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Letter to the Editor

Are ultra-luminous infrared galaxies the dominant extragalactic population at high luminosities?

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Abstract. Based on the recent QSO surveys it is shown that, contrary to the widespread notion, high-luminousity QSOs are at least as numerous in the nearby universe as the ultraluminous far-infrared galaxies (ULIGs). Therefore, the fraction of ULIGs that have got a hidden quasar at the nucleus, for example in the dust shrouded phase, cannot be overwhelmingly large.

Key words: galaxies: interactions – galaxies: luminosity function – galaxies: starburst – galaxies: active – quasars: general – infrared: galaxies

1. Introduction

During the last few years, major progress has occurred towards understanding the temporal evolution of powerful double radio sources (e.g., Fanti et al., 1995; Readhead, 1995). This, in turn, has strengthened the case for orientation based connection between radio-loud quasars and powerful narrow-line radio galaxies (reviewed, e.g., by Antonucci, 1993; Urry & Padovani, 1995; Gopal-Krishna, 1996; Gopal-Krishna, Kulkarni & Wiita, 1996). The main factor responsible for this development is that, although a minor subset of the quasar population, the radio-loud quasars have the advantage of possessing observational (statistical) indicators of their viewing angle, such as the overall radio size, the prominence and polarization of the radio core, etc. Unfortunately, in the absence of such clues, the parent population of radio-quiet quasars (i.e., QSOs) and hence their proposed unified scheme has remained less well established. One possibility mentioned in the literature is a class of galaxies called Ultra Luminous Infrared Galaxies (ULIGs) (see, e.g., Antonucci 1993). An important hint in this direction came from the $IRAS$ observations which established the significance of this class of galaxies, which emit most of their radiation in the infrared/sub-millimetre region ($L_{IR} \geq 10^{12}\ L_{\odot}$, taking, $H_o = 75\ kms^{-1}.Mpc^{-1}$ and $q_o = 0.5$) (Soifer, Houck & Neugebauer, 1987). However, the situation could be more complex, since it has been demonstrated, that essentially all such objects are gas-rich galaxies undergoing mergers (e.g., Armus, Heckman & Miley, 1987; Sanders et al., 1988b; Melnick & Mirabel, 1990; Kim et al., 1995; Murphy et al., 1996), and thus the mergers seem to play a key role in producing the copious emission observed in the far-infrared (e.g., Harwit et al., 1987).

Another unexpected discovery, stemming from the redshift measurements of complete samples of $IRAS$ selected galaxies, was the realization that ULIGs ($L_{IR} \geq 10^{12}\ L_{\odot}$, extending up to $10^{14}\ L_{\odot}$) are the dominant population *at least* in the nearby extragalactic universe. It was found that in the local universe, the ULIGs are twice as abundant as the optically selected QSOs, the only other source population found at such high luminosities (Soifer et al., 1987; Sanders et al., 1988a; Sanders & Mirabel, 1996). An important offshoot of this finding is the currently much debated proposal according to which ULIGs represent the early phase during which the active nucleus, the QSO, remains obscured by the dusty Interstellar Medium (ISM) of the galaxy (e.g., Soifer et al., 1987; Sanders et al, 1989; Heckman, 1991; Terlevich, 1992; Lonsdale, Smith & Lonsdale, 1995; Egami et al., 1996). Under this hypothesis the relative abundances of Qsos and ULIGs would basically depend on the durations of the two phases.

2. How dominant is the ULIG population?

The need to revisit this question, which set the tone for the proposed physical connection between the radio-quiet QSOs and ULIGs, has arisen from the new determinations of the QSO luminosity function (QLF). These new QLFs reinforce the prevailing concern about the completeness of some earlier large-scale surveys for bright QSOs, which employed the criterion of $UV\ excess$ and, moreover, suffered from rel-

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atively large photometric errors: such as the *Palomar – Green Bright Quasar Survey*, PG/BQS: Schmidt & Green, 1983; and the sample discussed by Boyle et al., 1991). These surveys formed the basis for the inferred dominance of the ULIG population over the luminous QSOs in the local universe (Sect. 1). In recent years, a number of studies have indicated serious incompleteness in these QSO samples (e.g., see, Wampler & Ponz, 1985; Goldschmidt et al., 1992; also, Cristiani et al., 1995) and it has also been reported that a substantial fraction of QSOs at small redshifts do not show a large UV excess (e.g., Hawkins & Véron 1995; hereafter, HV95). Strong support to the apprehension of incompleteness has come from two independent QSO surveys which employ different search techniques and are, moreover, independent, or less critically dependent on the *UV excess* criterion. The earlier surveys based on this selection criterion (see above) showed a monotonic steepening of the QLF towards higher luminosities, which allowed the QLF to be represented by two power-laws, with the 'break' shifting to brighter absolute magnitudes with increasing redshift and thus giving an impression of pure luminosity evolution (e.g., Boyle et al., 1991). In contrast, the QLFs deduced from the two new surveys do not show any such clear pattern and are in fact featureless and consistent with a single power-law all the way to the highest luminosities. *This raises the possibility that highly luminous QSOs may be substantially more numerous than estimated previously.*

2.1. The two new optical samples of QSOs

(i) The optical-variability selected sample (HV95):

This sample was derived from QSO candidates above certain specified (blue) apparent magnitude limits at a fixed epoch 1977. The other search criteria include a stellar, or marginally resolved appearance, a well defined minimum flux variability and/or blue colour $(U - B) \leq 0$ (see HV95 for details). The spectroscopic follow-up of the candidates was carried out using the AAT and the ESO 3.6-m telescope and, in order to derive luminosity functions for successive redshift intervals, these data were supplemented with those obtained from the Edinburgh bright quasar survey (Goldschmidt et al., 1992). Interestingly, for all three redshift intervals covering the range $z = 0.7 - 2.2$, the QLF is found to be consistent with a single power-law. Secondly, these data show a strong evolution of the co-moving space density, ϕ, of QSOs of different luminosities (M_B in the range -24.5 *to* -27.5), consistent with $\phi \sim (1 + z)^{+6}$ which is similar to the early estimate from Schmidt (1968).

(ii) The Hamburg/ESO sample of QSOs (HES):

This is a new flux-limited sample of bright QSOs and Seyfert 1 galaxies, drawn from the ongoing large-sky Hamburg/ESO survey (HES: Köhler, et al. 1997). In this survey, QSO candidates are selected by automated procedures from digitized objective-prism plates taken with the ESO Schmidt telescope, followed by slit-spectroscopy of *all* candidates brighter than $B_{lim} \sim 17.0 - 17.5$. The HES is being extended to cover a total area of $\sim 5000\ deg^2$ at high galactic latitudes (Wisotzki et al., 1996). It does not discriminate against resolved objects and, moreover, has the potential to provide information on the brightest parts of the QLF, even at small redshifts. Thus, when completed, this survey is expected to define the QLF with unprecedented reliability. Nonetheless, even at this preliminary stage, the QLF, determined up to $z \sim 0.3$, is found to be consistent with a power-law slope (which, turns out to be quite similar to the slope found by HV95 for higher redshift bins; see above). In view of this general agreement and considering the early stage of the HES, we shall employ in the present study mainly the HV95 sample. In Fig. 1 the thick dotted curve shows the Local Luminosity Function (LLF) of optically selected AGN, based on the HES survey (Sect. 2).

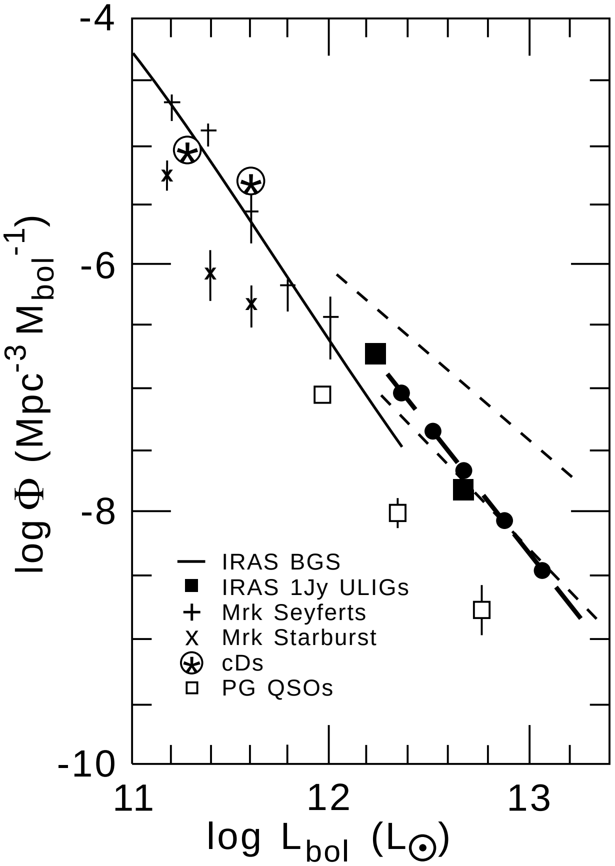

Fig. 1. The luminosity functions for infrared galaxies and other extragalactic objects, reproduced from Sanders & Mirabel (1996). Superposed are two broken lines showing the luminosity functions for QSOs derived from the recent dataset (HV95) employed in the present work, extrapolated to $z = 0.1$, taking the density evolution to be proportional to $(1 + z)^{-3}$ (upper curve) and $(1 + z)^{-6}$ (lower curve) (Sect. 3). The local luminosity function (LLF) of QSOs derived from the data of Wisotzki et al.(1996; HES) is shown by a thick dotted line (Sect. 2 and 3).

3. Local luminosity functions: QSOs *versus* ULIGs

Fig. 1 illustrates the local luminosity function (LLF) of IRAS detected luminous infrared galaxies, over the range $L_{bol} = 10^{11}$

to 10^{13} $L_{\odot}$. Also, shown is the corresponding LLF for the QSOs found in the PG survey. All these data points are taken from Sanders & Mirabel (1996), and are originally determined from the $IRAS$ RBGS (Sanders et al., 1996), $IRAS$ 1-Jy survey (Kim, 1995) and the PG survey (Schmidt & Green, 1983). They refer to a Hubble constant $H_o = 75\ kms^{-1}\ Mpc^{-1}$ and a typical redshift of $z \sim 0.1$. In order to superpose on these plots the recent estimates of QSO number densities given by HV95 for the redshift interval $z = 0.7 - 1.2$ ($z_{median} \sim 1.0$), we have scaled the latter to $H_o = 75\ kms^{-1}.Mpc^{-1}$ and then translated from $z = 1$ to $z = 0.1$, according to the best available estimate for the evolution law: $\phi \sim (1 + z)^6$ (e.g., HV95) (This may already be conservative in view of the considerably slower evolution inferred at small redshifts by Köhler et al., 1997). Following Sanders & Mirabel (1996), we have applied the bolometric luminosity correction for QSOs: $L_{bol} = 11.8$ x $\nu L_{\nu}(0.43\mu m)$. However, as a word of caution we note that such a procedure, albeit commonly used, implicitly assumes an isotropic emitter at all wavelengths, which is unlikely to be true for Qsos, but may be used as a first approximation; to be able to make a consistent comparison with the recent literature, we have thus followed the same steps.

From Fig. 1, it is evident that, firstly, the space density of the most luminous QSOs ($L_{bol} = 10^{12} - 10^{13}\ L_{\odot}$) in the local universe is systematically higher than the PG estimates, by almost an *order-of-magnitude*.

Secondly, over the luminosity range mentioned above, these revised QSO number densities are in fact very similar to the the densities of ULIGs, which is contrary to the general notion that the latter dominate the local universe at high luminosities (cf. Sect. 1). From the present work, the abundances of the two ultra-luminous populations, the ULIGs and the QSOs, appear to be quite similar at small redshifts; however, below $L_{bol} \sim 10^{12}\ L_{\odot}$, QSOs may well be less abundant (Fig. 1). This is also quite consistent with the local luminosity function derived from the HES survey reported by Wisotzki et al. (1996) (Fig. 1). One immediate consequence is that the fraction of *dust shrouded* quasars cannot be large, at most 50% and probably less, since several clear examples are known where the powerful infrared activity is primarily related to starburst, to all available evidence.

While a larger database is needed to arrive at robust estimates, the inferences reached here present a fairly plausible interpretation of the currently available data and provide some useful constraints on the temporal evolution of QSOs. For instance, if indeed, most QSOs initially pass through a dust shrouded phase (Sect. 1), then such a phase doesn't last much longer than the optically ultra-luminous phase. Also, once the postulated dusty cocoon has been largely blown away by the QSO radiation, a large fraction of the solid angle around the nuclear source (QSO) is left open by any residual obscuring torus around the nucleus (e.g., Hines et al., 1996). Theoretically, this is not unexpected in view of the high luminosities of the QSOs being considered here (e.g., Netzer & Laor, 1993; Königl & Kartje, 1994).

4. Summary

Employing the recent determination of the QSO luminosity function, we have shown that in the nearby universe high-luminosity QSOs ($L_{bol} \geq 10^{12}\ L_{\odot}$) are as least as abundant as ultra-luminous far-infrared galaxies (ULIGs). Thus, the latter are *not* the numerically dominant population at high luminosites, as is frequently claimed. This suggests that if an evolutionary connection between QSOs and ULIGs does exist, the time scales of the two phases are probably not very different.

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References

Antonucci, R.: 1993 Ann. Rev. Astron. & Astrophys. **31**, 473

Armus, L., Heckman, T., Miley, G.: 1987 Astron. J. **94**, 831
336, 606

Boyle, B., Jones, L., Shanks, T., Marano, B., Zitelli, V., Zamorani, G.: 1991 in "ASP Conf. Ser. 21, The Space Distribution of Qusars", ed. D. Crampton (San Francisco: ASP), 191

Cristiani, S. et al.: 1995 Astron. & Astroph. Suppl. **112**, 347

Egami, E., Iwamuro, F., Maihara, T., Oya, S., Cowie, L. L.: 1996 Astron. J. **112**, 73

Fanti, C., Fanti, R., Dallacasa, D., Schilizzi, R. T., Spencer, R. E., Stanghellini, C.: 1995 Astron. Astrophys. **302**, 317

Goldschmidt, P., Miller, L., La Franca, F., Cristiani, S.: 1992 Montly Not. Roy. Astr. Soc. **265**, 65P

Gopal-Krishna: 1996 in "Extragalactic Radio Sources", Eds. R. Ekers et al. (IAU Symp. No. 175), 373

Gopal-Krishna, Kulkarni, V.K., Wiita, P.J.: 1996 Astrophys. J. Letters **463**, L1

Harwit, M., Houck, J. R., Soifer, B. T., Palumbo, G. G. C.: 1987 Astrophys. J. **315**, 28

Hawkins, M. R. S., Véron, P.: 1995 MNRAS, **260**, 202 (HV95)

Heckman, T. M.: 1991 in "Massive Stars in Starbursts", eds. C. Leitherer et al., (STScI Symp. Ser. 5), 289

Hines, D. C., Schmidt, G. D., Smith, P. S., Cutri, R. M., Low, F. J.: 1995 Astrophys. J. Letters **450**, L1

Kim, D. -C.: 1995 in "The IRAS 1 Jy Survey of Ultra-luminous Infrared Galaxies", Ph.D. thesis, Univ. of Hawaii

Kim, D.-C., Sanders, D. B., Veilleux, S., Mazzarella, J. M., Soifer, B. T.: 1995 Astrophys. J. Suppl. **98**, 129

Köhler, T., Groote, D., Reimers, D. Wisotzki, L.: 1997 Astron. & Astroph. **325**, 502 - 510 (HES)

Königl, A., Kartje, J.F.: 1994 Astrophys. J. **434**, 446

Lonsdale, C.J., Smith, H. E., Lonsdale, C. J.: 1995 Astrophys. J. **438**, 632

Melnick, J., Mirabel, I. F.: 1990 Astron. Astrophys. **231**, L9

Murphy, T. W. et al.: 1996 Astron. J. **111**, 1025

Netzer, H., Laor, A.: 1993 Astrophys. J. Letters **404**, L51

Readhead, A. C. S.: 1995 Proc. Natl. Acad. Sci. **92**, 11447

Sanders, D.B., Mirabel, I.F.: 1996 Ann. Rev. Astron. & Astroph. **34**, 749

Sanders, D.B., Phinney, E. S., Neugebauer, G., Soifer, B. T., Matthews, K.: 1989 Astrophys. J. **347**, 29

Sanders, D.B., Soifer, B. T., Elias, J. H., Matthews, K., Madore, B. F.: 1988a Astrophys. J. **325**, 74

Sanders, D.B., Soifer, B. T., Elias, J. H., Neugebauer, G., Matthews, K.: 1988b Astrophys. J. Letters **328**, L35

Sanders, D. B., Surace, J., Egami, E., Mazzarella, J. M., Kim, D. C.: 1996 Astrophys. J. Suppl., in press

Schmidt, M.: 1968 Astrophys. J. **151**, 393

Schmidt, M., Green, R.F.: 1983 Astrophys. J. **269**, 352

Soifer, B. T., Houck, J. R., Neugebauer, G.: 1987 Ann. Rev. Astron. Astrophys. **25**, 187

Terlevich, R.: 1992 Relationship Between AGN and Sraburst Galaxies, ed. A. Filippenko (ASP-San Francisco), 133

Urry, C.M., Padovani, P.: 1995 Publ. Astron. Soc. Pac. **107**, 803

Wampler, E. J., Ponz, D.: 1985 Astrophys. J. **298**, 448

Wisotzki, L., Köhler, T., Groote, D., Reimers, D.: 1996 Astron. Astrophys. Suppl. **115**, 227

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