1

Black Hole Masses in Radio-Loud Quasars

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Abstract

Black hole mass estimates have been made for a number of quasars in a radio-selected sample using the virial estimator. It has been found that the range in black hole masses spans several orders of magnitude from $\sim 6 \times 10^6 M_\odot$ to $\sim 3 \times 10^9 M_\odot$. This is similar to the range in black hole masses seen for the radio-quiet quasar population. This is an interesting result as previous studies have not found low mass black holes in radio-loud quasars. A luminosity function has been derived for the sample of radio-selected quasars that can be used to explain this result. The luminosity function is possible due to the complete optical identification of the sample. We find that the space density of these radio-powerful quasars is different from optically-selected quasars and we suggest that this can explain why low mass radio-loud quasars are missed in optical/UV selected samples.

1.1 Introduction

One of the major questions outstanding in quasar astronomy is: What makes a quasar radio-loud? At optical wavelengths radio-loud and radio-quiet quasars have similar properties and yet there is a clear bimodality in the radio luminosity of quasars. The radio emission originates from the very central regions of the quasar and it is suggested that the black hole (BH) and accretion disk, responsible for generating the optical power in quasars, are also responsible for generating the radio-emission. It has been proposed that the mass of the BH is correlated with the radio activity of a quasar (Lacy et al. 2001, Dunlop et al. 2002) or that radio-loud quasar require a very massive BH in their cores (Laor 2000). Other studies have found that this may not be true and that the mass of the BH does not determine the radio properties of the quasars (Ho 2002, Oshlack, Webster & Whiting 2002, Woo & Urry 2002). In this contribution the results of BH estimates from a radio selected sample of quasars, the Parkes Half-Jansky Flat-Spectrum Sample (PHFS, Drinkwater et al. 1997), will be summarized and a luminosity function for these quasars is presented which provides an explanation for why different studies have produced different results regarding the relationship between BH mass and radio properties of quasars.

1.2 Black Hole Masses in Radio-Loud Quasars

We have investigated a sample of radio-selected quasars with large radio luminosities (for an alternative view see Jarvis & McLure (2002)). We have measured

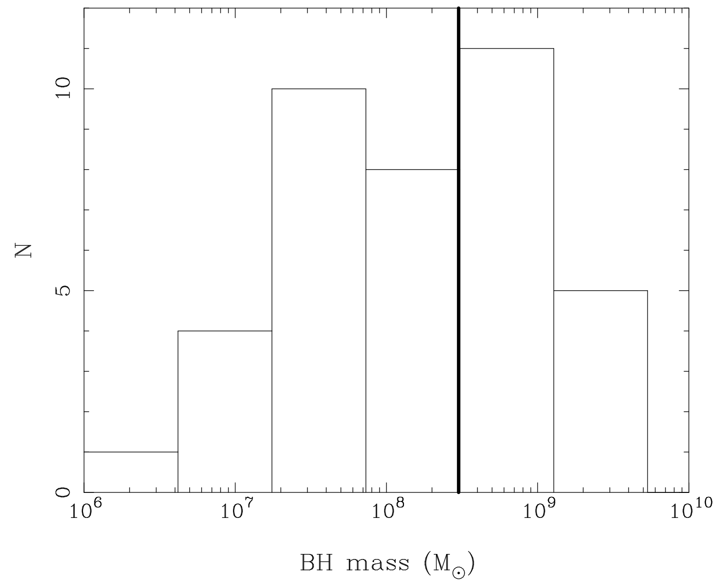

Fig. 1.1. The histogram of estimated BH masses of a sample of radio-loud quasars. It can be seen that there is a wide range in the values of the masses several of them below the limit suggest by (Laor 2000) for the lower limit of BH mass for radio-loud objects. This lower limit is indicated by the solid line.

the velocity widths of Hβ lines to indicate the velocity of the bulk motions of the gas in the broad line region. We determined the radius to the emitting gas using the empirical relationship between luminosity and radius measured by Kaspi et al. (2000). This enables us to use the radius and velocity to make virial estimates of the central BHs in a sample of 39 quasars from the PHFS. We find a large range in the values estimated for the BH mass. The distribution of the estimated masses is shown in Figure 1.1 and it is consistent with the distribution that has been measured for the radio-quiet population. In particular we find a significant number of quasars with low BH masses lower than those found by Laor (2000) when looking at the PG sample of quasars.

1.3 The Luminosity Function

The complete optical identification of the PHFS enables a luminosity function of these radio-selected quasars to be calculated. This provides information on the space density of radio-loud quasars, and also enables a comparison of the objects selected in radio and optical surveys shedding light on the effect of different selection techniques.

An unbiased subsample of quasars in the PHFS have quasi-simultaneous optical and near-infrared photometry which enables the accurate measurement of the shape of the spectral energy distribution (Francis, Whiting & Webster 2000). For these quasars a measurement of the rest frame B band magnitude can be made using K-corrections determined from photometric data points. This makes a crucial difference to the luminosity function as the wide range in colors of the quasars in the PHFS

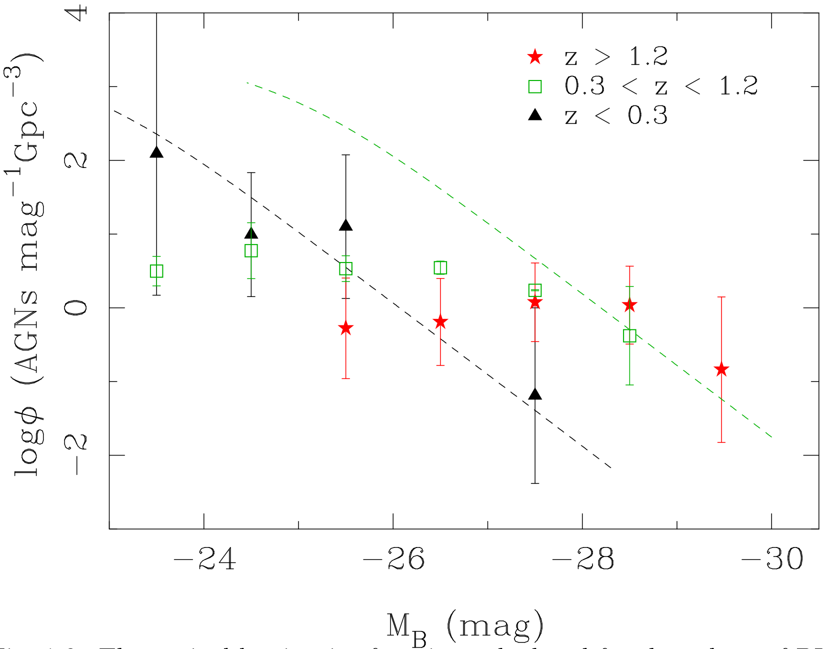

Fig. 1.2. The optical luminosity function calculated for the subset of PHFS quasars for which there is simultaneous photometry. The black triangles refer to objects with $z < 0.3$ the green squares for $0.3 < z < 1.2$ and the red stars for objects with $z > 1.2$. The two dashed lines are the luminosity functions derived for the 2QZ sample at $z = 0.3$ (black) and $z = 1.2$ (green) where pure luminosity evolution is observed (Boyle et al. 2000).

makes uniform K-corrections inaccurate. This subsample contains 157 quasars ranging in redshift up to $z = 3.6$, which have been used to create the luminosity function. Each quasar in the subsample is binned into luminosity bins each with a width of 1 magnitude. The $1/V_{max}$ volumes, which are calculated from the radio fluxes, are then added for each bin to get the number density for each magnitude bin i.e.

$$\phi(M)\Delta M = \sum_{M_i \in (M \pm \Delta M/2)} \frac{1}{V_{max}} \tag{1.1}$$

The luminosity function is shown in Figure 1.2. The quasars have been split into three redshift bins which can be used to give and indication of the type of evolution seen in the sample. The first redshift bin contains only a small number of objects and has redshifts $z < 0.3$ and is indicated in black. The redshift bin with the greatest number of objects has a range $0.3 < z < 1.2$ and is indicated in green while the high redshift bin contains the quasars with $z > 1.2$ and is shown by red stars. Also indicated in Figure 1.2 is the luminosity function derived by Boyle et al. (2000) using quasars from the 2dF Quasar Redshift Survey at two different redshifts. The black dashed line is the Boyle et al. (2000) luminosity function for $z = 0.3$ and the green line is for $z = 1.2$. It can be seen that the shape of the luminosity function shown here is very different from that measured from the 2dF Quasar Redshift Survey.

1.4 Discussion

Changing the ranges for the redshift bins doesn't change the result significantly. The low redshift luminosity function seems to follow the Boyle et al. (2000) luminosity function but the error bars are very large as there are only a few low redshift objects. For the low redshift function there are also luminosity bins which have no quasars, so the results are unreliable. The middle bin has the largest number of objects and is the most informative. The error bars are the smallest, and there are 67 objects in this redshift range.

What is extremely interesting is that the luminosity function is consistent with no change in space density of radio-loud quasars as a function of optical luminosity. In other words there are just as many optically bright radio-loud quasars as faint ones. This is different to optically-selected quasars where there is a steep drop off in space density at brighter magnitudes. This supports previous evidence which suggests the proportion of radio-loud quasars is higher for more luminous objects or, if an optically luminous quasar is selected it has a greater chance of being radio-loud than a lower luminosity quasar (Hooper et al. 1996, Goldschmidt et al. 1999). The results suggest that for $M_B > -28$ the space density of color-selected quasars from the 2dF survey and flat-spectrum quasars selected from the PHFS are similar. While at $M_B \sim -26$ the space density radio-loud quasars drops to about 1% of optically-selected quasars. This explains why radio-loud quasars taken from opically-selected surveys do not have low mass black holes as the radio-loud quasars found are more likely to be the high luminosity ones. Therefore to find low BH mass radio-loud quasars you need to look at radio-selected surveys.

One possible explaination for the difference in shape of the luminosity function of optically-selected and radio-selected sample may be that, at lower luminosities, a population of quasars with slightly different features is entering the radio-quiet population. For example, low luminosity AGN are often found in spiral galaxies while radio-loud quasars are almost exclusively found in elliptical galaxies. Therefore, if the number density of AGN with spiral hosts increases with decreasing AGN luminosity, but the number density of AGN with elliptical host stays constant, then this could explain the shapes of the two luminosity functions. The radio-loud luminosity function is flat due to a constant density of AGN with elliptical hosts with a certain fraction being radio-loud. The optically-selected luminosity function has a high density of quasars at low luminosities including a large number of AGN with spiral hosts. At very high luminosities we are left only with the AGN with elliptical hosts and therefore the highest fraction of radio-loud quasars.

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