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The mass function of local active black holes

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Abstract. We present estimated black hole masses and accretion rates for a well defined sample of local ($z < 0.3$) broad line AGN from the Hamburg/ESO Survey. We use these black hole masses to determine the active black hole mass function (BHMF) in the local universe. We find indications for anti-hierarchical growth of black holes, in the sense that the fraction of black holes in a high accretion stage significantly decreases with increasing mass. A comparison with the BHMF at higher redshifts also indicates that, at the high mass end, black holes are now in a less active stage than at earlier cosmic epochs. This strengthens the picture of cosmic downsizing of AGN activity, where the most massive black holes grew at early cosmic times, whereas at present mainly smaller mass black holes accrete at a significant rate.

Key words. Galaxies: active - Galaxies: nuclei - quasars: general

1. Introduction

The observed relations between the black hole mass and the properties of the spheroidal galaxy component imply a close connection between the growth of supermassive black holes (SMBH) and the evolution of their host galaxies. For an understanding of the influence of black hole growth on galaxy evolution over cosmic time, first the properties of growing black holes in the local universe have to be well understood. Thus it is important to measure black hole masses and accretion rates of large, well defined samples of AGN. A very useful tool to study the AGN population is the luminosity function (AGNLF). The observed evolution of the AGNLF has been used to gain insight into the growth history of black holes (e.g. Yu & Tremaine 2002; Marconi et al. 2004; Merloni 2004). However, this approach usually requires further assumptions. Alternatively, a direct determination of the active black hole mass function (BHMF) using AGN samples is able to provide additional constraints on black hole growth. Herein, by 'active black hole', we mean a black hole found as an AGN by the respective survey.

A dataset that is perfectly suited to study luminous low redshift AGN is provided by the Hamburg/ESO Survey (HES; e.g. Wisotzki et al. 2000). We will use a local AGN sample, drawn from the HES, to estimate their black hole masses and accretion rates and construct the active BHMF. For a more detailed description see our forthcoming paper (Schulze & Wisotzki, in prep.).

2. The sample

The Hamburg/ESO Survey is a wide-angle, slitless spectroscopy survey for bright QSOs, carried out in the southern hemisphere, us-

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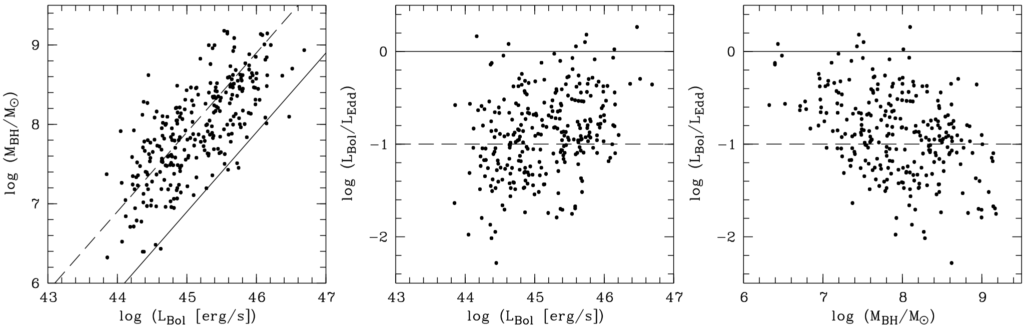

Fig. 1. Left panel: Black hole mass plotted versus bolometric luminosity. Middle panel: Eddington ratio versus bolometric luminosity. Right panel: Eddington ratio versus black hole mass is shown. The two lines indicate Eddington ratios of 0.1 and 1 respectively.

ing photographic objective prism plates which were digitized afterwards. The HES covers an area of ~9500 deg^2 within a magnitude range of $13 \lesssim B_J \lesssim 17.5$. The AGN candidates were selected mainly by a UV-excess-like color selection, based on the spectral energy distribution of the slitless spectra. Follow-up spectroscopy has been carried out to confirm their AGN nature.

The Hamburg/ESO Survey yields a well-defined, flux-limited sample with a high degree of completeness. The AGN candidate selection contains no morphological discrimination and covers a large area on the sky. It also effectively has no bright end cutoff, thus the HES is well suited to study the low-redshift AGN population.

The final Hamburg/ESO Survey QSO catalog contains 877 type-1 AGN. Spectra are available for most of them from the follow-up observations.

For our sample we select all objects with $z \leq 0.3$. In total the sample we used contains 329 type-1 AGN.

3. Black hole masses

Assuming virial equilibrium, black hole masses can be estimated by $M_{\mathrm{BH}} = f R_{\mathrm{BLR}} \Delta V^2/G$, where R_{BLR} is the size of the broad line region (BLR), ΔV is the broad line width in km/s and f is a scaling factor of order unity, which depends on the structure, kinematics and orientation of the BLR. Using the established scaling relationship between R_{BLR} and continuum luminosity of the AGN (e.g. Kaspi et al. 2005), we can estimate the black hole mass directly from our single-epoch spectra. We fitted the Hβ emission line, as well as nearby [O III] and Fe II lines by Gaussian components and measured the Hβ line dispersion from the fit. We estimated the black hole masses via

$$M_{\mathrm{BH}} = 24.6 \left(\frac{L_{5100}}{10^{44}\,\mathrm{ergs}^{-1}}\right)^{0.54} \left(\frac{\sigma_{\mathrm{line}}}{\mathrm{km/s}}\right)^{2} M_\odot \quad (1)$$

where L_{5100} is the continuum luminosity λL_λ at 5100 Å, and σ_{line} is the line dispersion of Hβ, using $f = 3.85$ (Collin et al. 2006) as well as the $R_{\mathrm{BLR}} - L_{5100}$ scaling relation of Bentz et al. (2007).

Additionally we estimated the bolometric luminosity of the AGN, applying a bolometric correction factor of $f_L = 9$ to the continuum luminosity, i.e. $L_{\mathrm{bol}} = 9\,L_{5100}$. Combining both gives the Eddington ratio $\epsilon = L_{\mathrm{bol}}/L_{\mathrm{Edd}}$, what can be understood as a normalized accretion rate. In Fig. 1 we plot these three quantities against each other.

In the left panel we plot M_{BH} versus L_{bol}. A correlation between the two is visible, although with significant scatter caused by the distribution of Eddington ratios.

The right panel shows that the Eddington ratio is anticorrelated with M_{BH}. Note that the absence of objects in the lower left corner is mainly caused by incompleteness. These objects have small black hole masses and low

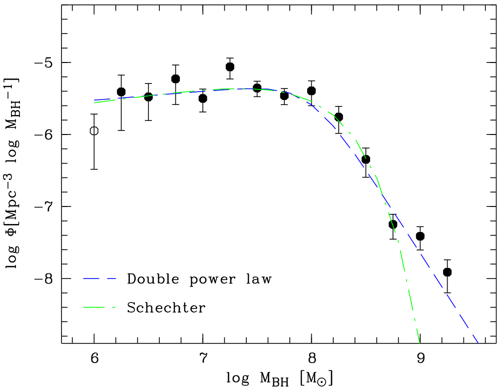

Fig. 2. The differential active black hole mass function for $z < 0.3$. The dashed line shows the double dower law fit to the BHMF, whereas the dashed dotted line gives the Schechter function fit.

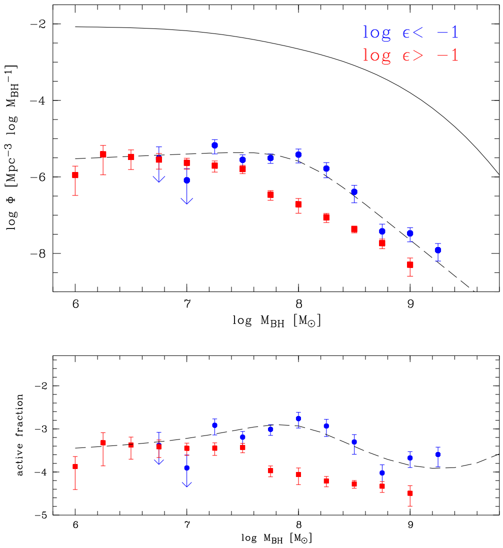

Fig. 3. Comparison of our active black hole mass function with the inactive BHMF of Marconi et al. (2004)(solid line). The active BHMF (upper panel) and the corresponding active fraction (lower panel) is shown for two Eddington ratio bins, above (red squares) and below (blue circles) log $\epsilon = -0.1$. The dashed line gives the double power law fit to the total BHMF.

accretion rates, thus have low luminosities and will be preferentially missed by our flux-limited survey. On the other hand, the absence of objects in the upper right part of the diagram seems to be physical. These objects would have high black hole masses and high accretion rates and would thus be bright AGN, visible in our survey. Thus there really is a lack of these high mass, high accretion rate AGN in the local universe. This result is even more pronounced in the analysis of the active black hole mass function.

4. The active black hole mass function

With the black hole masses estimated for our well defined sample, we constructed the binned active BHMF, similar to the determination of a luminosity function, using the classical $1/V_{\max}$ estimator (Schmidt 1968).

To correct for evolution within our small redshift bin $0 < z < 0.3$ we applied a simple pure density evolution model within the redshift bin, i.e. $\rho(z) = (1+z)^{k_{\rm D}}$ with $k_{\rm D} = 5$, thus adjusting our BHMF to redshift zero.

The active BHMF is well fitted by a double power law with an almost flat low mass slope of $\alpha \approx -0.9$ and a steep decrease toward high black hole mass with $\beta \approx -3.3$, with a break mass at $10^8 M_\odot$. Below $M_{\rm BH} \approx 10^7 M_\odot$ the BHMF is highly uncertain and potentially incomplete due to selection effects.

5. Discussion

The derived mass function of active black holes can be compared to the local mass function of quiescent black holes, as for example determined by Marconi et al. (2004), shown as the solid line in Fig. 3.

The lower panel in Fig. 3 shows the fraction of local black holes in an active stage as a function of the black hole mass. This activity fraction can be understood as a duty cycle for a black hole with given mass, at least in a statistical sense. For the whole sample the active fraction is roughly constant with black hole mass, with about 0.1 % of all black holes being in an active stage in the present universe.

To be less biased by selection effects we split our sample into two subsamples, based on the Eddington ratio ϵ at $\log \epsilon = -1$. The low-ϵ

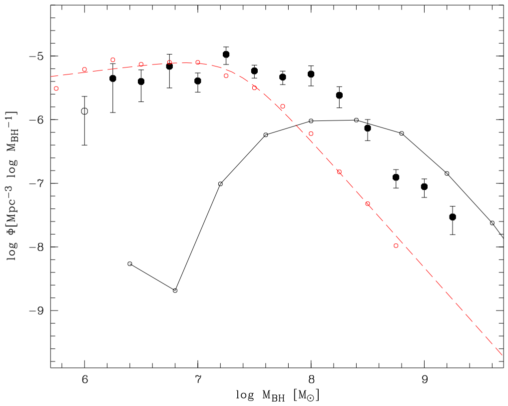

Fig. 4. Comparison of our $z \leq 0.3$ BHMF (filled circles) with the active BHMF of Greene & Ho (2007) (open red circles and dashed line) for $z \leq 0.35$ as well as with the BHMF within $0.3 \leq z \leq 0.7$ from Vestergaard et al. (2008) (black line and open circles).

subsample (circles) shows substantial incompleteness at low mass, thus we cannot make a clear statement on the behavior of the active fraction for low-ϵ black holes.

For the high-ϵ subsample our BHMF seems to be nearly complete. For this subsample we see that the active fraction decreases significantly with black hole mass from $\epsilon \approx 10^{-3}$ at low black hole mass towards $\epsilon \approx 10^{-4}$ at higher black hole mass. This downturn happens at $\log M_{\rm BH} \approx 7.5$. This result is in general agreement with the picture of anti-hierarchical growth of black holes (e.g. Merloni 2004), where the most massive black holes grew at early cosmic times and are preferentially in an less active stage in the present universe, and at present mainly smaller mass black holes grow at a significant rate.

Recently, other studies have also presented determinations of the active BHMF. Greene & Ho (2007) presented the local ($z < 0.35$) active BHMF, using the SDSS DR4 main galaxy sample as well as the QSO sample, looking for broad Hα lines. We compare their BHMF with our result in Fig. 4. The BHMFs are inconsistent with each other, especially at high black hole mass. This discrepancy is already present in the comparison of our AGN luminosity functions, thus we suspect the sample selection in the work of Greene & Ho (2007) is causing this incompleteness.

For higher redshift black holes, recently Vestergaard et al. (2008) presented an active BHMF from the SDSS DR3. We compare our $z \leq 0.3$ BHMF with their lowest redshift bin BHMF ($0.3 \leq z \leq 0.68$), shown in Fig. 4. The decline of the space density at the lowest $M_{\rm BH}$ is mainly due to incompleteness in this mass range caused by the flux limit of the survey. At the high mass end the BHMF shows a similar slope but a larger space density than our HES BHMF. This suggests a substantial decrease of the active fraction at the high mass end towards lower redshifts, exactly as would be expected in the scenario of anti-hierarchical black hole growth.

6. Conclusions

By a comparison of our local active BHMF with the local quiescent BHMF as well as with the higher-z active BHMF we have found evidence that strengthens the scenario of anti-hierarchical growth of black holes, at least at low redshifts.

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