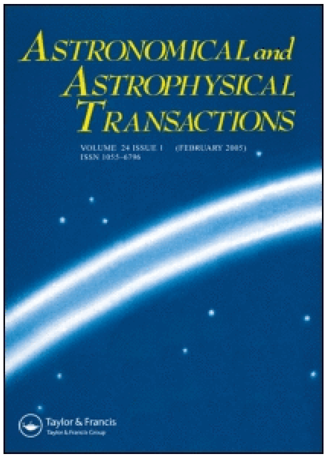

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REDSHIFT DISTRIBUTION OF QSOs AS A PROBE OF INITIAL SPECTRUM ON SMALL SCALES

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The dependence of the quasar abundance at different redshifts ($n_{\rm QSO}(z)$) on initial power spectrum is studied. It is shown that the preferable model for explaining the observable number density of QSOs over redshift (Schmidt *et al.*, 1991) is the tilted CDM model with $\Omega_b = 0.1$ and $n = 0.7$. The possibility of the reconstruction of initial power spectrum on small scale from the observable data on the quasar abundance over redshift is analysed too. It is shown that such spectrum in comparison with standart CDM has steep reducing of power at $1 \le k \le 10h\rm{Mpc}^{-1}$ and bump at $k > 10h\rm{Mpc}^{-1}$.

KEY WORDS **Initial power spectrum, dark matter, quasars**

The aim of this paper is to calculate the distribution of number density of QSOs over redshift in preferable models of formation of the large-scale structure of the Universe and also to solve the reverse problem of the determination of the phenomenological power spectrum of density fluctuations giving theoretical redshift distribution of QSOs which is the closest to the observed one. The basis of this paper is the scenario of formation of elements of the large scale structure of the Universe in the peaks of random Gaussian density fluctuation field. In this approach, galaxies and objects of other scales form in peaks of density fluctuations which have an amplitude $\delta \equiv \delta\rho/\rho \ge \nu_{\rm th}\sigma_0$, where σ_0 is the r.m.s. amplitude of such fluctuations, $\nu_{\rm th}$ is some threshold height which corresponds to minimal amplitude when objects of corresponding scale still form. In the theory of Gaussian peaks (Bardeen *et al.*, 1986), comoving number density of peaks $n(\nu \ge \nu_{\rm th})$ is

$$n(\nu_{\rm th}) = \int_0^\infty t(\nu_{\rm th}, q) N_{\rm pk}(\nu)\, d\nu \qquad (1)$$

where $t(\nu_{\rm th}, q) = (\nu/\nu_{th})^q/(1 + (\nu/\nu_{\rm th})^q)$ is the threshold function, $N_{\rm pk}(\nu)$ is the differential number density of peaks in amplitude range $(\nu, \nu + d\nu)$.

We suppose that QSOs are an active short-term stage of massive galaxies ($M \ge 2\times 10^{11} M_\odot$) (see also Nusser & Silk, 1993) which are formed in the peaks of an initial

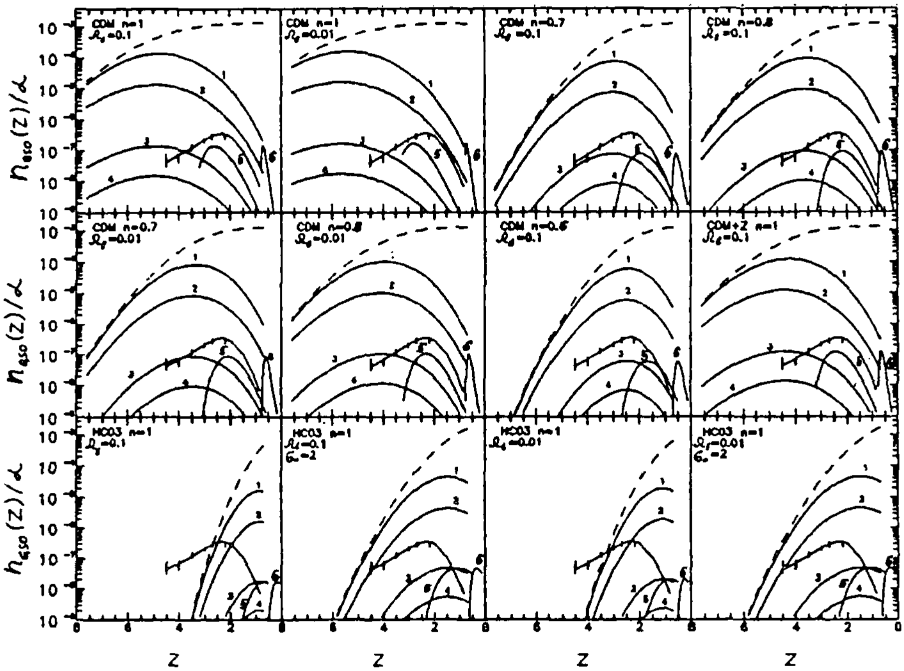

Figure 1 The ratio of the number density of QSOs (Mpc^{-3}) to the efficiency factor (defined as the fraction of visible galaxies harbouring QSO) against redshift (solid lines) in CDM models with $n = 1$, 0.8, 0.7, 0.6 and hybrid HC with $n = 1$ and $\Omega_{\mathrm{HDM}} = 0.3$ for baryon density $\Omega_b = 0.1$ and 0.01 and different QSO lifetimes τ_{QSO} and time delays $\Delta\, t$: *1*, ($\tau_{\mathrm{QSO}} = 10^8$ years, $\Delta\, t = 0$); *2*, $(10^7, 0)$; *3*, $(10^5, 0)$; *4*, $(10^4, 0)$; *5*, $(10^5, 10^9)$; *6*, $(10^5, 5 \times 10^9)$; solid line with error bars is the observed $n_{\mathrm{QSO}}(z)$ from Schmidt *et al.* (1991), the dashed line is the number density of galaxies ($h = 0.5$).

random Gaussian density fluctuation field in consequence of gravitational instability. The total concentration of such peaks is equal to that for $n_g^{\mathrm{obs}} \simeq (h/4.6\,\mathrm{Mpc})^3$ ($h = H/100$ km/s/Mpc is Hubble parameter) and determine the single parameter of the threshold function (e.g. threshold height) (Bardeen *et al.*, 1986; Hnatyk *et al.*, 1991). The QSO stage of galactic evolution begin soon after collapse of central regions of peaks or later by a certain time interval which is called time delay. Concentration of QSOs over different redshifts $n(z)$ and their correlation functions $\xi(z, r)$ depend on moments of spectrum, duration of QSO stage, time delay and steepness of the threshold function.

The high peaks, which are roughly spherically symmetric, collapse (appearance of the first contraflows in dark matter and generation of shock wave in baryon component) at

$$z_{\mathrm{col}} = 0.59\nu\sigma_0 - 1 \tag{2}$$

as it follows from Tolman model. If the QSO stage begins immediately after collapse, at cosmological time $t_c(z_c)$, and lasts for τ_{QSO}, then we can correlate to these

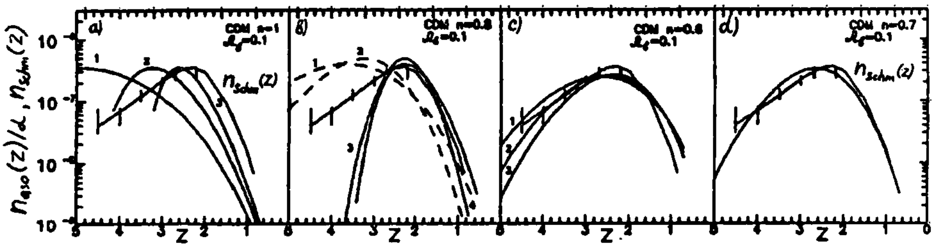

Figure 2 The observed number density of QSOs, $n_{\mathrm{Schm}}(z)$, and the theoretical one (divided by efficiency factor) n_{QSO}/α in CDM models with $\Omega_b = 0.1$, $n = 1$, 0.8, 0.7, 0.6 and different QSO lifetimes (τ_{QSO}), time delays ($\Delta\, t$) and parameters of threshold function (q): a) solid line *1*, ($\tau_{\mathrm{QSO}} = 2.5 \times 10^5$ years, $\Delta\, t = 0$, $q = 4$); *2*, (2.5×10^5, 6×10^8, 4); *3*, (2.5×10^5, 10^9, 4). b) dashed line *1*, ($\tau_{\mathrm{QSO}} = 4.5 \times 10^5$ years, $\Delta\, t = 0$, $q = 6$); *2*, (4.5×10^5, 0.8); solid line *3*, (4.5×10^5, 8×10^8, 6); *4*, (4.5×10^5, 7×10^8, 8). c) solid line *1*, ($\tau_{\mathrm{QSO}} = 4.5 \times 10^5$ years, $\Delta\, t = 0$, $q = 3$); *2*, (4.5×10^5, 0.4); *3*, (4.5×10^5, 0.5). d) solid line, ($\tau_{\mathrm{QSO}} = 4.3 \times 10^5$ years, $\Delta\, t = 10^8$ years, $q = 6$) ($h = 0.5$).

moments (t_c) and ($t_c - \tau_{\mathrm{QSO}}$) the peaks of height ν_c and $\nu_c + \Delta\, \nu$, respectively, which collapse at the same moments. The number density of QSOs in such approach will be equal to the number density of peaks with the amplitude from the range $\nu_c, \nu_c + \Delta\, \nu$:

$$n_{\mathrm{QSO}}(z) = \alpha \int\limits_{\nu_c}^{\nu_c + \Delta \nu} t(\nu_{\mathrm{th}}, q) N_{\mathrm{pk}}(\nu)\, d\nu \tag{3}$$

where z corresponds to the moment of cosmological time $t_c + \Delta\, t$. The dimentionless coefficient α (efficiency factor) is visible part of galaxies harbouring QSOs. For given spectra it allows to find τ_{QSO}, $\Delta\, t$ and q for maximum approximation of theoretical number density of QSOs to observable one (Schmidt *et al.*, 1991). The results of such calculations for different spectra are shown in Figures 1–2. As we can see, the duration of QSO stage multiplied by efficiency factor α is proportional to amplitude of the number density of QSOs, meanwhile the time delay displaces the maximum of redshift distribution of QSOs to lower z. The redshift distribution of QSOs at small $z\,(< 2)$ is very sensitive to the threshold function parameter q. The preferable model for explaining the observable number density of QSOs is the tilted CDM model with $\Omega_b = 0.1$ and $n = 0.7$ (Figure 2). In this model the duration of QSO stage τ_{QSO}, time delay $\Delta\, t$ and threshold function parameters are the following: $\tau_{\mathrm{QSO}} = 4.3 \times 10^5$ years, $\Delta\, t = 10^8$ years, $q = 6$. The biasing parameter of bright galaxies is $b_g = 1.67$.

The next step of our research is to find the initial power spectrum of density fluctuations from the curve of QSO number density over redshift, given by Schmidt *et al.* (1991). At first let us simplify (3) by assuming that $\tau_{\mathrm{QSO}} \ll t_c$, which is valid in all cases considered above:

$$n_{\mathrm{QSO}}(z) = \alpha t(\nu_{\mathrm{th}}, q) N_{\mathrm{pk}}(\nu)\, \Delta \nu \tag{4}$$

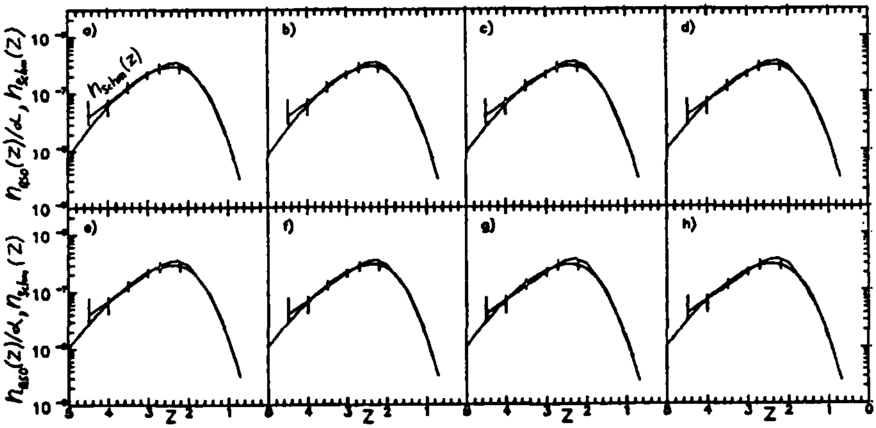

Figure 3 The observed redshift distribution of QSOs (Schmidt *et al.*, 1991) and theoretical $n_{\rm QSO}(z)$ for spectra with the momenta obtained by solution of the reverse problem and corresponding QSO lifetimes (for all solution $\tau_{\rm QSO} \approx 4.4 \times 10^5$ years), and time delay $\ll$ cosmological time) ($h = 0.5$).

where

$$\Delta\nu = 1.13(z_c + 1)^{2.5} \frac{\tau_{\rm QSO}}{t_0 \sigma_0}. \tag{5}$$

Now, let us write Eq. (6) for different points of the curve of QSO number density over redshift

$$n_{\rm Schm}(z_k) = n_{\rm QSO}(z_k), \tag{6}$$

and equation for number density of bright galaxies which elapsed the QSO stage, $n_g^{\rm obs} = n(\nu_{\rm th}, q)$. This system of equations can be solved by the method of minimization of divergence vector relative to unknown values σ_0, σ_1, σ_2, q, $\nu_{\rm th}$, b_g, $\tau_{\rm QSO}$,

Table 1. The parameters of cosmological models (Ω_b, n), the momenta of spectra on galaxy scale for them ($\sigma_{j,g}$, γ), biasing b_g and the parameters of the threshold function ($q, \nu_{\rm th}$) of bright galaxies and QSOs ($h = 0.5$)

Model	Ω_b	n	$\sigma_{0,g}$	$\sigma_{1,g}$	$\sigma_{2,g}$	γ	b_g	q	$\nu_{\rm th}$
CDM	0.10	1.0	3.60	3.59	5.97	0.60	1.40	4	3.20
CDM	0.01	1.0	4.01	4.03	6.60	0.62	1.34	4	3.24
CDM	0.10	0.7	2.51	2.20	3.40	0.57	1.53	4	2.91
CDM	0.10	0.8	2.85	2.61	4.12	0.58	1.47	4	3.01
CDM	0.01	0.7	2.76	2.47	3.84	0.57	1.48	4	2.95
CDM	0.01	0.8	3.13	2.91	4.61	0.59	1.43	4	3.05
CDM	0.10	0.6	2.20	1.84	2.80	0.55	1.60	4	2.81
CDM+Z	0.10	1.0	3.24	3.22	5.28	0.60	1.42	4	3.23
HC0.3	0.10	1.0	1.31	0.86	1.24	0.45	1.76	2	3.20
HC0.3	0.10	1.0	2.00	1.31	1.90	0.45	1.15	–	–
HC0.3	0.01	1.0	1.47	0.96	1.20	0.46	1.67	2	3.25
HC0.3	0.01	1.0	2.00	1.34	1.95	0.46	1.23	–	–

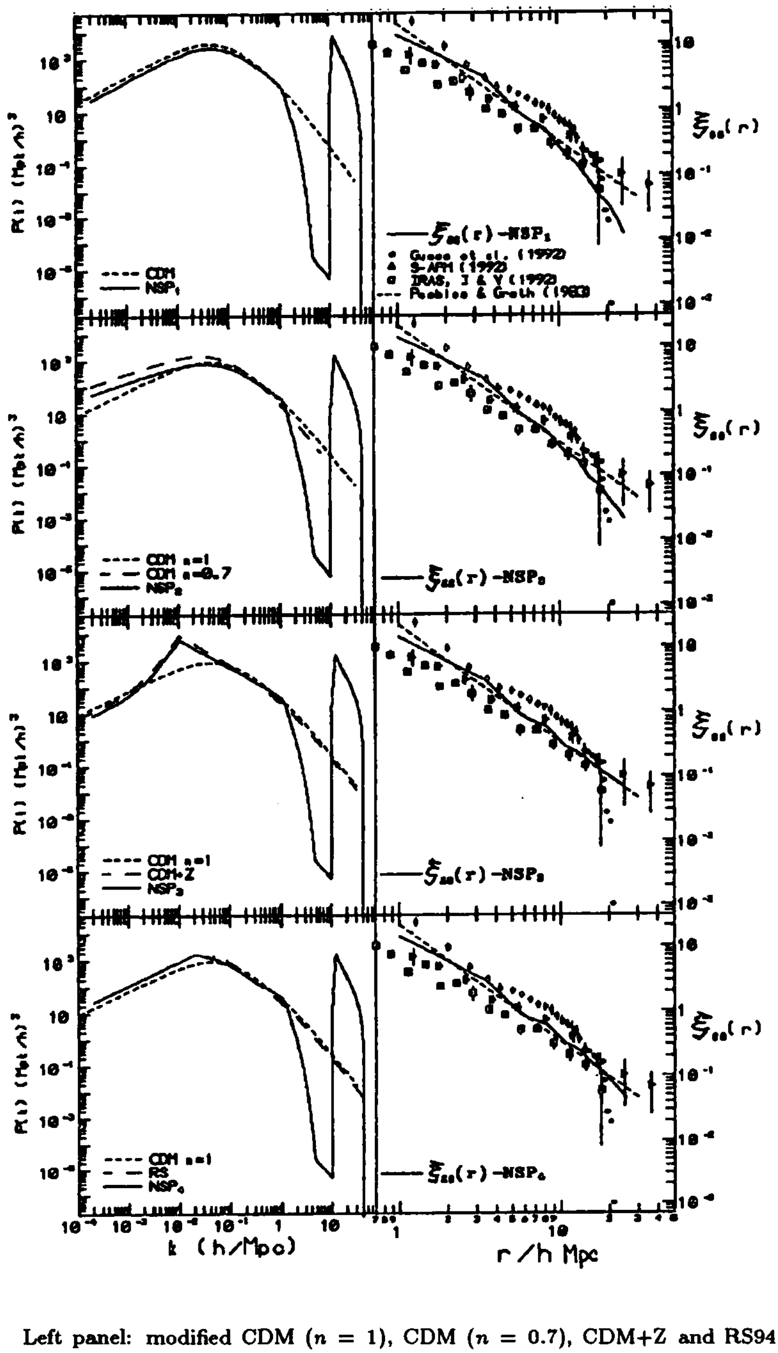

Figure 4 Left panel: modified CDM ($n = 1$), CDM ($n = 0.7$), CDM+Z and RS94 spectra on small scale (NSP_1, NSP_2, NSP_3, NSP_4, respectively,) which give the momenta obtained by solution of the reverse problem (the first solution from Table 2); right panel: corresponding to them the correlation functions of galaxies and observable ones.

Table 2. The momenta of spectrum on galaxy scale $\sigma_{j,g}$, parameters γ, galaxy biasing b_g, the parameters of the threshold function q, and ν_{th}, duration of QSO stage τ_{QSO}, time delay $\Delta\, t$ obtained by solution of reverse problem (from observed quasar number density) (h = 0.5)

	$\sigma_{0,g}$	$\sigma_{1,g}$	$\sigma_{2,g}$	γ	b_g	q	ν_{th}	$\tau_{QSO} \times 10^5$ *years*	$\Delta\, t$ *years*
a)	2.37	1.16	1.89	0.30	1.72	8.3	2.09	4.4	0.0
b)	2.38	1.11	1.84	0.28	1.72	8.3	2.08	4.4	0.0
c)	2.45	0.85	1.52	0.19	1.74	8.5	2.03	4.4	0.0
d)	2.53	0.58	1.12	0.12	1.75	8.5	1.98	4.4	0.0
e)	2.53	0.57	1.10	0.12	1.75	8.5	1.98	4.4	0.0
f)	2.49	0.28	0.58	0.05	1.77	8.6	1.93	4.4	0.0
g)	2.61	0.19	0.40	0.03	1.77	8.6	1.92	4.4	0.0
h)	2.74	0.39	0.73	0.80	1.69	8.3	1.87	4.4	7×10^7

and $\Delta\, t$. The particular solutions obtained in such way are presented in Table 2, and number density of QSOs for some of them is shown in Figure 3. The general property of all solutions is relation of moments $\sigma_1 < \sigma_2 < \sigma_0$. Now, for $\sigma_0, \sigma_1, \sigma_2$, and b_g obtained here we can try to build up the initial power spectrum, which will give observable redshift distribution of QSO definetely. This procedure is ill posed problem because the moments of spectrum are its integral characteristics. But as long as the first three moments gather their values in sufficiently narrow range of spectrum ($0.1 \leq k \leq 40$) because in the class of unoscillation spectra such problem can be solved definitely. Such spectra NSP_1, NSP_2, NSP_3, NSP_4, which have been obtained by means of modifications of flat CDM ($n = 1$), tilted CDM ($n = 0.7$), CDM+Z, and RS94 (Novosyadlyj, 1996), respectively, are shown in Figure 4.

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