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ON THE BLACK HOLE MASSES, ACCRETION RATES AND UNIFICATION OF SEYFERT GALAXIES

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Introduction. A lot of facts, established during the last 20 years, indicate that the most likely power source of active galactic nuclei (AGN) is the disk accretion onto a supermassive black hole (Rees [1]). As it is well known a black hole is completely defined by its mass *(M)* and its angular momentum *(S).* Analogically one could suppose that it is possible to describe fuliy the greater part of AGN only by their black hole masses, accretion rates of infalling matter *(dM/dt)* and orientation to the observer if the structure is nonaxisymmetric. *S, dS/dt* and the magnetic fields through the disk are also important factors for AGN energetics and some observational characteristics like jets for instance.

In this paper we investigate the unification of Seyfert galaxies in terms of their black hole masses and accretion rates. (We do not consider the influence of the black hole angular momentum - maybe it has to be taken into account when unification of radiogalaxies and quasars is studied.) For almost hundred and fifty well known active galaxies of various Seyfert types we established good correlation between *M*and *dM/dt.*

It is accepted here that *UV* continuum is produced mainly in the accretion disk through viscous release of gravitational energy of infalling matter. This continuum ionizes gas clouds which produce observed emission lines. The alternative models, in which continuum and part of the lines are produced in the disk by reemission of hard X-ray photons coming from the central source or inner disk are not considered here, although this process could take place in some objects contributing to a part of the emission.

Let us remember that there are at least two types of regions in AGN: ones emitting broad lines (broad line region or BLR), and, others emitting narrow lines (NLR). The type of active galaxy

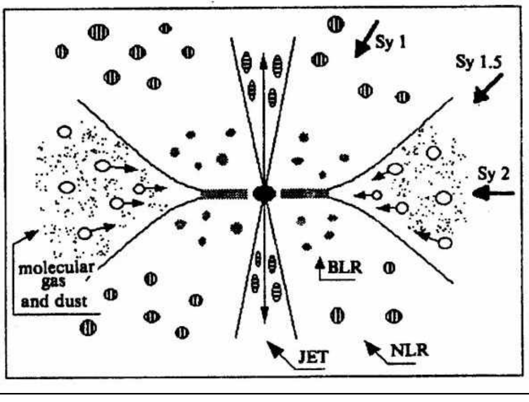

Fig. **1**. Schematic representation of unified AGN model. Seyfert type depends on orientation of this structure to the observer. If the black hole and accretion disk are seen directly - this is Seyfert 1, if not - Seyfert 2 is defined by the presence of broad emission in the spectrum: Seyfert 1 's contain both broad and narrow lines while Seyfert 2's - only narrow ones. The simplest unification scheme supposes that there is BLR in Seyfert 2 types but it is hidden from us by a thick thorus of molecular gas and dust (Fig. 1). In this case, therefore, depending on the orientation to the observer, Seyfert galaxies should appear like type 1 's or type 2's without being intrinsically different. A lot of observational facts confirm this unified picture, but some other facts do not do this (for more details see Antonucci [2]).Too much discussions have been induced by a recent discovery that a part of Seyfert 2 galaxies, observed in polarized light, reveal Balmer emission with broad wings, i.e. these type 2 objects harbour Seyfert 1 nucleus (Antonucci & Miller [3]).

Black hole mass and accretion rate estimation. For mass estimation of nuclear black holes we applied the emission line method (the so called "dynamical") of Wandel & Mu-shotsky [4]. This method uses that if the emitting gas is gravitationally bound, the FWHM of some line defines Keplerian velocity (*u*) of emitting clouds, which mean distance from the centre (*R*) is estimated from the line luminosity ($L_{|ine}$). It could be written that

$$L_{line} = 4\pi R^2 wNnj/3 \tag{1}$$

$$u \sim FWHM=(2GM/R)^{0.5} \tag{2}$$

and therefore *M* is a function of known parameters. The [OIII]5007 narrow line is used here, as it is believed that NLR is similar for all Seyfert types. Some standard conditions of emitting [OIII] region are supposed: covering factor $w= 10^{-1} - 10^{-2}$; gas density $n = 10^4 - 10^5$ cm^3; column density $N=10^{20}-10^{21}$ cm^{-2}. Using that [OIII] specific emissivity is. $j_{|OIII|}=1.2\ 10^{-24}$ erg.cm^3/s for masses the following expression could be derived (Wandel & Mushotzky [4]):

$$M_8 = 2\,(L_{[OIII]42})^{0.5}\, u_{300}{}^{2} \tag{3}$$

where $M_8 = M/10^8\ M_{®}$ - mass of the black hole, $M_{@}$ - Solar mass, $L_{[omi42]} = L_{[OIII]}/10^{42}$ erg/s, $u_{300} = u$ /300 km/s.

It is much more difficult to estimate correctly the accretion rates. Bolometric luminosity of AGN could be used as $L=ac^2dM/dt$ (here *a* is the mass-energy transfer efficiency coefficient, taken usually equal to 0.1 for disk accretion), but it is hard to determine fluxes in all spectral bands (mostly UV, soft and hard X-rays). Observationally estimated bolometric luminosity could be deeply modified if the photons are emitted anizotropically (along the cone), what is supposed in the unified models. One less model dependent way for crude but easy estimation of accretion rates is based on connection between the ionizing continuum and line luminosities (*Hβ* for instance). If accretion occurs through the disk and mainly the viscous heating of infalling m< produces UV photons, the ionizing continuum is a function of *M* and *dM/dt.* Therefore, the line luminosities are also a function of these two parameters and of the conditions and structure of the emitting region. Photoionization equilibrium for optically thick gas leads to the next expression for *Hβ* luminosity:

$$L_{H\beta} = (w.L_{ion}.j_{H\beta})/(<h\nu>.a_{H\beta}) \tag{4}$$

where $a_{H\beta}$ is the case B recombination coefficient and L_{ion} is the ionization luminosity. Therefore $L_{H\beta} = A.L_{ion}$, where *A* is a coefficient equal to 10^{-2} for BLR (w = 0.2 - 0.3) and to $10^{-3} - 10^{-4}$ for NLR (w = 0.02). An important assumption here is that the emitting regions structure (covering factor) does not vary strongly from object to object and does not scale with masses. Connection between L_{ion} and accretion parameters (*M* and *dM/dt*) is obtained from standard thin accretion disk spectra (Ross, Fabian & Mineshige [5]). The accretion rate *dM/dt* as a function of *M* (already known) and $L_{H\beta}$ is derived to be

$$\log dM/dt = 0.89(\log L_{H\beta} +A)+0.16\log M - 41.33 \tag{5}$$

Errors are in order of magnitude or less. The results obtained using some other line luminosity, instead of $L_{H\beta}$, are not significantly different.

Data and results. Using data from the literature (Whittle [6l, Nelson & Whitle [7]) it is found for black hole masses to be mainly between 10^7 and 10^9 $M_{©}$, which is not unexpected for the Seyfert galaxies. Mass distribution of 143 AGN is shown in Fig. 2. It is seen that mass distributions for Seyfert 1 and Seyfert 2 types are not exactly the same but the difference is not significant enough to separate them into two different classes based on this parameter. This absence of apparent intrinsic physical differentiation between AGN's indirectly supports the unified model.

Although the sample is not complete, it is interesting to note, that the Seyfert 2 galaxies with hidden Seyfert 1 nucleus (from about 10 known such "hidden Seyfert 1 's" we found 6 in the used list) show very high masses - 10^9 Mo, and so they fill the high mass tail of Seyfert 2's distribution. By their masses these objects could be distinguished from both Seyfert 1 and Seyfert 2 galaxies and therefore may really form a separate subclass. Of course, another possible explanation is that NLR clouds of these hidden type l's are nongravitationally accelerated, leading to overestimation of the mass of the central object. Radio luminosity distribution also shows that these objects are not ordinary Seyfert galaxies. In every case, further investigations are needed for the right conclusion.

In Figure 3 is represented *"M-*$L_{H\beta}$*"* dependence for the same active galaxies. It is seen that there is a good correlation between masses and $H\beta$ luminosities for each type of AGN. Seyfert 1 's and Seyfert 2's show almost equal distribution slope, which is slightly different from slopes of intermediate types (Seyfert 1.5; 1.8 & 1.9). This difference, of course, could be due to the small number of objects (especially for Seyfert 1.8 and 1.9). Although, if the unified model is accepted, a possible interpretation of this fact is based on supposition of various geometries (or covering factors) of obscuring regions for big and small black hole masses.

Using that in Seyfert 1 's $H\beta$ is emitted mainly from BLR while in Seyfert 2's - mainly from NLR, it is possible to convert “*M-*$L_{H\beta}$" distributions to *"M-dM/dt"* ones (see expression (2)) and the last relation is represented in Fig. 4. We do not calculate *dM/dt* for the intermediate type (Seyfert 1.5) because the contributions of BLR and NLR to the whole A/$_p$ emission are unknown. As a rule galaxies do not have accretion rates, exceeding critical (Edington's) one

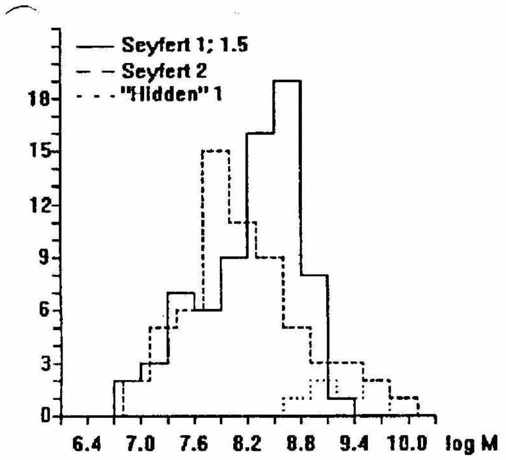

Fig. 2. Distributions of black hole masses of various Seyfert types

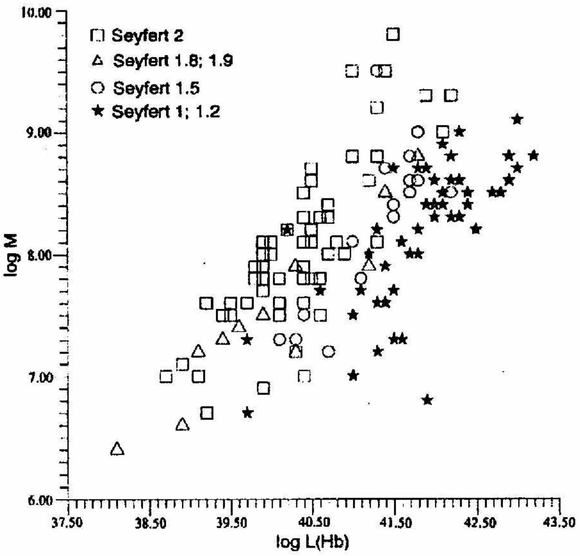

Fig. 3. Black hole masses (in Solar masses) versus H_β luminosity (in erg/s) for various Seyfert types: Seyfert 1, 1.2 are plotted as stars; Seyfert 1.5 – as circles; Seyfert 1.8, 1.9 – as triangles and Seyfert 2 – as squares

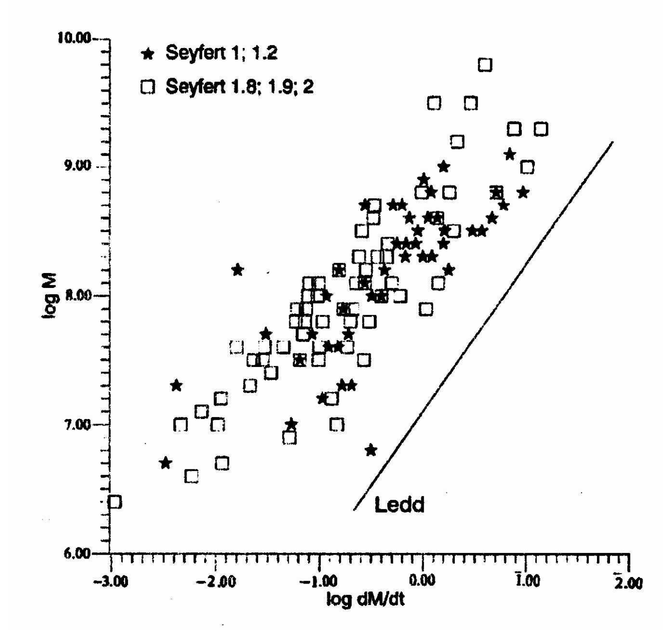

Fig. 4. Black hole masses (in Solar masses) versus accretion rates (in Solar masses per year) for various Seyfert types: Seyfert 1, 1.2 are plotted as stars; Seyfert 1.8,1.9 and Seyfert 2 - as squares

(Fig.4). Linear approximation of AGN distribution is given by log $dM/dt = 0.991ogM_8 - 0.63$, correlation coefficient R=0.83. We obviously could not confirm the issue that $m=(dM/dt)/(dM/dt)_{cr}$ increases with M as it has been reported from other authors, estimating masses and accretion rates using different methods (Aldrovandi [8]; Petrov&Velichkova [9], Wandel [10]; etc.). Accretion rates in units of critical accretion rates are found to be mainly between 10^{-1} and 10-^{2}.

Discussion and conclusion.The results, especially for accretion rates, are quite unsure as various AGN could have BLR and NLR with parameters, much too different from the accepted above. Systematic errors are not excluded as different emitting regions are treated - BLR and NLR. The nonphotoionizing contribution to $H\beta$ emission luminosity and the photoionization of hard X-rays, which could be significant especially for BLR, are not also considered. There is not strong evidence that covering factor *(w)* does not scale with masses leading to different tilt of *"M-dM/dt"* dependence. In spite of all this, there is a good correlation between black hole masses and $H\beta$ luminosities, which we interpret as a correlation between masses and accretion rates. Distribution of AGN on *"M-dM/dt"* plane is almost independent of Seyfert type (Fig.4) - differences for various types do not exceed the errors of estimation. So, neither mass of black hole, nor accretion rate could play some important role in determination of the type of Seyfert galaxy and this fact do not contradict to the simplest unified schemes. The last statement is probably not true for the hidden Seyfert l's, which place in such unified schemes appeared to be quite special.

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