Vol 12 No 11, November 2003
1009-1963/2003/12(11)/1310-07

Chinese Physics

© 2003 Chin. Phys. Soc.
and IOP Publishing Ltd

Central black hole masses of galaxies*

Fan Jun-Hui(樊军辉)†

Center for Astrophysics, Guangzhou University, Guangzhou 510400, *China*

(Received 11 April 2003; revised manuscript received 2 June 2003)

In this paper, the stellar velocity dispersions in the host galaxies are used to estimate the central black hole masses for a sample of elliptical galaxies. We find that the central black hole masses are in the range of $10^{(5.5-9.5)}M_{\odot}$. Based on the estimated masses in this paper and those by Woo & Urry (2002) and the measured host galaxy absolute magnitude, a relation, $\log(M_{\rm BH}/M_{\odot}) = -(0.25 \pm 4.3 \times 10^{-3})M_{\rm R} + (2.98 \pm 0.208)$ is found for central black hole mass and the host galaxy magnitude. Some discussions are presented.

Keywords: radio galaxies, black holes, masses
PACC: 9850S, 9760L, 9850F

1. Introduction

It is now believed that there are supermassive black holes at the centre of galaxies. In the case of active galactic nuclei (AGN), the supermassive black hole plays an important role in the explanations of the observations. Very recently, theoretical work about the physics process near black holes appears in many papers.[2−10,36] The central black hole mass estimations have attracted much attention, and many authors have tried to estimate the masses using different methods, 1) the reverberation mapping technique,[11,12] 2) the gas and stellar dynamics technique,[13−15] 3) variability timescale technique,[16,17] 4) the broad-line width technique (McLure & Dunlop; Vestergaard, based on the assumption that the clouds in the broad-line region (BLR) are gravitationally bound and orbiting with Keplerian velocities).[18,19] The central black hole mass is also found to be correlated to bulge luminosities,[20] the bulge mass,[14] the bulge velocity dispersion,[21−23] and the radio power.[24] However, very recently, Ho[25] found that the radio continuum power either integrated for the whole galaxy or isolated for the core, is poorly correlated to the central black hole mass. The relation between the central black hole mass and the radio loudness is also investigated (see Woo & Urry[1] and the reference therein). The tight $M_{\rm BH}$-σ correlation can be used, in return to estimate the central black hole mass in the assumption that the relation holds for other sources as did in the papers, for example, by Barth *et al*[26] and Wu *et al*,[27] who used the $M_{\rm BH}$-σ relation to estimate black hole mass for Mkn 501 and other AGNs. In addition, Cao[28] estimated black hole mass for a sample of BL Lacertae objects based on the assumption that broad emission lines are emitted from clouds ionized by the radiation of the accretion disc surrounding the black hole. In this paper, we also use the known $M_{\rm BH}$-σ relation to estimate black hole mass for a sample of elliptical galaxies. In section 2, we show the sample and the result. In section 3, we present discussions and a brief summary.

H_0=75km s^{-1} Mpc^{-1}, and q_0=0.5 are adopted throughout the paper.

2. Mass estimation method and result

2.1. Method

Based on the measured black hole masses and the bulge velocity dispersions, Gebhardt *et al*[22] and Merritt & Ferrarese[29] found the tight correlation between the two parameters for both normal and active galaxies. Later on, Tremaine *et al*[30] obtained a similar

*Project supported partially by the National Natural Science Foundation of China (Grant No 19973001), National 973 project (Grant No G19990754), the National Science Fund for Distinguished Young Scholars (Grant No 10125313), and Guangdong Fund for Top Scholars (Q02114).

†E-mail: fjh@gzhu.edu.cn

relation with a middle slope.

$$M_{\rm BH} = 1.2 \times 10^8 M_\odot (\frac{\sigma}{200 \text{ km s}^{-1}})^{3.75},^{[22]}$$

$$M_{\rm BH} = 1.3 \times 10^8 M_\odot (\frac{\sigma}{200 \text{ km s}^{-1}})^{4.72},^{[29]}$$

$$M_{\rm BH} = 1.2 \times 10^8 M_\odot (\frac{\sigma}{200 \text{ km s}^{-1}})^{4.02}.^{[30]}$$

If we assume those relations hold for all galaxies, then they can be used for mass estimation as long as the velocity dispersion is known. In the following section we will show the sources for which the velocity dispersions are measured.

2.2.Sample and results

In 1987, Djorgovski & Davis[31], gave an elliptical sample with velocity dispersions. They are listed in Table 1, in which Col. 1 gives the name, Col. 2 the host galaxy absolute magnitude, Col. 3 the velocity dispersion, Col. 4 the masses ($\log M^{\rm G}$) obtained from a relation by Gebhardt *et al*,[22] Col. 5 the masses ($\log M^{\rm F}$) obtained from a relation by Merritt & Ferrarese,[29] Col. 6 the masses ($\log M^{\rm T}$) obtained from a relation by Tremaine *et al*,[30] Col. 7 the masses ($\log M^{\rm MP}$) obtained from a relation in the present paper, Col. 8 the masses ($\log M^{\rm MBF}$) obtained from a relation given by Bettoni *et al*[32] and Falomo *et al.*[33]

The obtained masses are in the ranges of $\log M^{\rm G}(M_\odot) = 5.98-9.17$, $\log M^{\rm F}(M_\odot) = 5.47-9.49$, and $\log M^{\rm T}(M_\odot) = 5.88 - 9.30$. The corresponding averaged masses are $\log M^{\rm G} = 8.22\pm0.59$, $\log M^{\rm F} = 8.29\pm0.74$, and $\log M^{\rm T} = 8.28\pm0.63$.

From the black hole mass ($M_{\rm BH}$) estimated in a paper by Woo & Urry[1] and the present paper, and the host galaxy absolute magnitude ($M_{\rm R}$) given in a paper by Urry *et al*,[34] we find that there is a significant relation of $M_{\rm BH}$ and $M_{\rm R}$, $\log(M_{\rm BH}/M_\odot) = -(0.25 \pm 4.3 \times 10^{-3})M_{\rm R} + (2.98 \pm 0.208)$.

Table 1. Black hole masses calculated from dispersions and host galaxy magnitudes.

Name	$M_{\rm R}$	$\log\sigma$	$\log M^{\rm G}$	$\log M^{\rm F}$	$\log M^{\rm T}$	$\log M^{\rm MP}$	$\log M^{\rm MBF}$
NGC 57	–21.76	2.502	8.833	9.062	8.938	8.398	7.880
NGC 97	–20.92	2.086	7.272	7.099	7.266	8.189	7.460
NGC 194	–21.55	2.332	8.195	8.260	8.255	8.345	7.775
NGC 221	–16.21	1.898	6.567	6.212	6.510	7.016	5.105
NGC 410	–22.36	2.458	8.667	8.855	8.761	8.547	8.180
NGC 430	–20.92	2.497	8.814	9.039	8.918	8.189	7.460
NGC 533	–22.52	2.471	8.716	8.916	8.813	8.587	8.260
NGC 584	–20.91	2.369	8.334	8.435	8.403	8.186	7.455
NGC 596	–20.22	2.233	7.824	7.793	7.857	8.014	7.110
NGC 636	–19.61	2.238	7.842	7.816	7.877	7.862	6.805
NGC 661	–21.01	2.272	7.970	7.977	8.013	8.211	7.505
NGC 680	–20.77	2.362	8.307	8.402	8.375	8.151	7.385
NGC 720	–20.61	2.350	8.262	8.345	8.327	8.111	7.305
NGC 741	–22.37	2.477	8.739	8.944	8.838	8.550	8.185
NGC 750	–22.76	2.297	8.064	8.095	8.114	8.647	8.380
NGC 751	–22.79	2.369	8.334	8.435	8.403	8.654	8.395
NGC 777	–22.21	2.525	8.919	9.171	9.031	8.510	8.105
NGC 821	–20.60	2.332	8.195	8.260	8.255	8.109	7.300
NGC 890	–19.92	2.260	7.925	7.920	7.965	7.940	6.960
NGC 1016	–22.42	2.479	8.746	8.954	8.846	8.562	8.210
NGC 1052	–21.13	2.310	8.112	8.156	8.166	8.241	7.565
NGC 1132	–22.38	2.394	8.427	8.553	8.504	8.552	8.190
NGC 1172	–18.85	2.299	8.071	8.104	8.122	7.673	6.425
NGC 1199	–20.45	2.322	8.158	8.213	8.214	8.072	7.225
NGC 1209	–21.00	2.412	8.495	8.638	8.576	8.209	7.500
NGC 1395	–21.25	2.396	8.435	8.562	8.512	8.271	7.625
NGC 1407	–21.48	2.438	8.592	8.760	8.681	8.328	7.740
NGC 1426	–19.49	2.196	7.685	7.618	7.708	7.833	6.745

Table 1. (*Continued*)

Name	$M_{\rm R}$	logσ	log$M^{\rm G}$	log$M^{\rm F}$	log$M^{\rm T}$	log$M^{\rm MP}$	log$M^{\rm MBF}$
NGC 1439	–19.74	2.270	7.962	7.967	8.005	7.895	6.870
NGC 1521	–21.49	2.326	8.172	8.232	8.231	8.331	7.745
NGC 1587	–21.48	2.360	8.300	8.392	8.367	8.328	7.740
NGC 1600	–23.25	2.509	8.859	9.095	8.966	8.769	8.625
NGC 1653	–21.57	2.442	8.607	8.779	8.697	8.350	7.785
NGC 1700	–22.04	2.369	8.334	8.435	8.403	8.467	8.020
NGC 2476	–20.68	2.276	7.985	7.996	8.030	8.129	7.340
NGC 2778	–19.67	2.274	7.977	7.986	8.021	7.877	6.835
NGC 2832	–22.81	2.483	8.761	8.973	8.862	8.659	8.405
NGC 2872	–21.82	2.473	8.724	8.926	8.821	8.413	7.910
NGC 3070	–21.69	2.382	8.382	8.496	8.456	8.380	7.845
NGC 3091	–21.68	2.408	8.480	8.619	8.560	8.378	7.840
NGC 3158	–22.56	2.563	9.061	9.350	9.183	8.597	8.280
NGC 3193	–20.56	2.265	7.944	7.944	7.985	8.099	7.280
NGC 3226	–20.58	2.316	8.135	8.185	8.190	8.104	7.290
NGC 3853	–20.54	2.246	7.873	7.854	7.909	8.094	7.270
NGC 3862	–21.30	2.412	8.495	8.638	8.576	8.283	7.650
NGC 4168	–19.76	2.260	7.925	7.920	7.965	7.900	6.880
NGC 4239	–18.25	1.740	5.975	5.466	5.875	7.524	6.125
NGC 4261	–21.92	2.530	8.938	9.195	9.051	8.438	7.960
NGC 4318	–17.93	1.991	6.916	6.651	6.884	7.444	5.965
NGC 4365	–21.16	2.418	8.517	8.666	8.600	8.248	7.580
NGC 4374	–21.53	2.471	8.716	8.916	8.813	8.340	7.765
NGC 4387	–19.27	2.045	7.119	6.905	7.101	7.778	6.635
NGC 4406	–21.73	2.408	8.480	8.619	8.560	8.390	7.865
NGC 4434	–18.73	2.058	7.168	6.967	7.153	7.643	6.365
NGC 4458	–18.85	2.000	6.950	6.693	6.920	7.673	6.425
NGC 4472	–22.40	2.498	8.817	9.044	8.922	8.557	8.200
NGC 4473	–20.62	2.294	8.052	8.081	8.102	8.114	7.310
NGC 4478	–19.69	2.158	7.542	7.439	7.555	7.882	6.845
NGC 4486	–22.62	2.525	8.919	9.171	9.031	8.612	8.310
NGC 4486	–16.50	2.274	7.977	7.986	8.021	7.088	5.250
NGC 4489	–19.00	1.820	6.275	5.843	6.196	7.711	6.500
NGC 4551	–19.63	2.083	7.261	7.085	7.254	7.867	6.815
NGC 4552	–20.80	2.436	8.585	8.751	8.673	8.159	7.400
NGC 4564	–19.98	2.217	7.764	7.717	7.792	7.955	6.990
NGC 4621	–21.02	2.352	8.270	8.354	8.335	8.213	7.510
NGC 4649	–22.08	2.537	8.964	9.228	9.079	8.477	8.040
NGC 4660	–19.89	2.292	8.045	8.071	8.094	7.932	6.945
NGC 4782	–22.89	2.585	9.144	9.454	9.272	8.679	8.445
NGC 4783	–21.78	2.438	8.592	8.760	8.681	8.403	7.890
NGC 4867	–19.23	2.348	8.255	8.336	8.319	7.768	6.615
NGC 4874	–22.78	2.418	8.517	8.666	8.600	8.652	8.390
NGC 4881	–20.92	2.286	8.023	8.043	8.070	8.189	7.460
NGC 4886	–19.95	2.190	7.663	7.590	7.684	7.947	6.975
NGC 4889	–22.89	2.592	9.170	9.487	9.300	8.679	8.445
NGC 5129	–22.02	2.400	8.450	8.581	8.528	8.462	8.010
NGC 5322	–21.73	2.491	8.791	9.011	8.894	8.390	7.865
NGC 5424	–21.31	2.149	7.509	7.396	7.519	8.286	7.655

Table 1. (*Continued*)

Name	$M_{\rm R}$	logσ	log$M^{\rm G}$	log$M^{\rm F}$	log$M^{\rm T}$	log$M^{\rm MP}$	log$M^{\rm MBF}$
NGC 5490	–21.60	2.403	8.461	8.595	8.540	8.358	7.800
NGC 5638	–20.84	2.225	7.794	7.755	7.825	8.169	7.420
NGC 5796	–21.34	2.501	8.829	9.058	8.934	8.293	7.670
NGC 5813	–20.93	2.364	8.315	8.411	8.383	8.191	7.465
NGC 5831	–20.24	2.233	7.824	7.793	7.857	8.019	7.120
NGC 5845	–18.65	2.387	8.401	8.520	8.476	7.623	6.325
NGC 5846	–18.42	2.279	7.996	8.010	8.042	7.566	6.210
NGC 5846	–21.24	2.398	8.443	8.572	8.520	8.268	7.620
NGC 5966	–21.36	2.250	7.887	7.873	7.925	8.298	7.680
NGC 5982	–21.59	2.394	8.427	8.553	8.504	8.355	7.795
NGC 6086	–22.33	2.509	8.859	9.095	8.966	8.540	8.165
NGC 6137	–23.05	2.453	8.649	8.831	8.741	8.719	8.525
NGC 6146	–22.30	2.364	8.315	8.411	8.383	8.532	8.150
NGC 6166	–25.42	2.480	8.750	8.959	8.850	9.309	9.710
NGC 6173	–22.64	2.336	8.210	8.279	8.271	8.617	8.320
NGC 7391	–20.23	2.481	8.754	8.963	8.854	8.017	7.115
NGC 7454	–20.24	2.134	7.453	7.325	7.459	8.019	7.120
NGC 7458	–20.67	2.167	7.576	7.481	7.591	8.126	7.335
NGC 7562	–21.47	2.459	8.671	8.859	8.765	8.326	7.735
NGC 7619	–21.51	2.519	8.896	9.143	9.006	8.335	7.755
NGC 7626	–21.63	2.431	8.566	8.727	8.653	8.365	7.815
NGC 7660	–21.33	2.320	8.150	8.203	8.206	8.291	7.665
NGC 7768	–22.41	2.560	9.050	9.336	9.171	8.560	8.205
NGC 7778	–21.72	2.322	8.158	8.213	8.214	8.388	7.860
NGC 7785	–21.57	2.382	8.382	8.496	8.456	8.350	7.785
IC 179	–20.73	2.447	8.626	8.803	8.717	8.141	7.365
IC 962	–20.86	2.185	7.644	7.566	7.664	8.174	7.430
IC 1211	–21.11	2.212	7.745	7.694	7.772	8.236	7.555
IC 4051	–19.58	2.362	8.307	8.402	8.375	7.855	6.790

3. Discussion

In AGNs, the central black hole plays an important role in the observational properties and has drawn much attention. The central black hole mass should shed some lights on the evolution process in AGNs.[26,28,35] In the present paper, we use the known $M_{\rm BH}$-σ relation to estimate the masses for an elliptical galaxies. The estimated masses from different relations are quite similar as shown above.

The relation between the host galaxy absolute magnitude ($M_{\rm R}$) and the central black hole mass was discussed by Bettoni *et al*[32] and Falomo,[33] who found $\log M_{\odot} \propto -0.5 M_{\rm R}$. Here, we obtained $\log(M_{\rm BH}/M_{\odot}) = -(0.25 \pm 4.3 \times 10^{-3}) M_{\rm R} + (2.98 \pm 0.208)$. When we adopted our relation to the mass estimation for galaxies given in a paper by Bettoni *et al*,[32] our mass estimation is compared with those from both velocity dispersion and the relation by BF[32,33] (see Fig.1(a) and 2(a) for histograms). The K-S tests are shown in Fig.1(b) for $M^{\rm MP}$ and $M^{\rm MBF}$ and Fig.2(b) for M^{σ} and $M^{\rm MP}$. The K-S test indicates that the null hypothesis cannot be rejected at the 0.01 and $< 10^{-6}$ confidence level for $M^{\rm MP}$-$M^{\rm MBF}$ and M^{σ}-$M^{\rm MP}$ respectively. When we compare the masses estimated from velocity dispersion and those by BF relation for the sources in the paper by Bettoni *et al*,[32] we find that a K-S test indicates that the null hypothesis cannot be rejected at 10^{-5} confidence level. But when we use BF relation to estimate the black hole mass of galaxies listed in Table 1, we find that the mass given by BF relation is lower than that by velocity dispersions (see column 8 in Table 1). The histograms and K-S tests are shown in Fig.3 for $M^{\rm MP}$ and $M^{\rm MBF}$ and Fig.4 for M^{σ} and $M^{\rm MP}$. The K-S test indicates that the null hypothesis cannot be rejected at the $< 10^{-6}$ and 9.3×10^{-4} confidence level for M^{MP}-$M^{\rm MBF}$ and M^{σ}-$M^{\rm MP}$ respec-

tively. The difference is caused by the fact that the mass estimation of our relation gives higher central black hole masses than the relation by BF when the host galaxy magnitude is dimmer than –23.92 magnitude, but the latter relation gives lower central black hole masses than the former relation when host galaxy magnitude is brighter than –23.92 magnitude. However, both relations give similar black hole masses for the sources with host galaxy absolute magnitude being about –24.0 magnitude. Does our result indicate that there is different $M_{\rm BH}$-$M_{\rm R}$ relation for different brightness host galaxy? This should be confirmed with more data.

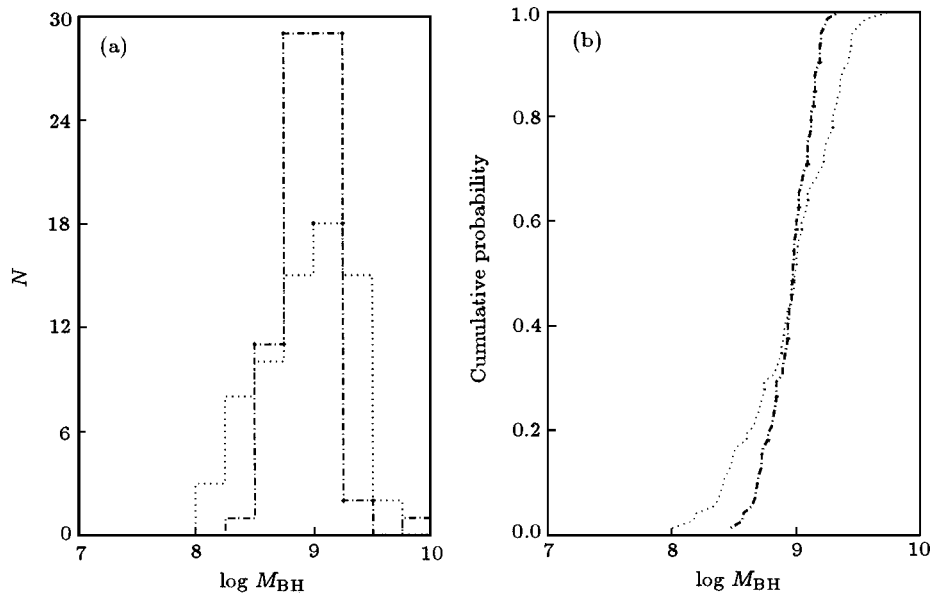


Fig.1. (a) Histogram of black hole mass for the sources listed in a paper by Bettoni *et al* (dotted curve stands for data from our relation, dot-dashed curve for data from BF relation); (b) cumulative probability of black hole mass.

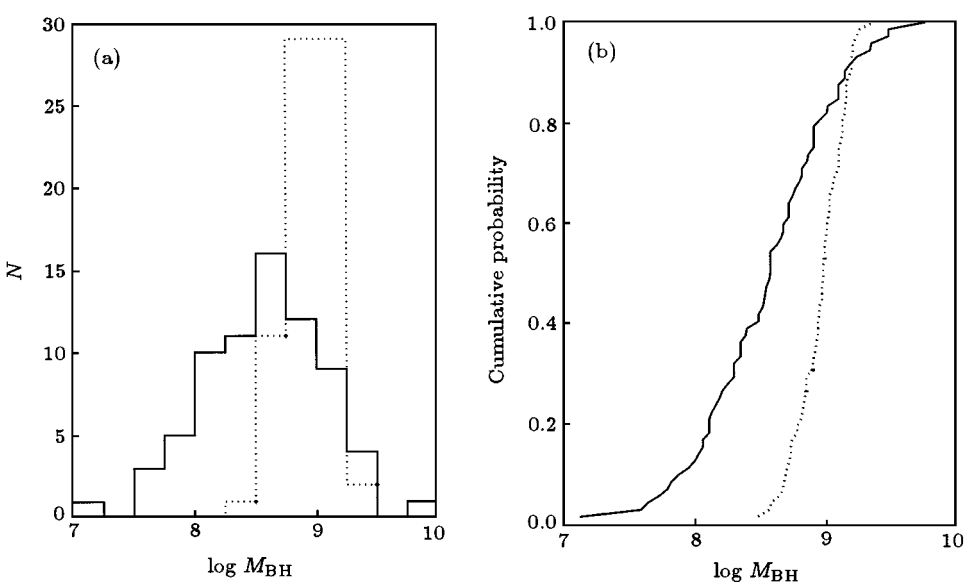


Fig.2. (a) Histogram of black hole mass for the sources listed in a paper by Bettoni *et al* (dotted curve stands for data from our relation, solid curve for data estimated from velocity dispersions); (b) cumulative probability of black hole mass.

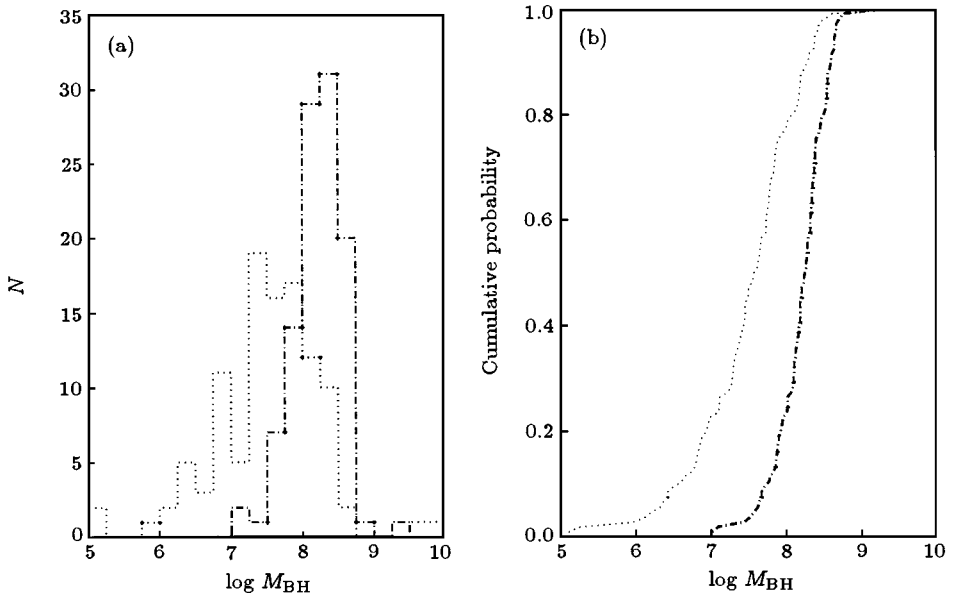


Fig.3. (a) Histogram of black hole mass for the sources listed in the present paper (dotted curve stands for data from our relation, dot-dashed curve for data from BF relation); (b) cumulative probability of black hole mass.

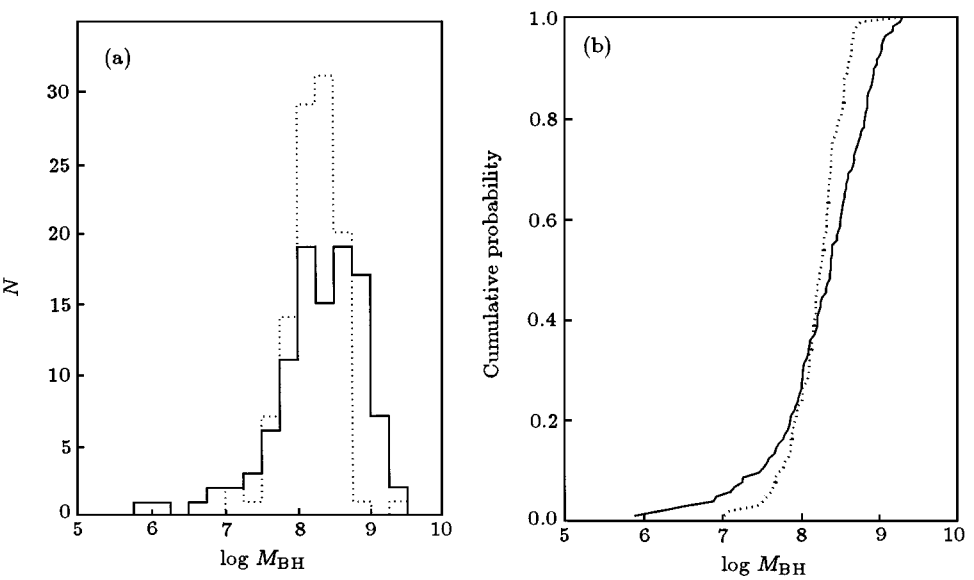


Fig.4. (a) Histogram of black hole mass for the sources listed in the present paper (dotted curve stands for data from our relation, solid curve for data estimated from velocity dispersions); (b) cumulative probability of black hole mass.

Our conclusions are as follows: 1. The central black hole masses estimated in the present paper are in the range of $10^{(5.5-9.5)}M_{\odot}$. 2. There is an $M_{\rm BH}$-$M_{\rm R}$ relation, $\log(M_{\rm BH}/M_{\odot}) = -(0.25 \pm 4.3 \times 10^{-3})M_{\rm R} + (2.98 \pm 0.208)$.

Acknowledgements

The author would like to thank Professor K.S. Cheng who invited me to visit the University of Hong Kong so that I finished part of this work there.

References

[1] Woo J H and Urry C M 2002 *Astrophys. J.* **579** 530
[2] Wang, D X 1999 *Acta Phys. Sin.* **48** 1552 (in Chinese)
[3] Zhao Z and Zhu J Y 1999 *Acta Phys. Sin.* **48** 1558 (in Chinese)
[4] Jing J L 2001 *Chin. Phys.* **10** 234
[5] Chen J H, Jing J L and Wang Y J 2001 *Chin. Phys.* **10** 1071
[6] Song T P and Yao G Z 2002 *Acta Phys. Sin.* **51** 1144 (in Chinese)
[7] Li C A, Meng Q M and Su J Q 2002 *Acta Phys. Sin.* **51** 1897 (in Chinese)
[8] Zhang J Y and Zhao Z 2003 *Acta Phys. Sin.* **52** 2096 (in Chinese)
[9] Zhang J Y 2003 *Acta Phys. Sin.* **52** 2358 (in Chinese)
[10] Wang Y J and Tang Z M 2002 *Astrophys. J. Suppl. Ser.* **282** 363
[11] Wandel A, Peterson B M and Malkan M A 1999 *Astrophys. J.* **526** 579
[12] Kaspi S, Smith P S, Netzer H, Maoz D, Jannuzi B T and Giveon U 2000 *Astrophys. J.* **533** 631
[13] Genzel R *et al* 1997 *Mon. Not. R. Astron. Soc.* **291** 219
[14] Magorrian J *et al* 1998 *Astron. J.* **115** 2285
[15] Kormendy J and Gehbardt K 2001 *Proc. 20th Texas Symp. on Relativistic Astrophysics* ed Martel H & Wheeler J C
[16] Fan J H, Xie G Z and Bacon R 1999 *Astron. Astrophys.* **136** 13
[17] Cheng K S, Fan J H and Zhang L 1999 *Astron. Astrophys.* **352** 32
[18] McLure R J and Dunlop J S 2001 *Mon. Not. R. Astron. Soc.* **327** 199
[19] Vestergaard M 2002 *Astrophys. J.* **571** 733
[20] Kormendy, J and Richstone D 1995 *Ann. Rev. Astron. Astrophys.* **33** 581
[21] Ferrarese L and Merritt D 2000 *Astrophys. J.* **539** L9
[22] Gebhardt K *et al* 2000 *Astrophys. J.* **543** L5
[23] Ferrarese L *et al* 2001 *Astrophys. J.* **555** L79
[24] Franceschini A, Vercellone S and Fabian A C 1998 *Mon. Not. R. Astron. Soc.* **297** 817
[25] Ho L C 2002 *Astrophys. J.* **564** 120
[26] Barth A J, Ho L C and Sargent W L W 2002 *Astrophys. J.* **566** L13
[27] Wu X B, Liu F K and Zhang T Z 2002 *Astron. Astrophys.* **389** 742
[28] Cao X W 2002 *Astrophys. J.* **570** L13
[29] Merritt D and Ferrarese L 2001 *Astrophys. J.* **547** 140
[30] Tremaine S, Gebhardt K, Bender R, Bower G, Dressler A, Faber S M, Filippenko A V, Green R, Grillmair C *et al* 2002 *Astrophys. J.* **574** 740
[31] Djorgovski S and Davis M 1987 *Astrophys. J.* **313** 59
[32] Bettoni D, Falomo R, Fasano G and Govoni F 2002 astro-ph/0212162
[33] Falomo R 2002 astro-ph/0212164
[34] Urry C M *et al* 2000 *Astrophys. J.* **532** 816
[35] Fan J H 2003 *Astrophys. J.* **585** L23
[36] Zhang X *et al* 2000 *Acta Phys. Sin.* **49** 379 (in Chinese)