AN EVOLUTIONARY ANALYSIS OF QUASARS

Tom Heymann
E-mail: y.heymann@yahoo.com

3 rue Chandieu, 1202 Geneva, Switzerland

Abstract

The principal objective of this study was to investigate the formation and evolution of quasars. A method to build the density-distance curve for quasars was proposed, by applying a geometric normalization to account for the sampling bucket volume. Then the distribution of quasar relative magnitude was investigated, and led to a first order rate kinetics for the decay which was attributed to the nuclear activity of quasars.

The quasar density-distance curve and quasar decay are in favor of the big bang hypothesis. Furthermore bright quasars seem to be formed by coalescence during an early epoch close to the big bang which is one of the underlying hypothesis in the herein study. The analysis of bright quasar formation gives us some insights on the environmental conditions under which they were formed (i.e. collision rate, density of celestial objects, and the energy availability in the universe).

Keywords

Big bang, coalescence, decay, density, half-life, magnitude, quasar, redshift

Introduction

One of the challenges is to provide some evidence from observational data to discriminate between the two antagonist hypothesis: the big bang versus the stationary universe theory (steady state theory). The steady state theory has been proposed by Hoyle et al. (1993) as an alternative to the big bang. Let us introduce this topic from a philosophical angle. Time may be defined as a way to position a succession of events in a given referential. In the big bang hypothesis the underlying idea is the existence of an initial event releasing the energy and matter from which all celestial objects are formed. In the stationary hypothesis, celestial objects are formed from a multitude of events by continuous input of energy and matter. By investigating the evolution of quasar density with time, Löbert (1993) came to the conclusion that the observations supported the big bang hypothesis. The idea of a cosmological evolution of quasars was already introduced by Schmidt (1978).

Bright quasars being rare objects and very luminous make them potentially good candidates to analyse evolutionary theory of the universe, but a first focus is to understand how they are formed themselves and their evolution which is the scope of the present study. Kontorovich et al. (1991) suggested that quasars are formed by coalescence. Here the problem is approached by analysing quasars through the normalised density-distance curve, and relative magnitude distributions hoping to find some clues on the formation and evolution of these objects.

Wagner (2005) mentioned the application of coagulation-fragmentation models to aerosol technology and astrophysics, which is supported in the present study for the specific case of bright quasar formation. The aim of the present study is not to provide a model for quasar formation, but rather to understand the fundamentals, general concepts and mechanisms involved such as coalescence and fragmentation; how they may be characterised; and, dominant process for given conditions.

Material and methods

Normalisation of celestial object counts to build the density-distance curve

Let us consider an observer positioned at the centre of a sphere of radius r (figure 1). Now this observer is looking at the sky in the z direction according to a cone of interior angle θo with respect to the z axis. The observer is counting a given type of celestial objects within this cone, and measures the redshift for each object.

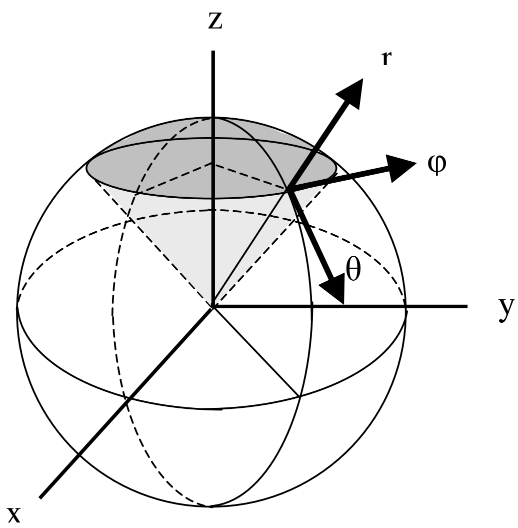

Figure 1: Representation of a conical observation in spherical coordinates, where r is the radius, φ is azimuth between [0, 2π] , and θ the zenith angle is between [0, θo] with θo the interior angle of the cone.

A histogram of the object counts versus redshifts is obtained by counting the set of objects contained in each redshift buckets, e.g. [0, 0.1, 0.2, …]. This histogram requires to be normalised in order to obtain the density-distance curve. This is done by computing the volume of the sampling space of the buckets. Below is derived the expression of this volume, function of r_0 the lower radius of the sampling bucket, and Δr the radius width of the bucket.

The sampling bucket volume for a conical observation is described by the following integral:

$$V_{ro,\Delta r} = \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\theta_0} \sin\theta d\theta d\varphi \int_{r_0}^{r_o+\Delta r} r^2 dr \tag{1}$$

By solving integral (1), the volume of the sampling buckets for a spherical sampling (θo = π) is expressed as follows:

$$V_{r_0,\Delta r} = \frac{4\pi}{3}\left((r_0+\Delta r)^3 - r_0^3\right) \tag{2}$$

Where: $V_{r_0,\Delta r}$ is the volume of the sampling space for a given bucket, r_0 is the lower radius of the sampling bucket, and Δr the radius width of the bucket.

The quasar counts computed for each buckets need to be converted into spherical values. Given the SDSS survey spectroscopic area of 5’740 square degrees, which is the surface coverage in the {right ascension in degrees} and {180/π*sin(declination)} plan (the solid angle), bucket counts are multiplied by the following ratio:

$$\eta = \frac{4\pi\ (180/\pi)^2}{5'740} = 7.2 \tag{3}$$

Conversion of redshifts to distances

Redshifts were converted to light travel distances using the calculator from Wright (2006). Assuming a flat universe, the following cosmological parameters were used for this conversion: Ho = 71 [km $s^{-1}Mpc^{-1}$], $\Omega_M = 0.27$, and $\Omega_{vac} = 0.73$.

Relative magnitude

The distribution of the relative magnitude has been investigated in the present study. The relative magnitude represents the brightness of a celestial object with respect to a reference (the Milky Way in the present case).

$$R = \left(100^{0.2}\right)^{-20.5-M} \tag{4}$$

Where: R is the quasar relative magnitude, -20.5 is the Milky Way absolute magnitude, $100^{0.2} \approx 2.51$ is the amount of brightness ratio given Norman Pogson (1857) magnitude system, and M is the quasar absolute magnitude.

Expansion of the universe and quasar density

Let us consider two quasars initially separated by a distance X_0. Ignoring the acceleration and assuming a constant expansion coefficient, the expansion speed at which they are moving away is $v = HX$ (where H is the Hubble constant).

This translates into the following differential equation: $\frac{dX}{dt} = HX$, that has for solution : $X(t) = X_0 e^{Ht}$. Therefore, distances would double every 9.3 Gyr, and space volume every 3.1 Gyr. Assuming no formation of new quasars and a homogeneous universe, the expansion of the universe should be reflected in the slope of the density-distance curve.

(note 5)

Sources of data

The DR5 release of the SDSS (Sloan Digital Sky Survey) Quasar Catalog described in Schneider et al. (2007) was used for bright quasars (77,429 objects classified as quasars). The data are publicly available at http://www.sdss.org. The DR5 release of the CAS (Catalog Archive Server) was used to retrieve faint magnitude quasars (Thakar et al, 2008); however, absolute magnitudes were not available. Both surveys have a spectroscopic area of 5'740 square deg.

Results

Using the data from the CAS and SDSS Catalog, was constructed the counts histogram versus redshift (figure 2). The bright quasar histogram is published by Schneider et al. (2007).

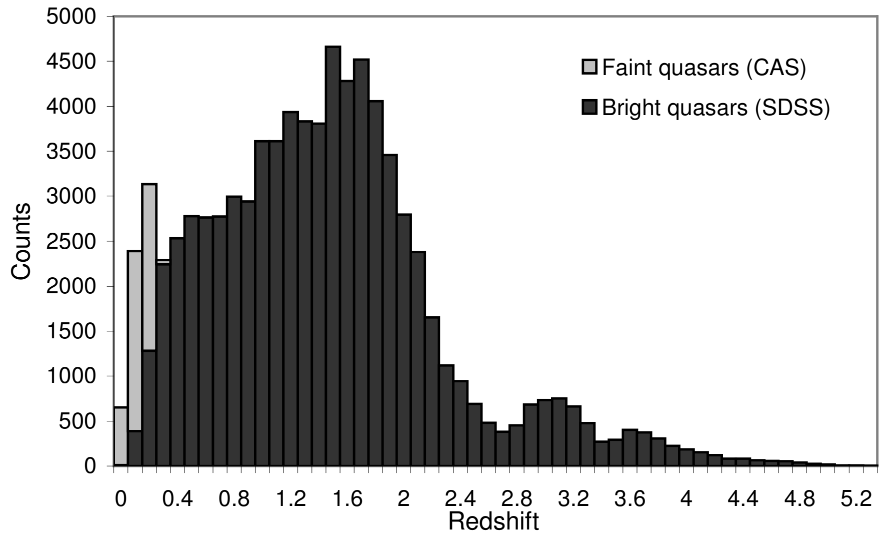

Figure 2: Counts-redshift histogram. The counts are based on redshift buckets of width 0.1.

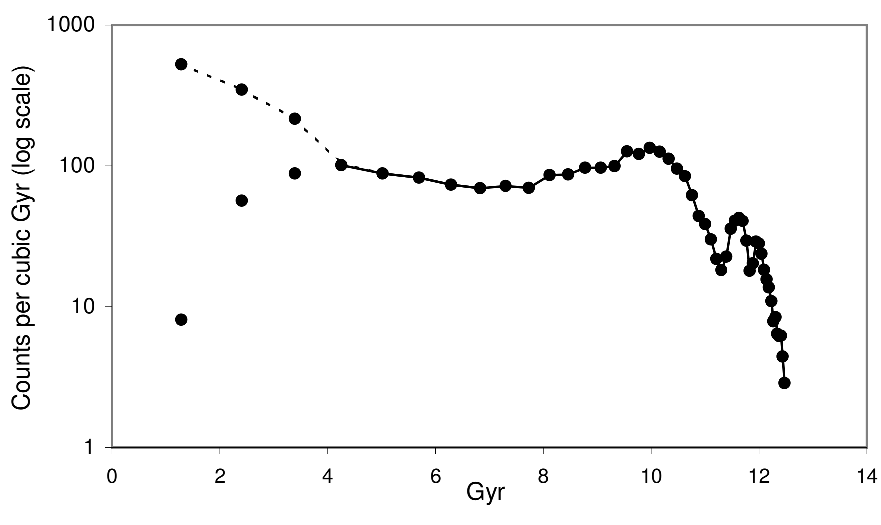

Figure 3: Density-distance curve derived from the equivalent spherical sampling, where Gyr are billion light years from today. Distances are computed from redshift conversion with the calculator of Wright (2006). Bright quasar observations below 4 Gyr appear to be biased due to the cut-off for small relative magnitude quasars (figure 4). The dotted line includes faint magnitude quasars retrieved from the CAS.

From figure 3, it appears that bright quasars were formed during the 10 to 12.5 billion light year period. Considering that bright quasars are formed by coalescence, the slope of the density-distance curve during this epoch presuppose a high collision rate (dense universe). The oscillations around 11.5 and 12 Gyr have been explained by Schneider et al. (2007) as being noise due to stellar reshift interference.

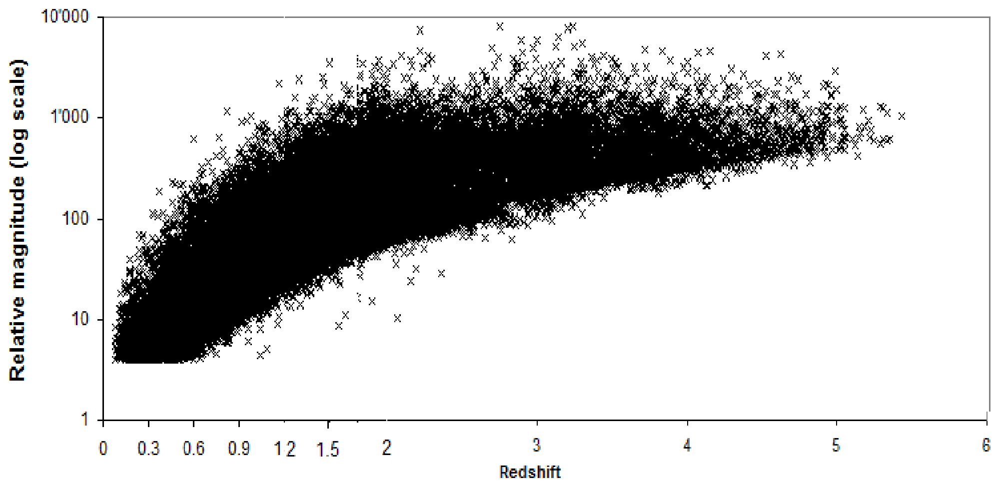

Figure 4: Plot of individual quasar relative magnitude versus redshift.

From figure 4, a cut-off can be detected in the redshift range from 0 to 0.4 which corresponds roughly to distances up to 4 Gyr. Quasars of relative magnitude below 4 (absolute magnitude above –22.0) have been excluded from the catalog. Hence, the measures of count density and quasar average relative magnitude are biased for distances below 4 Gyr.

Figure 4 shows an increase of the relative magnitude with redshift, which is attributed to the decay of quasars with respect to time as quasar energy is being dissipated by nuclear activity (cf. discussion).

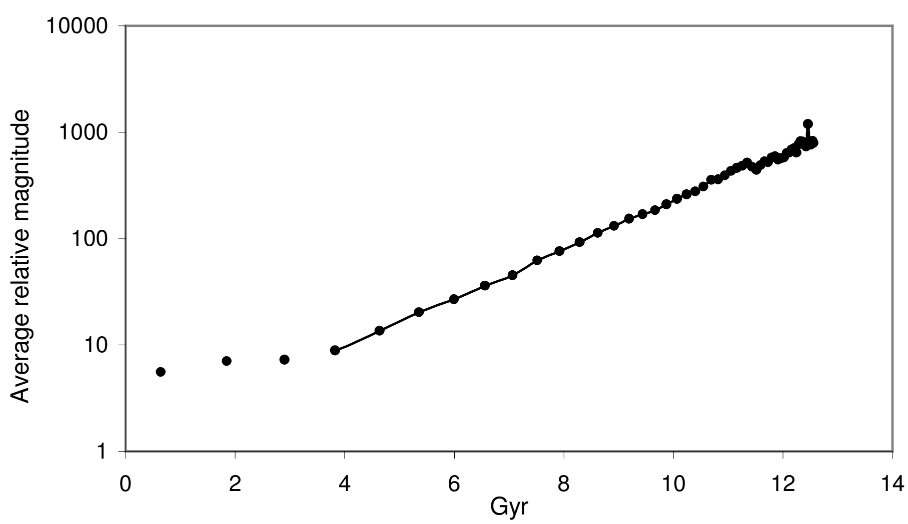

Figure 5: Average relative magnitude per quasar (log-scale) versus light travel distance in Gyr. The quasar average relative magnitude was measured as the sample average for buckets of redshift width 0.1. Observations below 4 Gyr appear to be biased due to the cut-off for small relative magnitude quasars (figure 4).

Excluding the part of the curve with distances below 4 Gyr, the average relative magnitude in log-scale is linear with respect to time. Based on this observation, was inferred that the decay of quasar relative magnitude follows a first order kinetics. Doing a linear regression this decay (K) is estimated at 0.52 per Gyr with a correlation R-square of 99.5%. At this speed, the average quasar will have the same magnitude than today Milky Way in about 380 million years.

At the beginning the author thought that dispersion of the quasar relative magnitude (figure 6) would provide some insights of the degree of chaos as we get closer to the big bang epoch. The expectation is that high collision rate increases the dispersion measure due to energy gain by coagulation, and eventually fragmentation of quasars by collision (of an explosive or non explosive nature). The author believes that fragmentation due by collision is unlikely to happen under the conditions over the period being observed, as it would require much higher energies. In the explosive fragmentation scenario, the expectation is to get a splitting of the dispersion measure at two distinct scales (macroscopic and microscopic scale). Note that there is no evidence that fragmentation itself would increase the dispersion measure, whereas coagulation and agglomeration shall.

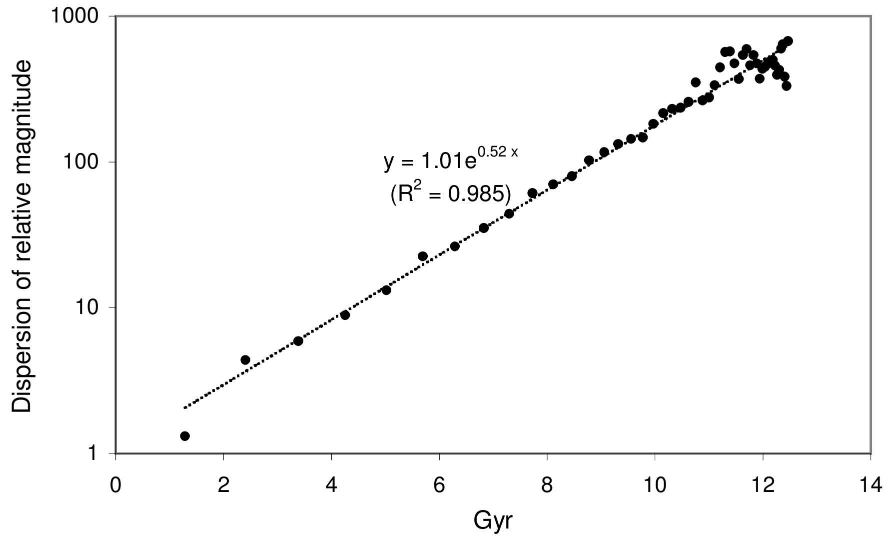

Figure 6: Dispersion of quasar relative magnitude (log-scale) versus light travel distance in Gyr. The dispersion was measured as the sample standard deviation for buckets of redshift width 0.1. Note that for the regression, the part of the curve with redshift above 4.7 was excluded due to noise and non linearity.

Comparing the rate of the exponential coefficient for both figure 5 and 6, can be deducted that dispersion is somehow directly proportional to the quasar average relative magnitude – this is verified mathematically. Let us apply the first order decay kinetics to each individual quasars in a given time bucket, and set the relative magnitude of the ith object to $R_i = A_i e^{Kt}$, where Ai is the corresponding relative magnitude as of today. As a consequence the average relative magnitude of the sample follows a first order kinetics: $\mu_t = \mu_0 e^{Kt}$. For a sample of N observations, the standard-deviation may be expressed as follows:

$$\sigma_t = \sqrt{\frac{\sum_{i=1}^{N} \left(A_i e^{Kt} - \mu_t\right)^2}{N-1}} \qquad \text{Hence:} \quad \sigma_t = e^{Kt} \sqrt{\frac{\sum_{i=1}^{N} A_i^2 + N\mu_0^2 - 2\mu_0 \sum_{i=1}^{N} A_i}{N-1}}$$

From the above can be inferred that the likelihood of having collisions is generally neglectable compared to the decay rate of quasars. However, for redshift above 4.7, the dispersion is decreasing slowly below the regression line. Although this is subject to interpretation, this anomalous increase in dispersion over time may indicate a high collision rate, where coagulation dominates (i.e. dense universe during the period prior redshift 4.7).

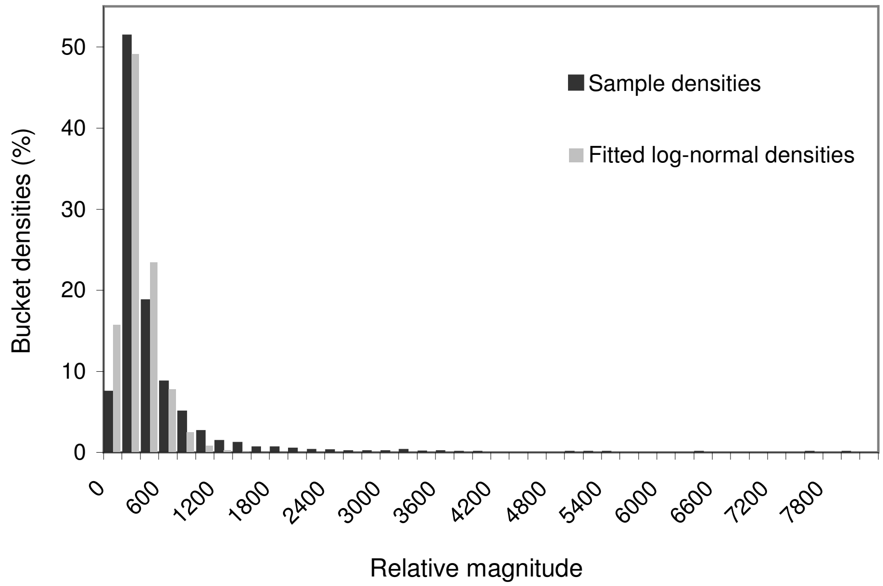

Figure 7: Transversal distribution of quasar relative magnitude for the redshifts between 3.0 and 3.3. Densities computed on buckets of 200 relative magnitude width. The log-normal distribution was fitted with its cumulative density function ($\mu = 5.8$, $\sigma = 0.5$).

From the transversal distribution of quasar relative magnitude (figure 7), about 50% of the quasar sample are concentrated in the 200 to 400 relative magnitude bucket, and the distribution has a very thin tail up to 8000 relative magnitude. The transversal distribution exhibits a close to log-normal distribution. It is well documented in the literature that the dimension of aerosol particles formed by coalescence (Sheldon, 2000) may be approximated by the log-normal distribution. There are two broad approaches to model coalescence and fragmentation, respectively models based on physical processes described by the aerosol General Dynamic Equation (Sheldon, 2000) and, on stochastic processes (Wagner, 2005). Many models have been proposed in the literature for aerosol formation (e.g. nucleation, coagulation, coalescence, and accretion); however, the suitability of these models to describe quasar formation is beyond the scope of the present study.

Discussion

In order to analyse quasar formation and evolution, the following analysis were undertaken using the SDSS Quasar Catalog (Schneider et al, 2007): a normalized density-distance curve was constructed (including faint quasars from the CAS), and the distribution of quasar relative magnitude was investigated.

The (count) density-distance curve has been obtained based on the converted spherical sampling with quasars retrieved from the SDSS survey - the quasar counts were normalized to account for the sampling volume between each redshift bucket. Data for light travel distances below 4 Gyr appear to be biased due to a cut-off for small relative magnitude quasars (figure 4); therefore, faint magnitude quasars from the CAS were added to build the density-distance curve. From the quasar density-distance curve, bright quasars were formed in the 10 to 12.5 billion light years period (redshift range 1.8 - 5.4). For the succeeding period starting from 7 Gyr to 10 Gyr ago, the density decreases from a peak of 132 to 68 counts per cubic Gyr, which corresponds to the volume expansion rate (cf. note 5). Therefore, the assumption is that there is virtually no new quasar formation in this young universe. For the period starting from 7 Gyr ago until today, can be observed a rise in the density of faint quasars. It is unsure what causes faint quasar formation; although, the process seems to be dependent on the age of the universe. The author believes that faint quasar formation may be correlated with the density of galaxies in the universe. Still further investigations would be required to confirm this. It should be emphasized that celestial object classification and selection algorithm (Schneider et al., 2007) may impact materially the shape of the density-distance curve.

Quasars appear to have a roughly homogeneous distribution in the universe given the projection into the right ascension and sinus of declination plan. Given today density of 519 quasar counts per cubic Gyr, the number of faint quasars in the visible universe is estimated at 6.0 millions (i.e. visible universe of 14 Gyr radius).

The quasar sample average relative magnitude versus light travel distance has been analysed (figure 5). As a heuristic the relative magnitude is being used as a measure of the nuclear activity of quasars. The quasar relative magnitude decreases with time according to a first order rate kinetics estimated at 0.52 per Gyr, which is equivalent to a half-life of 1.33 Gyr. This is close to the half-life of potassium-40, which is the preferred method for the datation of magmatic rocks. This decay is attributed to quasar energy dissipation by radioactive decay and electromagnetic emissions.

One question that arises is whether the big bang is better described as a transition from a very energetic and dense universe to a colder universe, or is of an explosive nature. Earlier was introduced the concept of explosive fragmentation which would be characterised by a split of the dispersion measure, resulting in two distinct distributions respectively at the macroscopic and microscopic scale. However, we doubt that explosive fragmentation is applicable to the big bang. The WMAP studies presume the existence of a plasma phase given the ionisation of the universe at a very short time after the big bang (Lewis et al, 2006). The high energy of quasars formed during a later phase (redshifts from 1.8 to 5.4) let us think that the primitive universe was much richer in energy than today[1]. Quasars were in average about 830 times the Milky Way actual magnitude 12.5 Gyr ago (redshift 5.1), whereas today they have an average relative magnitude of about 1.22. The coalescence hypothesis for the formation of bright quasars provides a good explanation for the fact that quasars are rare objects in the universe (compared to galaxies and stars), given the low probability of collision between celestial objects. From the quasar formation rate for redshifts between 1.8 and 5.4, is inferred that collision rate was high, and presuppose a dense universe during the bright quasar formation epoch.

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[1] Note that this statement does not take into consideration dark energy (non visible) that accounts for about 70% of today universe (Cline, 2003). As of today dark energy is more of a concept than a source of energy in itself, which is being used in cosmological models, and to explain related phenomenology. The question is whether quasars may be used as an indicator of the energy availability in the universe, as other celestial entities may not follow the decay rate of quasars.