QUASAR AND AGN EVOLUTION

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I. Recently, the so called pure luminosity evolution (PLE) model for the AGN luminosity function has gained popularity as new data have been shown to agree with its assumptions (Marshall 1988, Boyle *et. al.* 1988). In PLE the luminosity function, $\Psi(L, z)$, can be written in the form $\Psi(L, z) = S(L/g(t))/g(t)$. Using the continuity equation, which the objects must satisfy,

$$\frac{\partial}{\partial t}\Psi(L,t) + \frac{\partial}{\partial L}\dot{L}\Psi(L,t) = S(L,t)$$

where S is the source function, it can be shown that PLE is possible if all of the objects are created at a time t_o within a short period compared to the Hubble time ($S \propto \delta(t - t_o)$) and they all evolve in luminosity in the same manner, $L = L_o g(t - t_o)$, independent of L_o.

II. These conditions on the evolution of AGN luminosities are very restrictive especially if, as claimed, the idea of PLE is extended to include the Seyfert galaxies. We show below that this picture is difficult to attain with the accretion disk model of AGN. It is important, therefore, to ascertain the validity of the PLE model. Our analysis of the QSO data shows some difficulty with the PLE interpretation. We use data from the samples shown in Table I where we give the total number, N, sky coverage, $d\Omega$, the limiting B magnitude, and the appropriate references.

Table I QSO Surveys

Sample	N	$d\Omega\,(deg^2)$	B_{lim}	Reference
MBQS	32	87.65	17.65	*Ap. J.***287**, 1984
		21.30	17.25	
AB	22	37.20	18.25	*Astr. Ap. Suppl.* **80**, 1980
BF	35	1.72	19.80	*Ap. J.* **269**, 1982
AAT	167	0.35	20.40	*M.N.R.A.S.* **227**, 1987
		0.70	20.65	
		3.15	20.90	
Marano	23	0.69	21.00	*M.N.R.A.S.* **232**, 1988
Koo & Kron	29	0.29	22.60	*Ap. J.* **325**, 1988

III. The accretion disk model for AGN predicts a form for the physical evolution of QSO's. Figure 1, from Wandel and Petrosian (1988), compares the observed UV spectral index and UV luminosity of a sample of AGN (low z IUE data, high z ground base data) with that expected from a model parameterized by the mass, M, and dimensionless accretion rate $\dot{m} = \dot{M}c^2/L_{edd}$, for a maximally rotating Kerr black hole. Dotted and dashed lines show various possible evolutionary paths. Newly formed AGN with maximally rotating Kerr black hole and with high M and $\dot{m}$ quickly increase in mass, maintaining constant luminosity, until $\dot{m} < 1$. After this point, as $\dot{m}$ decreases, they will asymptotically approach a curve of constant mass (dotted lines). The rate of evolution along this path depends

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upon the value and evolution of the accretion rate, $\dot{M}$. If the black hole is Schwarzschild at formation, then a path like the dashed line is obtained. The initial horizontal evolution is due to spin-up from Schwarzchild to Kerr black hole. Evidently, the evolutionary path is complicated, and depends on the initial mass of the black hole and the evolution of the accretion rate. Furthermore, a high luminosity QSO cannot evolve into low luminosity QSO or Seyfert galaxy of comparable spectral index, and no high spectral index Seyferts or QSO's are found. From this we conclude that physical evolution of AGN's in the accretion disk model contradicts pure luminosity evolution for AGN.

IV. We have used a nonparametric method (Petrosian 1986) and a number-flux test (Loh and Spillar 1986, Caditz and Petrosian 1988) to test the pure luminosity evolution model over the redshift range $0 < z < 2.2$. We show in figure 2 two typical nonparametric luminosity functions – one for the redshift bin $0 < z < 0.3$ and one for $1.4 < z < 1.8$. These luminosity functions are calculated for an $\Omega = 1$, $\Lambda = 0$ Friedman cosmology and the evolutionary law $L = L_o(1+z)^{3.5}$ as derived by Marshall (1988). The high z luminosity function shows a clear break whereas in the low z bin no break is found. The luminosity function appears to maintain its shape only over the redshift range $0.6 < z < 2.2$ but not at lower redshift as required by PLE. **V.** Figure 3 shows the results of the number-flux test applied to the same data. This test is independent of the particular form of the luminosity function and requires only that its shape remains constant. The vertical axis is proportional to $\rho(z)$, the possible evolution of the comoving density, times the derivative of the comoving volume, dV/dz, divided by z^2. In the case of PLE, with $\rho(z)$ constant, the data points should follow a curve of constant Ω. Evidently, no reasonable value of density parameter, Ω, can be made to fit the data and we conclude, once again, that pure luminosity evolution does not hold over this redshift range. We have repeated the same analysis for the AAT data alone and, as shown by the filled circles, this data also does not agree with PLE.

We note that, as described by M. Smith (in these proceedings), new data show possible density evolution in addition to the luminosity evolution described above.

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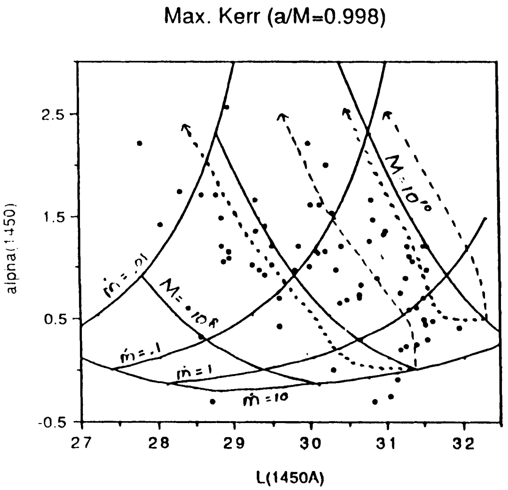

Figure 1 UV ($\lambda = 1450\AA$) spectral index and luminosity relation for AGN. Filled circles for Seyfert galaxy, open circles for QSO. Lines of constant mass, M, and constant $\dot{m} = \dot{M}c^2/L_{edd}$ based on the accretion disk model around a maximally rotating Kerr black hole are also shown. The two dashed lines show schematic evolutionary paths for $\dot{M} \approx$ constant for an initial Kerr black hole, and the two dotted lines show the paths starting from a Schwarzschild black hole which spins up to a maximally rotating Kerr black hole during the horizontal portion of the path.

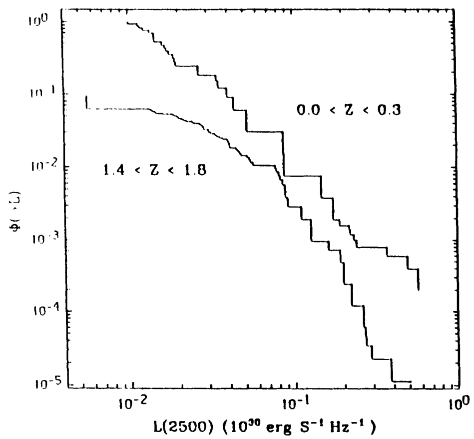

Figure 2 Cumulative luminosity functions $\Phi(> L) = \int_L^\infty \Psi(L)\, dL$ for two redshift bins showing typical luminosity functions with a break at high z and no evident break at low z.

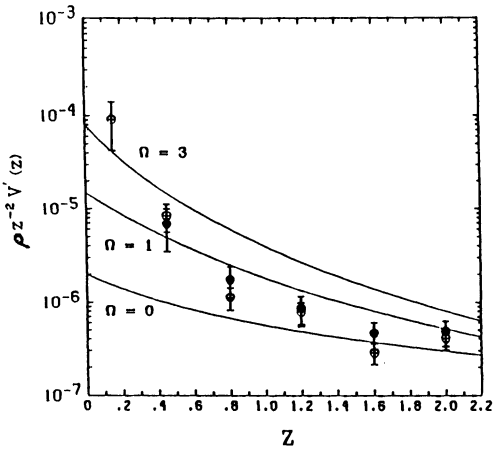

Figure 3 Product of comoving density, $\rho(z)$, and derivative of comoving volume $V'(z)$ divided by z^2 *vs.* redshift, z. Open circles for the combined sample, closed circles for the AAT data alone. Lines for pure luminosity evolution (constant $\rho(z)$ and shape) and for various values of cosmological density parameter are shown for $\Lambda = 0$.

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