This assumption though arbitrary, is found by us to be broadly consistent with the observed fraction of quasars at different flux-densities. However, these assumptions are not likely to affect seriously the predicted PI(S) for sources with $P < 10^{26}$ W Hz^{-1} sr^{-1} and $z < 0.5$. This range includes most of the galaxies seen on the PSS but very few of the quasars, except at high flux-densities.

For convenience, we will define FBLF for the same ranges of P and M_p as used by Auriemma et al. (1977) as mentioned earlier. Based on the available information on BLF referred to above and using the above assumptions, we have arrived at an empirical FBLF for predicting PI(S). This is summarised in Table II, where all the entries are expressed as multiples of 0.05, since a better accuracy is not warranted by the existing observations. We wish to emphasize that our intention here is only to obtain a model FBLF consistent with literature which can serve as a first approximation for the prediction of PI(S) of galaxies identified through PSS. In particular, care must be exercised while using this model for deep identifications ~~or~~ for the case of quasars. We are attempting a more detailed study of the cosmological implications of the identification statistics of radio sources and the results will be published in due course. It may be noted that the predicted values of PI(S) are somewhat lower, particularly at the weaker flux density levels, for the FBLF model considered by us than for the case when all radio galaxies are assumed to have the same value of optical luminosity. The differences are only a few percent for models R and S (discussed below) but are up to 5 or 10 percent for models 4b and 5 at $S_{408} \lesssim 100$ mJy.

Table II. Fractional Bivariate Luminosity Function of Radio Galaxies

	Fraction of galaxies					Quasars
log P_{408} \ M_p	-19.5	-20.5	-21.5	-22.5	-23.5	
< 22.3	0.50	0.50	--	--		--
22.3-23.1	0.30	0.35	0.35	--		--
23.1-23.9	0.20	0.25	0.50	0.05		--
23.9-25.5	0.05	0.30	0.50	0.15		--
25.5-26.3	--	0.25	0.50	0.15		0.10
26.3-27.1	--	0.25	0.40	0.15		0.20
> 27.1	--	0.10	0.30	0.10		0.50

4.4 - MODEL PREDICTIONS

The calculated values of PI(S) (for $\Delta \log S = 0.25$) for the three models mentioned at the beginning of Section 4.2 are shown in Fig. 1 by the curves labelled 4b, 5 and R to denote the corresponding models. The agreement with the observations is seen to be rather poor, especially for model 5 of WPL. It predicts too many sources to be identified with galaxies in PSS compared to the observations over a wide range of flux-densities. On a closer inspection of the predicted luminosity distribution at various flux-densities by this model, we could trace the discrepancy to the nature of the evolution function itself. The main difference between model 5 of WPL and the other two is that it introduces evolution even for relatively low radio luminosities. For instance, at a redshift of $z = 0.25$, the evolution introduced is a factor of about 5 for $P = 10^{24.5}$ W Hz^{-1} sr^{-1} and 10 for $P = 10^{25}$ W Hz^{-1} sr^{-1}. The other models studied by us do not introduce any evolution at all at these luminosities. Thus model 5 of WPL predicts about 27% of all sources between 0.5-0.9 Jy to be contributed by the source of luminosities in the range $10^{24.7-25.5}$ alone, out of which a majority arises from $0.1 < z < 0.25$. On the contrary only about 15 percent of the sources of these flux-densities have actually been identified with galaxies on PSS, and even the total identification with any object registered in PSS including QSOs or BSOs is only about 25 percent. If we had considered the limiting magnitude of PSS as 19.0 or 20.0 instead of 19.5 as assumed in Section 4.1, the predicted identification would be only a few percent lower or higher respectively. Further, if the predictions were made by assuming the absolute optical magnitude of galaxies identified with radio sources as $M_{pg} = -21.8$ (for $H_o = 50$ km s^{-1} Mpc^{-1}) as has been done by previous workers (e.g. Katgert et al. 1979), rather than considering the FBLF given in Table 1, the predicted identification would be a few percent higher at the 5C level. Thus, we conclude that it is not possible to make model 5 of WPL consistent with the PI(S) data given in Fig. 1. This conclusion is also independent of any possible uncertainties in the LLF as discussed below.

As seen from Fig. 1, model 4b is in reasonable agreement with the observations for $S_{408} > 0.1$ Jy, but its predicted identification rates are too high at the 5C level. Again, on inspection of the luminosity distributions at various flux-densities, we find this could largely be due to an overestimate of the assumed LLF at luminosities 10^{23-25} W Hz^{-1} sr^{-1}. As mentioned earlier, the assumed LLF is indeed appreciably higher than that expected from the direct observational determinations of LLF of ellipticals. Also, at these luminosities, the available luminosity distribution of S > 10 Jy involves very few sources and hence even large changes in the LLF could still be reasonable within the expected observational uncertainties. Hence it is interesting to examine the consequence of using a lower LLF than that used by WPL at these luminosities. Since the accuracy of our data does not warrant a rigorous procedure for the determination of LLF from PI(S), we will only indicate the results for an arbitrary choice of LLF intermediate between the observational estimates and that used by WPL, as shown by the broken line in Fig. 2. For P > $10^{24.5}$ W Hz^{-1} sr^{-1}, the LLF of WPL is retained. The resulting PI(S) is shown by the curve labelled 4b' in Fig. 1, which is seen to be in better agreement with the observations than the original curve for model 4b. The predicted values of PI(S) for the model 4a of WPL for their LLF is somewhat higher than those for model 4b'.

A revision of LLF as above without revising the EF is not in conformity with the procedure outlined by WPL, which requires that the evolution parameters be optimised again for the observed source counts. This has been attempted by us for the model of type 4b, for which we find that an excellent agreement with the source counts for $S_{408} > 10$ mJy is restored with the modified LLF for the following choice of parameters:

$$\log P_1 = 25.0, \ \log P_2 = 27.5, \ z_c = 10,$$

where the symbols have the same meaning as in model 4b of Wall et al. (1977). For convenience, this model is denoted by the symbol S the resulting prediction for this revision is also shown in Fig. 1 (labelled S) and it can be seen that this leads to a better agreement with the observed PI(S) data. It may be noted here that the radio galaxies seen on PSS at low flux-densities are mainly of low luminosities for which models of type 4b or R do not predict any evolution. Thus the difference in the predicted PI(S) arises largely from the different counts predicted by these models at low flux-densities. For instance, model 4b underestimates the counts at the 5C level with respect to the observations, whereas model R overestimates them. Thus, our conclusion regarding the need for revising LLF is independent of the nature of the evolution function as long as the evolution is not significant for P $\lesssim 10^{24.5}$ W/Hz/sr.

5. - DISCUSSION AND CONCLUSIONS

The optical identification statistics have been summarised for a sample of about 500 radio sources in the Ooty occultation survey corresponding to $S_{327} > 0.3$ Jy and $|b| > 20°$. In view of their accurate radio positions and also the structural information provided by the occultation observations, reliable data are available on their optical identifications based on Palomar Sky Survey prints. By supplementing these data with the identification statistics available in literature for the sources from the 3CR, B2, 5C3, 5C7 and 5C12 catalogues, we have derived a flux-density dependence of the percentage identification of radio sources with galaxies, PI(S), as registered in PSS. The observed PI(S) data for the Ooty sources agree well with those of B2 sources which have a similar range of flux-densities.

The PI(S) relation determined by us for galaxies seen on PSS for radio sources with a flux density range of about 1000:1 at 408 MHz is compared with the predictions of models of local luminosity function as derived by Wall et al. (1977; 1980) and by Robertson (1980). These models are based on observed radio source counts and luminosity distribution of strong radio sources. We find that the PI(S) data do not support model 5 of Wall et al. inspite of its consistency with the radio source counts. A similar result is also indicated by Wall et al. (1980). We find that the model 5 is rejected more clearly if differential rather than integral PI(S) data is considered. The PI(S) relation is in reasonable agreement with model 4(b) of Wall et al. and with the 'standard' free form model of Robertson. In contrast to the model 5, the latter two are characterized by the absence of any evolution for luminosities lower than 10^{25} W Hz^{-1} sr^{-1} at 408 MHz, as is also indicated from the deep identication work by Katgert et al. (1979). Further, the predictions get closer to the PI(S) data by taking the LLF in the radio luminosity range of about 10^{23-25} WHz^{-1} sr^{-1} to be somewhat lower than that assumed by Wall et al., and to be closer to that for ellipticals as determined by Auriemma et al. (1977) and others.

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