Quasars: Their Evolution, Absorption Lines and the Intergalactic Gas

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QUASAR EVOLUTION

For many years now it has been known that the number vs. magnitude counts of quasars is the prima facie evidence of a cosmological evolution of this class of objects. Down to an apparent magnitude B ~ 19 the number of quasars increases by almost a factor 8 per magnitude interval, compared to a factor 4 obtained in an Euclidean universe filled with a uniform distribution of sources, and correspondingly less for the classical Friedmann models of Gen. Relativity due to the red-shift effects. This strong evolution has been recently questioned[1] because of several biases which may artificially steepen the slope of the counts in the optical surveys. Deep surveys of quasars selected via multi-colour techniques down to B ~ 23 have confirmed the long standing inference that the number count relationship must flatten beyond B ~ 20 [2,3]. As a consequence, pure density evolution models, where only the number density of quasars increases with the redshift z, leaving unchanged the shape of the local luminosity function, are ruled out, since too many quasars are predicted at faint magnitudes compared to the dramatic flattening of the counts (see, e.g., ref. 4).

These findings have been fully confirmed by a recently published survey of UVX selected quasars[5] which, most importantly, is large enough (170 objects with $B < 20.9$, $z < 2.2$ and $M_B < -23$) to permit a somewhat detailed description of the evolution of the luminosity function. It is found that the luminosity function, best parameterized by two power laws (the steeper one applicable to the most luminous objects), is globally shifted toward higher luminosities according to a power law of the form $(1 + z)^{3.6}$, almost a hundredfold increase at $z = 2.2$, while the derived local ($z = 0$) luminosity function is consistent with the luminosity function of Sy 1 nuclei[6]. The flattening of the counts is a direct consequence of the break in the luminosity function.

These results very much strengthen earlier conclusions based on studies of different combinations of optical samples[2,4,7,8] and provide some conclusive evidence on the long debated question of the precise nature of the evolution. Luminosity dependent density evolution models[9] and luminosity (or luminosity dependent) evolution models in which the luminosity increase is an exponential in the look-back time[10] do not appear to be consistent with present data. The question of the precise form of the luminosity function and its evolution is important also because it may shed light on the physics of quasars. Thus, a pure luminosity evolution poses a severe energetic problem, since it indicates that the order of 10^{9-10} $M_\odot$ must be radiated away during the life-time of a typical object[9,11], while a break in the luminosity function may indicate the presence of competing emission mechanisms[7].

The extension of the studies to samples complete at higher redshifts is probably important to pin down the precise form of the evolution. While most authors agree on the decline of the evolution beyond a redshift z ~ 2.5, the cut-off does not appear to be as sharp as it was thought to be[12,13]. The quasar distribution at high redshifts remains very uncertain. Attempts to interpret the decline in the number of quasars in terms of an increased amount of dust absorption at higher z in the host galaxies or in the surrounding intergalactic medium[14] seems to be contradicted by the observations that do not indicate the presence of a gradual increase of the reddening of quasar spectra at high z [15]. The redshift record is now set at $z = 4.43$ [16], close to the limit of the multi-colour technique used to discover this quasar[17]. This raises the important question of how to discover quasars at even higher redshifts where the optical detection techniques so far used seem to fail, while at the same time the detection of even one object with a redshift significantly larger than 5 would have profound implications on the long debated question of the epoch at which structures in the Universe are believed to have formed.

Since most quasars, if not all, are X-ray loud[18], it is clear that X-ray observations provide a powerful tool to investigate the cosmological properties of these objects, independent from the sometimes uncertain selection effects which may bias the optical surveys. The Einstein Medium Sensitivity Survey has provided a complete sample of X-ray selected quasars and Sy 1 nuclei[19]. The slope of the X-ray source counts is steep, clearly showing the presence of a strong cosmological evolution within the framework of the Friedmann models, but not as steep as that observed in the optically selected samples since it corresponds to an increase in the number of objects of only about a factor 5 per magnitude interval. Although a number of effects may satisfactorily account for the different slopes, it appears that the X-ray source counts derived from the optical counts (via the observed X-ray to optical flux ratios) overpredict the observed one by a factor 1.5-2.5 [20,21]. Some ways out have been proposed, but this discrepancy has not been satisfactorly solved as yet[21,22].

Although the cosmological evolution of radio loud quasars (about 10% of total) is well established, the evolution rate does not appear to be as strong as the one derived from the optically selected samples[23]. Within the statistics now available there is no significant difference between the evolution rates of quasars with flat and steep radio spectra[23,24]. Similarly, the radio luminosity function of flat spectrum radio quasars appears to fall at relatively large redshifts ($z \geq 2.5$) by a substantial factor, while this remains uncertain for the steep spectrum subclass[25,26]. The precise forms of the evolution of the radio luminosity functions are not yet constrained by the observations, but a pure luminosity evolution may be difficult to understand in view of the fact that the radio source lifetimes are believed to be much shorter than the Hubble time.

Following earlier work, it has been argued that the luminosity functions and surface densities of quasars can be noticeably affected by gravitational lensing due to compact objects (such as stars, Jupiters and black holes) either in galaxies or randomly distributed[27,28]. The brightening of quasars by minilensing can strongly influence the source counts, if their intrinsic luminosity function is steep[29]. Until now, however, there is no statistical and/or astrophysical evidence that this may indeed be the case.

Finally, it should be mentioned that the quasar counts (and also the extragalactic radio source counts) apparently could be interpreted within the framework of the chronometric cosmology without any evolution[30], but the validity of this result has been recently questioned[31].

CLUSTERING OF QUASARS

The clustering properties of quasars remain a somewhat controversial subject. While clustering on scales $\leq 10h^{-1}$ Mpc ($h = H_0/100$) has tentatively been detected in a UVX selected sample[32], clustering on these small scales has not been found in a much larger sample selected from IIIa-J objective prism plates[33] and in a comparable size sample of objects selected from blue grens plates[34]. There is no indication of general clustering at scales $> 10\ h^{-1}$ Mpc, although one has found[34] a group of seven quasars confined within a volume of size $\sim 50\ h^{-1}$ Mpc and with a dispersion in redshift consistent with velocity dispersions expected in an expanding supercluster.

QUASAR ABSORPTION LINES

The absorption lines found in the quasar spectra provide a unique tool to investigate the properties of the intergalactic gas at large distances, the physical parameters, composition and evolution of the intergalactic clouds and of the interstellar gas in galaxies at large redshifts, the large-scale distribution of matter over a wide range in redshift, and other properties relevant to cosmology and cosmogony. An excellent review of this subject can be found in ref. 35.

Several absorption systems are of interest here since they are generally interpreted as due to intervening absorbers:

a) The Lyα-only systems (sharp absorption lines blueward of the Lyα emission line) are usually interpreted as due to intervening intergalactic clouds with typical column densities $N(HI) < 10^{16}$ cm^{-2}. These clouds are commonly thought to be tenuous condensation of highly ionized hydrogen with mass of the order of a few times 10^7 $M_\odot$ and size ~ 10 kpc in pressure equilibrium with a hotter intergalactic medium or, maybe, gravitationally bound by cold dark matter[36].

b) The heavy element systems present, in addition to Lyα, narrow lines of heavier elements consistent with a composition not too different from solar and are typically found at intermediate column densities, $10^{16} < N(HI) < 10^{20}$ cm^{-2}. These systems are almost always found also in the Lyman limit systems, so called because of the Lyman discontinuity becoming detectable when the optical depth at $\lambda < 912$ Å is $\tau \gtrsim 1$, that is for column densities $N(HI) \gtrsim 1.5\times10^{17}$ cm^{-2}. It has been assumed that the heavy element systems are formed in the outer regions of intervening galaxies. However, it has been recently argued[37] that the similarity of the column density distribution function to that of Lyα-only systems strongly supports the hypothesis of one absorber population, intergalactic clouds with (perhaps) chemical composition ~ 0.1 the solar value. The fact that by definition the heavy elements absorption lines are not found in the Lyα systems implies a small degree of ionization, hence total column densities $\leq 10^{17}$ cm^{-2} and, therefore, clouds of small size ($\leq 10^{18}$ cm). It should be stressed here that while this suggestion may explain a number of properties of the absorption system samples, it still remains difficult to understand how the enrichment in heavy elements has occurred and the lower limit to the absorber size ($\gtrsim$ 3 kpc) derived from Lyα systems in the two components of a double quasar due to gravitational lensing[38].

It should be noted that not all the heavy element systems necessarily originate in intergalactic clouds. For instance, the predicted number of Lyman limit systems due to absorption in intervening spiral galaxies is a factor ~ 6 smaller than the ones observed for column densities $\lesssim 3\times10^{18}$ which comprise ~ 85% of the heavy element systems, while for larger column densities the predictions agree with observations[37]. It should also be noted that the sky coverage of these absorbers is ~ 50% [37], and thus any background radiation capable of ionizing hydrogen can be largely affected. The origin of the intergalactic clouds is unknown.

c) The damped Lyα systems (very strong Lyα absorption with associated heavy element lines of low ionization) are found at large column densities $N(HI) > 10^{20}$ cm^{-2} and are believed to be associated with intervening HI disk galaxies[39]. The density of these systems implies that ~ 20% of the sky is covered by gaseous disks with large column densities in the redshift interval z (2-3), a factor five in excess of the one predicted[40].

Finally, it is generally believed that the Lyα systems show a clear indication of cosmological evolution in the sense that their co-moving density appears to increase with z [41], an effect which would entail an increase of the number density and/or of the average size of the Lyα absorbing clouds. Since the same does not appear to be true for the heavy element systems, this has been considered as a further evidence against a common origin of the two types of absorption systems. However, a number of anomalies elucidated in the analysis of published samples indicate the possible presence of (poorly understood) selection effects which may render any statement concerning the evolution rather uncertain[42].

Clarification of these matters is important also because the Lyα absorption lines can provide a very powerful tool to probe the large scale structure of the Universe at large redshifts.[43]

INTERGALACTIC GAS

Spectrophotometric observations of a sample of high redshift ($z \sim 3$) quasars, combined with the statistical properties of the Lyα absorption systems to correct for the apparent depression of the continuum shortward of Lyα, has led to a downward revision of more than an order of magnitude on the Gunn-Peterson upper limit to the amount of neutral hydrogen present in the diffuse intergalactic gas.[44] The *new limit corresponds to* $n(HI) < 9 \times 10^{-14}\ h\ cm^{-3}$ (at $z = 0$). *Under the hypothesis* that the intergalactic gas is maintained fully ionized by the UV radiation from quasars (at $z \sim 2.6$) and that it is in pressure equilibrium with the Lyα clouds one finds $n(H_{tot}) < 4.6 \times 10^{-7}\ h\ cm^{-3}$ and a total contribution to the density of the Universe of $\Omega_0(H) < 0.05\ h$.

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