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Gas accretion in black holes as an energy source in the nucleis of active extragalactic objects

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On the basis of Aldrovandi's model and other sources (D a v i d s o n, 1972; S h i e l d and O k e, 1975; P a c h e c o and S t a i n e r, 1976; N e t z e r and D a v i d s o n, 1979) we analyzed the spectra of 98 active objects — both Seyfert galaxies and X-ray objects. The accretion rate of the gas and the mass of the black hole were determined using ionized helium's relative intensity and hydrogen lines' luminosity and accretion rate, respectively. The results are presented in Table 1. For 47 of the objects listed therein (about 50 per cent) the UV emission of the accretion disk around the massive black hole in the object's nucleus is the probable ionization source; these objects are listed separately in Table 2, together with the black hole's mass in 10^8 $M_\odot$ units, and the accretion rate in $M_\odot$ per year units. Some of the objects listed in Table 2 are known X-ray sources. As seen in Figure 1, one and the same relation is fitted with a rather high correlation coefficient. Both facts are subsidiary indications in favour of the estimations made.

Key words: galaxies, Seyfert, black holes, accretion disk.

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1. Introduction

A l d r o v a n d i (1981) has shown that the UV continuum, caused by the accretion disk around massive black holes, is a probable ionization source in emission lines' regions of active extragalactic objects. Offering an explanation for the common spectral characteristics of objects of different class, as related to one and the same source, this model aroused interest.

D a v i d s o n (1972), and S h i e l d s and O k e (1975) proved that the emission lines in the spectra of quasars and Seyfert galaxies are caused by the photoionization, induced by ultraviolet radiation, generally an extrapolation of the power law spectra. N e t z e r and D a v i d s o n (1979) presumed that such a continuous spectrum could be entailed by an accretion disk around the black hole. P a c h e c o and S t a i n e r (1976) studied the thin disk, where all gas particles rotate on Keplerian orbits, with physical conditions preserving the homogeneity of the perpendicular disk. They proved that for a given accretion rate $\dot{M}$, luminosity in the lines H_β-L_{H_β} is proportional to the mass square of the black hole M_8^2 (M_8 is the mass in 10^8 $M_\odot$ units). On the other hand the relative intensity of the lines of the ionized helium $I_{\lambda 4686}/I_{H_\beta}$ is proportional to the number of photons of energy $E \geqslant 54,4$ eV, and $E \geqslant 13,6$ eV. The latter values are directly dependent on $\mu = \dot{M}/M_8^2$.

On the ground of these restrictions, Aldrovandi put forward a method of black hole's mass estimation and accretion rate determination, using as basic parameters luminosity in the H_β-L_{H_β} lines and the relative intensity of ionized helium lines $I_{\lambda 4686}/I_{H_\beta}$. Aldrovandi's model sets an additional restriction — emission gas in the Lyman continuum is supposed to be optically thick.

2. Estimation of the black hole's accretion rate and mass

The method under discussion was used for the spectral analysis of 98 Seyfert galaxies. The data for about 70 per cent of all objects were taken from other papers presented by P e t r o v (1980) and V e l i c h k o v a (1986). All data were reduced to $H = 75$ km/s.Mpc, where H is Hubble's constant. The observed flux and line intensity were corrected for the reddening and for galactic absorption. Luminosity in the H_β line is expressed by the equation:

$$L_{H_\beta} = 1,9074.10^{57} Z^2 (1+Z)^2 F_{H_\beta} \quad [\text{erg/s}]. \tag{1}$$

For all objects the redshift is taken from the P a l l u m b o et al. catalogue (1983) For convenience Aldrovandi's nomograms were appropriately reduced.

The analysis of the spectrophotometrical data covered two stages:

a) determination of the accretion rate of the gas in the black hole, using the relative intensity of ionized helium lines;

b) determination of the mass of the black hole by hydrogen lines' luminosity and accretion rate.

The results are presented in Table 1.

So far, a number of researchers have estimated the extreme values of black hole mass and accretion rate, explaining the spectral characteristics of emission gas in active objects.

R e e s (1977) suggested that the Doppler widths of emission lines are the result of the gravitational contraction and that luminosity in the lines is lower than or equal to that of the absolute black body of temperature $T = 2.10^4$K. He estimated that $M_8 \geqslant 0,1$.

To provide an explanation for typical luminosity range of Seyfert galaxies and quasars ($L = 10^{44} \div 10^{46}$ erg/s), McC r a y (1977) obtained the value $0,01 \leqslant M_8 \leqslant 1$, when gravitation exceeds the luminosity pressure of the emission gas. The latter condition must be fulfilled in order to have any accretion at all.

Studying different types of active objects — Seyfert and radiogalaxies and quasars, A l d r o v a n d i (1981) extended the mass range of black holes to $0.1 \leqslant M_8 \leqslant 45$ so as to include even brightest quasars. For the same purpose he estimated accretion rate of galaxies — $0,1 \leqslant \dot{M} \leqslant 8$, and of quasars — $15 \leqslant \dot{M} \leqslant 1000$.

For 47 objects listed in Table 1, for which these conditions are fulfilled, the accretion disk around the black hole is indicated as a probable ionization source. These objects are listed separately in Table 2, together with other data — the black hole's mass, reduced to $10^8 M_\odot$ units, and the accretion rate in $M_\odot$ per year units.

The values for Mrk 79 are the average of three estimations, and those for NGC 4507, 7469 and II Zw 40 — the average of two. The question mark (?) after some objects stands for higher accretion rate, typical for quasars.

Figure 1 gives the relation mass/accretion rate. A cross marks all objects listed in Table 2. By the least squares' method the coefficients of regression and correlation were determined for three cases:

Table 1

Application of Aldrovandi's model to the active extragalactic nuclei

Object	4684/H_β	$\lg L_{H_\beta}$	$(\dot{M}/M_8^2)\cdot 10^{-28}$	M_8^2	References
1	2	3	4	5	6
Mrk 1	0,30	51,48	10,60	0,0008	1
3	0,18	52,19	5,2	0,008	1
5	0,006	49,89	0,3	0,004	2
6	0,15	53,45	4,8	0,12	3
10	0,44	53,31	20,0	0,05	25
34	0,28	52,60	9,5	0,008	1
36	0,19	49,76	0,66	0,0002	2
42	0,11	52,00	3,16	0,008	4
78	0,35	52,16	12,6	0,0022	1
79	0,012	53,00	0,48	1,0	5
79	0,25	53,00	8,7	0,04	3
79	0,14	53,76	3,0	0,7	25
110	0,20	53,75	6,1	0,4	25
176	0,43	51,36	19,1	0,0002	1
198	0,075	51,43	2,3	0,0006	1
268	0,78	52,00	2,24	0,018	1
270	0,22	58,86	6,3	0,0001	1
273	0,33	51,61	6,1	0,0007	1
279	0,16	51,76	5,0	0,004	3
304	0,15	54,53	5,0	2,5	25
335	0,33	53,92	10,0	0,3	25
348	0,22	51,41	6,8	0,0007	1
Mrk 352	0,44	53,02	20,6	0,01	25
Mrk 359	0,19	51,64	5,6	0,002	4
450	0,015	53,54	0,56	4,0	6
463E	0,12	52,75	3,31	0,055	7
463W	0,17	51,78	5,13	0,035	7
493	0,24	52,28	7,59	0,006	4
506	0,21	52,56	6,31	0,01	3
509	0,29	54,62	7,94	1,7	25
533	0,32	52,17	11,2	0,035	7
573	0,36	51,85	14,1	0,001	1
573	0,38	51,15	14,8	0,0001	8
600	0,05	53,29	1,51	0,64	6
612	0,29	55,37	10,0	6,6	7
622	0,20	51,05	5,01	0,0005	7
744	0,16	54.36	4,79	1,77	9
766	0,12	52,09	3,39	0,064	4
783	0,064	53,08	2,0:	0,24:	4
833	0,042	52,20	1,26	0,06	7
1066	0,13	51,73	3,72	0,0038	10
1066	0,08	51,56	2,40	0,0048	11
1126	0.20	50,93	6,03	0,003	4
1158	0,11	52,59	3,16	0,042	7
Mrk 1239	0,16	52,45	4,68	0,014	4
NGC 1068	0,41	51,81	16,2	0,0008	1
1386	0,46	51,38	20,9	0,0002	12
2110	0,062	50,92	1,78	0,001	13
2992	0.167	51,19	5,01	0.0007	13
NGC 3081	0,42	51,77	10,6	0,0008	12
NGC 3227	0,23	51,08	6,61	0,006	3
3783	0,38	52.61	14,1	0,007	14
4388	0,20	51,37	6,03	0,0007	15
4507	0,104	52,57	2,88	0,042	5
4507	0,16	52,57	4,79	0,02	12
5005	0.174	49,07	5,25	0,0001	7
5033	0,60	51,22	33,1	0,0001	13

Table 1 (continued)

1		2	3	4	5	6
	5506	0,177	50,99	5,25	0,004	13
	5548	0,26	52,85	7,94	0,026	3
	5643	0,52	51,62	26,9	0,0004	12
	5728	0,29	52,27	10,0	0,006	12
	6764	0,062	51,21	1,78	0,003	1
	6890	0,38	50,90	15,1	0,001	12
	72.13	0,045	51,69	2,63	0,01	16
	7469	0,14	52,88	4,17	0,067	3
	7469	0,25	53,62	7,94	1,7	25
NGC	7714	0,017	52,16	0,60	0,1	2
IC	3258	0,04	54,02	1,20	4,8	22
	3453	0,10	53,50	3,02	0,46	22
IC	5063	0,13	52,54	3,55	0,038	12
Akn	120	0,03	54,08	0,91	6,86	18
	160	0,095	50,54	3,16	0,0001	7
Akn	347	0,33	54,58	12,0	0,85	7
Kaz	26	0,044	52,17	1,32	0,05	7
M	82	0,015	49,16	0,56	0,0001	13
Pictor	A	0,165	52,46	5,01	0,001	19
I Zw	18	0,03	52,60	0,93	0,20	6
	18	0,018	49,95	0,63	0,006:	2
	92	0,15	52,79	4,47	0,05	7
II Zw	40	0,017	53,36	0,60	3,00	20
	40	0,017	50,26	0,60	0,00008	2
	40	0,03	53,36	0,93	0,96	6
	136	0,14	54,71	3,16	6,5	25
III Zw	2	0,07	53,52	1,58	0,8	25
	55	0,20	51,24	6,03	0,0008	1
VII Zw	403	0,013	50,28	0,50	0,0001	21
3C	99	0,44	52,23	20,0	0,002	23
	184.1	0,27	52,51	8,51	0,0083	1
	219	0,055	52,23	1,58	0,048	23
	223	0,28	51,90	8,91	0,002	23
	223.1	0,54	51,90	27,5	0,0008	23
3C	452	0,06	51,53	70,8	0,0001	1
4C	39.72	0,34	51,29	12,0	0,0004	23
PHL	2938	0,026	50,20	0,85	0,0007	2
UM	16	0,375	52,03	14,4	0,0002	7
	71	0,12	51,37	3,31	0,002	2
UM	213	0,05	51,96	1,51	0,025	2
DDO	64	0,02	52,95	0,74	0,74	6
MCG	6-30-15	0,35	51,53	2,40	0,0008	7
MCG	8-11-11	0,16	52,59	4,79	0,027	3
A	1228+12	0,043	52,73	12,6	0,13	6
A	2228-00	0,008	52,84	0,33	1	6
X	0459+034	0,055	52,39	1,58	0,065	24
X	0459+034 töt	0,23	52,39	7,59	0,008	24
Tol	0109-383	0,25	51,15	7,94	0,0003	17
PKS	1718-649	0,094	52,04	2,88	0,01	19
MR	2251—17815	0,013	54,23	0,50	23,91	19

L_{H_β} in photon/s

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a) for objects listed in Table 2, with a possible black hole in the nucleus;

(2) $$\lg M_s = 0{,}48 \lg \dot{M} - 0{,}38, \quad R = 0{,}86.$$

Note the high correlation coefficient in this case. For all objects studied by Aldrovandi he obtained the relation:

$$\lg M_s = 0{,}54 \lg \dot{M} - 0{,}46;$$

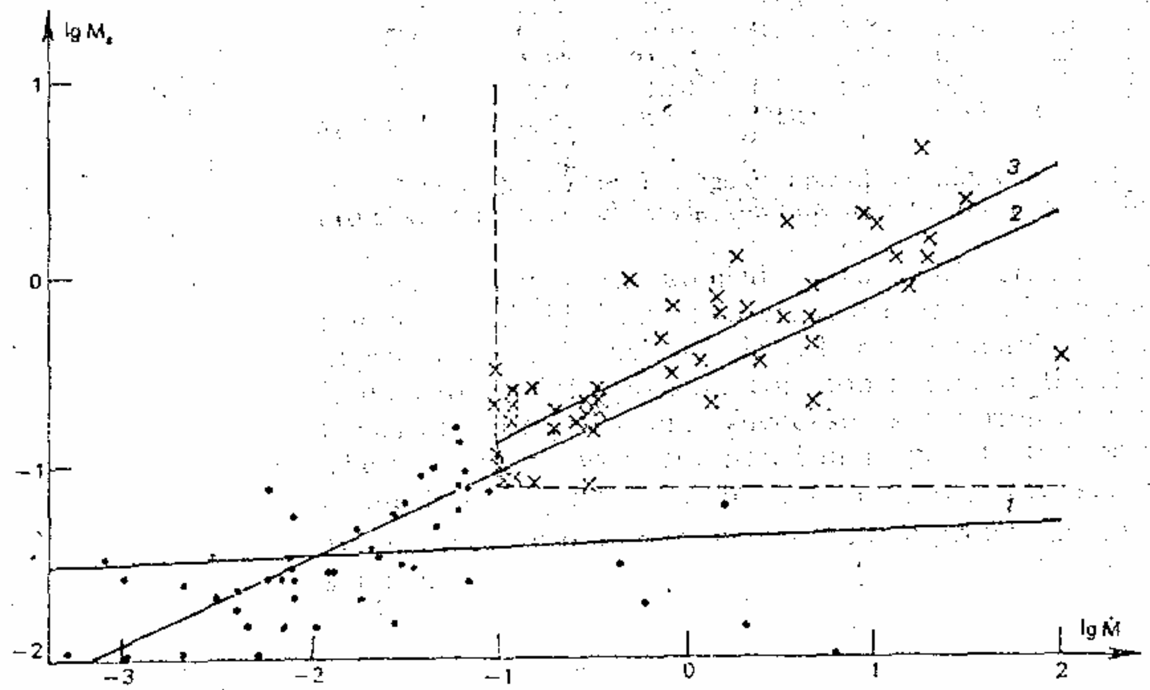

Fig. 1. "Mass of the black hole — accretion rate" ratio

1 — $\lg M_s = 0{,}05 \lg \dot{M} - 1{,}36$; 2 — $\lg M_s = 0{,}45 \lg \dot{M} - 0{,}56$; 3 — $\lg M_s = 0{,}48 \dot{M} - 0{,}38$; ● — all galaxies; X — objects included in Table 2

b) for all objects listed in Table 1 the relation is:

(3) $$\lg M_s = 0{,}45 \lg \dot{M} - 0{,}56, \quad R = 0{,}81;$$

c) for objects listed in Table 1 but not listed in Table 2 the relation is:

(4) $$\lg M_s = 0{,}05 \lg \dot{M} - 1{,}36, \quad R = 0{,}08.$$

It is interesting to note here that without taking into consideration Aldrovandi's restrictions, one and the same relation is satisfied with a fairly high correlation coefficient for all objects. This comes to corroborate the hypothesis of the common origin of ionization sources in the nuclei of active objects. Should we consider, though, only the objects, listed under c), we are faced with an obvious absence of any interrelation between M_s and $\dot{M}$, and this is at variance with the above basic contentions.

Table 2

Mass of the black hole and accretion rate for 47 active objects

Object		M_8	$\mathring{M}$	Object		M_8	$\mathring{M}$	Object		M_8	$\mathring{M}$
Mrk	6	0,35	0,91	Mrk	744	1,30	13,5	Akn	120	2,60	9,90
	10	0,22	4,60		766	0,25	0,34		347	0,92	16,2?
	34	0,09	0,12		783	0,49	0,76	Kaz	26	0,22	0,10
	79	0,68	1,60		833	0,25	0,12	I Zw	92	0,22	0,35
	110	0,63	3,50		1158	0,20	0,21	II Zw	40	1,30	1,90
	304	1,60	19,5?	Mrk	1239	0,12	0,10	II Zw	136	2,50	32,1?
	335	0,55	4,70	NGC	3783	0,08	0,16	III Zw	2	0,90	5,00
	352	0,10	0,31		4507	0,17	0,17	MR	2251—158	4,9	19,0?
	374	0,62	4,70		5548	0,16	0,33	3C	99	0,21	1,43
	450	2,00	3,60		7213	0,17	0,12		184,1	0,09	0,11
	463E	0,23	0,29		7469	0,36	1,30	3C	219	0,22	0,12
	463W	0,19	0,28	NGC	7714	0,32	0,10	MCG	8-11-11	0,16	0,21
	506	0,10	0,10	IC	3258	2,20	9,10	A	1228+12	0,36	2,63
	509	1,30	21,1?		3453	0,68	2,20	A	2228-00	1,00	0,52
	600	0,80	1,50	IC	5063	0,20	0,21	X	0459+034	0,26	0,16
Mrk	612	2,60	105?	DDO	64	0,86	0,87				

Data for Mrk 79 are average of three observations and for NGC 4507, 7469 and II Zw 40 — of two observations. The objects in which the accretion rate is typical for quasars are marked by an "?".

According to the applied Aldrovandi's criteria, the objects under investigation are subdivided into two groups: objects with a black hole in the nucleus, and objects for which such a hole is hardly probable. On the other hand, relation (3) is indicative of the possible common nature of the ionization source. This hypothesis was checked using Wilcockson's criterion at reliability $\alpha=0{,}01$ and $\alpha=0{,}05$. The two groups were compared in respect to two parameters, namely luminosity in the H_β—L_{H_β} line, and to $I_{\lambda 4686\,\mathrm{He\,II}}/I_{H_\beta}$, the second parameter used by us. With respect to both parameters the two groups do not belong to one and the same sample.

3. Conclusions

Using Aldrovandi's model for the analysis of the spectra of 98 active objects, we reached the following conclusions:

a) in about 50 per cent of all objects the ionization source may be the UV emission of the accretion disk around the massive black hole in the object's nucleus;

b) subsidiary indications, favouring the estimations made, are (1) some of the objects listed in Table 2 — Akn 120, Mrk 509, MCG 8-11-11, etc. are already known XR-emission sources; (2) the high correlation coefficient of black hole mass and accretion rate, as shown by Pacheco and Stainer.

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