COSMOLOGICAL EVOLUTION OF QUASARS AND MODELS OF THE ENERGY SOURCES

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The nature of the cosmological evolution of quasars imposes useful restrictions on models of the energy sources. A method is proposed for comparing the observed cosmological evolution of quasars with their evolution in a model of an accreting black hole. Various modifications of the model of accretion onto a black hole are considered. The proposed method can also be used to test other quasar models.

The suggestion is being made more and more often that the primary cause of the observed activity of quasars and radio galaxies is the presence in the central regions of these objects of supermassive black holes [1, 2]. In this connection, it would seem to be very important to consider the model of a quasar as a supermassive black hole in the light of the available observational data. In the present note, we propose a method for comparing the observed cosmological evolution of quasars with their evolution in the model of an accreting black hole. The method is as follows. Investigation of the distribution function of the quasars with respect to the apparent magnitude is helpful for characterizing the evolution of the objects in the distant past, and, in particular, makes it possible to determine the parameter \( k \), which characterizes the evolution of the objects (see (3)). On the other hand, this parameter can be determined from theory under the assumption that the energy source of the quasars is the accretion of matter onto collapsed objects. In the framework of the concept of a supermassive black hole, the following quasar models have been proposed:

a) a black hole in the nucleus of a galaxy of a type that emits due to accretion onto it of interstellar gas of the galaxy [1];

b) an isolated collapsed body in the intergalactic medium [3];

c) a black hole in a star cluster onto which there is accretion of the gas of stars broken up by the tidal forces of the black hole [4].

In the present note, it is shown that hypotheses a) and b) about the nature of quasars encounter serious difficulties in interpreting the cosmological evolution of quasars.

1. Evolution of Quasars

The number of objects that give a radiation flux between \( S \) and \( S + dS \) is [5]

\[
dN = AS^{-5/2}dS \left[ 1 + \sqrt{\frac{3}{S}} (z - 2\zeta - 2\kappa) \right].
\]  

Here, \( S \) is the flux from a source of power \( L \) at distance \( c/H_0 \) in Euclidean space,
H₀ is Hubble's constant, A is a constant, \( \overline{L} \) and \( \overline{k} \) are the distribution-weighted quantities determined by means of the formulas

\[
\overline{L} = \frac{\int_0^\infty W(L, 0) L^2 dL}{\int_0^\infty W(L, 0) L^3 dL},
\]

\[
\overline{k} = \frac{\int_0^\infty W(L, 0) \frac{dL}{dt} L dL}{H_0 \int_0^\infty W(L, 0) L^2 dL},
\]

and \( W(L, t) \) is the luminosity distribution function of the objects. In deriving the relation (1), we have assumed that the time \( t \) is measured from the present epoch, so that at the time of emission of the radiation by an object with red shift \( z \) we have \( t = -z/H₀(1 + z) \) and we have expanded the function \( W(L, t) \) in the parameter \( t \), which is small for sufficiently close objects \( z \leq 2 \); this is why the luminosity distribution function \( W(L, 0) \) for the present epoch \( t = 0 \) occurs in the integrands in (2) and (3). In formula (1), \( \alpha = 4 \) if the evolution effect of the sources reduces entirely to a change in their absolute magnitude. The detailed analysis of Schmidt [6] has shown that in quasars it is not so much the luminosity as the spatial density of the objects in unit comoving volume that evolves. This evolution occurs in accordance with the law \( \rho(z) \propto (1 + z)^p \) for \( z \leq z_{\text{max}} \), where \( p = 6 \) and \( z_{\text{max}} = 2-3 \), the evolution being the same in both the optical and the radio range. For this kind of quasar evolution, \( \alpha = 10 \). The quantity \( \overline{k} \) characterizes the change in the luminosity of objects; for the special case of identical and synchronously evolving sources of luminosity \( L_0 \) it is equal to \( \overline{k} = k = H_0^{-1} \frac{d \ln L_0}{dt} \bigg|_{t=0} \).

In formula (1), \( \beta = 3 - n \) if the spectral flux can be approximated by a power-law function of the frequency: \( F_\nu \propto \nu^\beta \). According to the data of Oke et al. [7] for quasars in the optical range, the mean value of \( n \) is \(-1.0 \).

The expression (1) is convenient for evaluating the observations. In practice, one must take from the observations the value of \( \varphi \):

\[
\varphi = S \frac{dN}{dS},
\]

and it then follows from (1) that

\[
\varphi = A \left( 1 + \frac{C}{\sqrt{\frac{\overline{S}}{S}}} \right),
\]

where \( C = 10 - 2\beta - 2\overline{k} \). Evaluating the observational data, one can find the function \( f(S) = C \sqrt{\frac{\overline{S}}{S}} \). By definition, \( \overline{S} \leq S \), and for \( C \) we therefore obtain the estimate

\[
C \geq \max f(S).
\]

Since the emission of supermassive black holes is expected to be maximal in the optical and ultraviolet ranges, to test the hypothesis under consideration one should use the results of quasar counts in the optical range. In [8], the dependence \( N(m) \) is obtained for quasars as a function of the apparent magnitude in the form \( \log N(m) = am + \text{const} \), where \( a = 0.69 \pm 0.04 \). Using this result and the method described above, we found that \( C \leq 5.2 \) and \( \overline{k} \leq -1.6 \) (for \( n = -1.0 \)). This estimate depends weakly on the value of \( a \).