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The black hole mass function of Type 1 AGN

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Abstract. An important question in the modern astrophysics is related to the origin and evolution of the supermassive black holes (SMBH) ubiquitous in the galaxy nucleus. In this work is shown a robust method to determine the estimator of the binned mass function of SMBH, n_{est}, hosted by type I AGN. The advantage of the method presented here is that the flux-limited of the survey was taken into account in a more accurate way. For this work it was considered data from Sloan Digital Sky Survey Data Release 7. We observed that the n_{est} was obtained with relative low bias and error. Also, it was noted that the BHMF declines at high redshifts and peaks in the range of $10^{8.6}\mathrm{M}_\odot$-$10^{9.3}\mathrm{M}_\odot$ shifting in the direction of high masses when z increases.

1. Introduction

In a recent work we have developed a new data mining process to obtain a statistical representative subsample of supermassive black holes (Pereira & Miranda, 2014). The advantage of our method with respect to previous works in the literature is that the flux-limited of the catalog was taken into account in a more accurate way. The basic key of the method is in the fact that we combine robust statistical methods: The Freedman-Diaconis rule (Freedman Diaconis 1980) to calculate the width of the bin used to obtain the probability density function of the bolometric quasar luminosity (PDFL); and non-parametric Monte Carlo bootstrap resample with replacement method (henceforward just bootstrap) to estimate the bias and error of the derived data. The advantage of this method is that no prior knowledge about the data distribution is necessary.

In that previous work we studied the mean Eddington ratio (MER) which is associated with both the dynamic of accretion as with the balance between the gravitational force and the radiation pressure of the accretion disk. We have shown that the MER was related to the mean bolometric luminosity and with the available gas to the growth of supermassive black holes. This last fact could be measured by the evolution history of the mean accretion rate. Thus, we could present for the first time a clear physical meaning for the MER.

Our intention is to study the connection between the Duty Cycle of type I AGN with the cosmic star formation rate. The Duty Cycle function is defined as the ratio between active and total supermassive black holes. For this propose, we have as a first step to understand how is the distribution of the population of the active black holes hosted by type I AGN. In this work we extend the method presented by Pereira & Miranda (2014) in order to calculate the estimator of the mass function of supermassive black holes.

In this work we use as data sample the Sloan Digital Sky Survey Data Release 7 (SSDS DR7) Quasar Catalog (Schneider, 2010), that contains 105,783 type 1 AGN (quasars) with luminosity greater than $M_i = -22.0$. In particular, we consider the catalog provided by Shen et al. (2011) - the SSDS DR7 Catalog of Quasar Properties. This catalog contains supplementary information like: the *full-width-at-half-maximum* (FWHM) of broad lines; central black hole masses (estimated using the FWHM); luminosity of broad lines as well as the bolometric luminosity of the quasars. Our final subsample contains 57, 496 objects with redshift from 0.03 up to 4.5.

This work is organized as follows: In the section 2. an improved method to obtain the estimator of supermassive black hole mass function is presented. Our final remarks are presented in the section 3.. We consider standard cosmological model (ΛCDM) with $\Omega_b = 0.04$, $\Omega_m = 0.24$, $\Omega_\Lambda = 0.76$, $h = 0.73$.

2. The supermassive black hole mass function

Page & Carrera (2000) presented an improved method, when compared with the traditional $1/V_a$, to construct binned luminosity functions. The great contribution of that work was the better way to take into account the survey flux limit. If we apply the same considerations of Page & Carrera (2000) to obtain the supermassive Black Hole Mass Function (BHMF), then it is possible to write:

$$n_{bh}^{est}(z, m_{bh}) = \frac{N_{AGN}}{\int_{m_{bh,min}}^{m_{bh,max}} \int_{z_{min}}^{z_{max}} \frac{dV}{dz} dz dm_{bh}}, \tag{1}$$

where n_{bh}^{est} is the binned estimate of the BHMF, N_{AGN} is the number of objects found in the bin Δm_{bh} and Δz. Note that, because the subsamples are constructed considering the probability density function of the bolometric quasar luminosity (PDFL) (see Pereira & Miranda, 2014), the z_{max} that appears in Eq. (1) is just the maximum redshift of an object into the bin, e.i., the z_{max} is determined by the flux-limit of the survey in a given bin.

The error in $n_{bh}^{est}(z, m_{bh})$ can be obtained by:

$$\delta n_{bh}^{est}(z, m_{bh}) = \frac{\delta N_{AGN}}{\int_{m_{bh,min}}^{m_{bh,max}} \int_{z_{min}}^{z_{max}} \frac{dV}{dz} dz dm_{bh}}, \tag{2}$$

where δN_{AGN} can be given by the Poisson error. We also compute the error given by Eq. (2) using the Bootstrap method (for details see the appendix of the work of Pereira & Miranda, 2014). We observe that this method provides, with high accuracy, the same δn_{bh}^{est} given by the Poisson error. This imply that the Bootstrap is well calibrated as an error and bias estimator.

It is important to stress that the found bias is lower than a few percents of the value of the n_{bh}^{est}. Here we consider a double power law to fit the n_{bh}^{est} in the following form:

$$n_{bh} = n_{bh}^{*} \left[\left(\frac{m_*}{m_{bh}} \right)^{\gamma_1} + \left(\frac{m_{bh}}{m_*} \right)^{\gamma_2} \right], \tag{3}$$

where γ_1, γ_2, n_{bh}^{*} and m_* are free parameters.

In Figure 1 are presented the BHMF for the redshift range [0.3, 2.1]. In general, we observe that the BHMF declines for high redshifts and that the BHMF peaks in the range of $10^{8.6}M_\odot$-$10^{9.3}M\odot$ shifting for the direction of higher masses when z increases. An important point is that our results are in accordance with the works of Vestergaard et al. (2008), who obtained the BHMF considering the traditional $1/V_a$, and Wang et al. (2006). In Table 1 we present the best fit data parameters in the redshift range of $z = [0.3, 2.1]$.

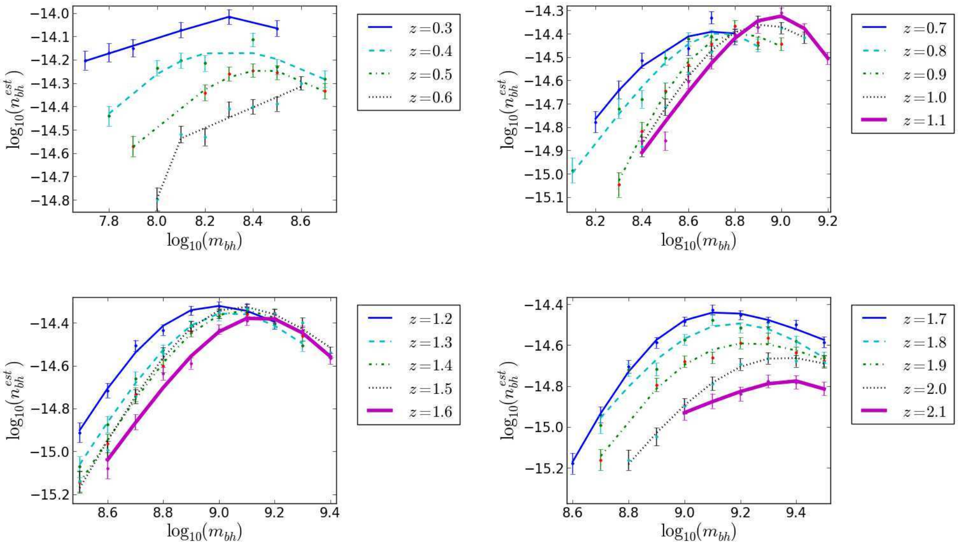

Figure 1. Binned Mass Function of supermassive black holes for redshifts $[0.3, 2.1]$.

3. Summary and perspectives

In this work is presented a new method to obtain the mass function of supermassive black holes. The difference of the method presented here, in relation to other methods described in literature, is that we employ a new data mining process in order to construct a representative subsample of the SMBHs. The major advantage of this method is the possibility of taking into account the catalog flux limit. This occurs because we consider the behaviors of the probability density function of the bolometric quasar luminosity distribution for each bin of mass, of the central black hole, and redshift. However, only a fraction of the original sample can be used to construct the final subsample.

In order to evaluate our method, it was considered the non-parametric Monte Carlo bootstrap resample with replacement (see Pereira & Miranda 2014 for details). From this method was calculated the bias of the obtained BHMF. We verify that the bias is lower than 4 percent of the final value of the BHMF estimators. This means that is possible to have a binning method to construct the BHMF with very low bias.

The BHMF declines at high redshifts and peaks in the range of $10^{8.6}M_\odot$-$10^{9.3}M_\odot$ shifting in the direction of higher masses when z increases.

The next step of our work will be calculate the mass function of the total supermassive black holes in order to obtain the Duty Cycle of quasar. Also we will present a

Table 1. Best fit parameters of BHMF at different redshifts

z	n^*_{bh} ($\times 10^{-15}$)	m_* ($\times 10^9$)	γ_1	γ_2
0.3	12.00	0.37	−6.41	−0.33
0.4	13.00	0.14	−0.66	−1.34
0.5	11.40	0.30	1.05	1.23
0.6	2.60	0.10	0.44	−80.03
0.7	7.60	0.38	−0.73	−1.56
0.8	8.00	0.60	−1.65	−1.32
0.9	7.09	0.47	−0.81	−2.28
1.0	8.46	0.71	−1.05	−1.73
1.1	9.15	1.11	−2.34	−1.35
1.2	8.57	0.71	−0.85	−2.27
1.3	8.56	0.93	2.10	1.19
1.4	8.87	1.05	2.08	1.27
1.5	8.8	0.94	2.32	1.04
1.6	8.48	1.36	1.81	1.63
1.7	5.82	0.86	2.71	0.59
1.8	6.23	1.27	−1.07	−1.78
1.9	4.43	1.12	2.14	0.65
2.0	4.10	1.70	−0.83	−1.76
2.1	2.51	3.79	0.57	3.53

robust model to connect the Cosmic Star Formation rate with the evolutionary history of supermassive black holes hosted by type I AGN.

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References

Page, M. J. & Carrera, F. J. 2000, MNRAS, 311, 433

Pereira, E. S. & Miranda, O. D. 2014, Ap&SS, 352, 801-807

Schneider, D. et al. 2010, AJ, 139, 6, 2360

Shen, Y. et al. 2011, ApJ Supplement Series, 194, 45

Vestergaard, M. et al. 2008, ApJ, 674, L1

Wang, J., Chen, Y. & Zhang, F. 2006, ApJ, 647, L17