Cosmological implications of the distribution of quasar forest lines

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The distribution of quasar forest lines may be use to derive the parameters of the cosmological model. In order to get an estimation of these parameters, one has to compare the assumed configuration and the assumed evolution of the absorbing clouds and filaments of neutral hydrogen. Two configuration models have been discussed so far, the cloud model and the bubble-wall model.

In the cloud model, the individual narrow absorption line is assumed to indicate an isolated cloud. These clouds are supposed to be homogeneously distributed in space, because no convincing clustering of the lines has been found. The equivalent width at rest shows the column density, and the distributions of both are usually assumed not to evolve in redshift. The HST spectra of near quasars are problematic, because we see more than expected by this model configuration.

In the bubble-wall model, the individual (but possibly blended) lines are supposed to indicate the wall of a void analogous to the voids in the galaxy counts. The walls itself might consist of clouds and filaments, which however cover the wall completely (at least for redshift $z > 2$). In this case, the line indicating a wall might be a blend of narrower lines not to be separated because of the only small velocity difference. This is the basis of the line counts of Priester et al. [11], [12]. The point is, that the evolution of the individual components of a wall does not affect the line counting as long as one can assume the walls to be covered completely. The wall components may shift apart in later times, reducing the probalbility of seeing the walls as absorption lines. This fits to the observation, that there are less absorption lines in the HST-spectra of near quasars than expected by this model. The connection to the cloud model, provided by the particularily thick point on the walls as formal clouds, has been considered in [6].

If we wish to include the evaluation of evolution effects, we have to model not only the line density on the redshift scale, but also the mean equivalent width depending on the redshift. The evolution model has to contain

- a model for the evolution of the universe, $H[z] = H_0 h[z]$,
- a model for the evolution of some size parameter for the absorbers, $S[z] = S_0 s[z]$,
- a model for the evolution of the density of hydrogen in the clouds effective in Lyman-alpha absorption, $R = R_0 r[z]$,
- a model for the evolution of the comoving number density of absorbers, $A[z] = A_0 a[z]$, especially to describe merging or fragmentation.
- a model of the configuration of these absorbers, approximated by a value for the effective dimension d ($d = 0$ for isolated, quasisherical clouds, $d = 1$ for filaments of the foam size L, and $d = 2$ for sheets and walls of this size),

With these definitions, the average Lyman-alpha effective mass density is given by

$$A[z] L^d S^{3-d}[z] R[z] = M[z]. \tag{1}$$

The total mass inside a sphere of redshift $< z$ is

$$M = \int_0^z M[z] O[z] \frac{\mathrm{d}z}{h[z]},$$

with the comoving surface

$$O[z] = 4\pi R_0^2 r^2[z], \quad r[z] = \frac{1}{\sqrt{\kappa_0}} \sin(\int_0^z \mathrm{d}z \frac{\sqrt{\kappa_0}}{h[z]})$$

Evolution in the number density A may be produced by merging or fragmentation. Merging should not change the internal physical density $R[z]$ essentially. Fragmentation should reduce the total Lyman-alpha effective mass density, if we understand it as coupled or triggered by star formation. Evolution in internal density could be the result of changing pressure, if the absorbers are pressure-confined. If the intercloud medium is a hot gas expanding adiabatically, we should expect the physical density to go as

$$R[z](1+z)^3 \propto (1+z)^5. \tag{2}$$

If the intercloud medium is isothermal because of reheating by quasar light for instance, we expect the comoving density $R[z]$ to be constant. Evolution in Lyman-alpha effective mass $M[z]$ might be due to accretion and cooling, which should increase the mass, or to heating by quasar light or star formation, which both would reduce the mass [4]. Evolution in dimension should be seen as evolution in structure, i.e. in condensation on the walls of a foam, on the adjoint network of edges or the pattern of vertices. The comoving size of these structures might well be assumed to be constant, as all particle simulations show. The evolution should be a subsequent condensation, beginning with walls ($d = 2$) and ending with vertices, i.e. superclusters ($d = 0$) [3].

The observed evolution may be that in number density of lines on the redshift axis, $N[z]$, and the evolution of their column density, $W[z]$. For the moment, we will assume simple (exponential) distribution laws, so that the mean values only are important. It would be a second step to consider models with evolving forms of the distributions.

The number of lines in a redshift intervall is now given by

$$N[z]H[z] = M[z]R^{-1}[z]S^{-1}[z] = A[z]L^d S^{2-d}[z], \tag{3}$$

where $H[z]$ denotes the evolving expansion rate of the universe. For an Einstein-deSitter model (Dark matter model) we have $h[z] = (1+z)^\chi$ with $\chi = \frac{3}{2}$. If we are forced to agree some other evolution exponent χ, we have to choose a Friedmann-Lemaitre model with

$$h^2[z] = \lambda_0 - \kappa_0(1+z)^2 + \Omega_0(1+z)^3 \tag{4}$$

The column density $W[z]$ is proportional to the product of the physical density in the clouds, $R[z](1+z)^3$, with the physical length of the path of light through the cloud, $S[z](1+z)^{-1}$:

$$W[z] \propto R[z]S[z](1+z)^2. \tag{5}$$

The sum of the column densities of the lines in a redshift intervall yields the total Lyman-alpha effective mass corrected for the factor $(1+z)^2$,

$$N[z]H[z]W[z] \propto M[z](1+z)^2 \tag{6}$$

The total column density till redshift z may be estimated by

$$W = \int_0^z N[z]W[z]\mathrm{d}z = \int_0^z M[z](1+z)^2 \frac{\mathrm{d}z}{h[z]}. \tag{7}$$

Without evolution in configuration, we get the evolution equations

$$\begin{aligned} n[z]h[z] &= a[z]s^{2-d}[z], & (8)\\ w[z] &= r[z]s[z](1+z)^2, & (9)\\ n[z]h[z]w[z] &= m[z](1+z)^2. & (10) \end{aligned}$$

If the dimension evolves, the first equation changes into

$$n[z]h[z] = a[z]s^{2-d}[z](\frac{L}{S_0})^{d-d_0}. \tag{11}$$

1 The data

We simply approximate the data by an average density of lines on the redshift scale in the form[1] $n[z] = (1+z)^\nu$ and the average equivalent width in the form $w[z] = (1+z)^\omega$.

It is not too trivial a matter to count the lines in the absorption forests, and there is no consensus about it. We adopt as example the values of Lu, Wolfe and Turnshek [13]:

$$\nu = 2.37 \ldots 2.75, \quad \omega = 0$$

The method of analysis, however, may be used for other and better data as well. In particular, we see an evolution in the equivalent width, $\omega \approx 1.2$, with $\nu \approx 0.4$. The evolution of the equivalent width has been found to vanish in the evaluation of a smaller and rougher data set [15]. In the meantime, for the distribution of column densities a power spectrum has been adopted,

$$f[W,z] = (\frac{W}{W[z]})^{-\beta}, \quad \beta \approx 1.7$$

Such a distribution, however, shields a possible evolution in column density from observation. The observed evolution is the combination

$$N^*[z] = N[z]W^\beta[z]. \tag{12}$$

Hence, we have to interpet the value of Lu et al. as

$$\nu + \beta\omega = 2.37 \ldots 2.75.$$

The three theoretical equations between the evolution exponents

$$\begin{aligned} \varrho + \sigma + 2 &= \omega \\ \alpha + (3-d)\sigma + \varrho &= \mu \\ \mu + 2 - \omega &= \nu + \chi \end{aligned}$$

may be evaluated now.

At this point, the main conclusion is that about the evolution of mass. If we accept the assumption of $\omega = 0$, an Einstein-deSitter universe yields $h[z] = (1+z)^\chi$, $\chi = \frac{3}{2}$, and we get $M[z] \approx M_0(1+z)^\mu$, $\mu = 1.75 \ldots 2.25$. Because of the formula

$$\frac{1}{\tau_M} = \frac{1}{M}\frac{\mathrm{d}M}{\mathrm{d}t} = H_0\ h[z]\ \mu, \tag{13}$$

this implies for an Einstein-deSitter universe the Lyman-alpha effective mass to decay with the characteristic time of only 0.07 Hubble times. In spite of this fast decay, Ly-alpha clouds are still observed at the redshift $z < 0.05$. If the decay cannot be modelled in accordance with this fact, one has to accept a smaller value of μ, with the result to accept a smaller value for χ. If $\chi < \frac{3}{2}$ in the intervall $2 < z < 4$, we have to calculate with a Friedmann-Lemaitre universe. This conclusion is independent of the evolution in the number density $A[z]$, the size parameter $S[z]$, the density $R[z]$, or the configuration dimension d. All the particular models

[1] We write here the exponent to $n[z]$ as ν to parallelize the notation of the quantity in question with its exponent. Elsewhere, the exponent ν is usually denotes by γ. We eventually write $r[z] = (1+z)^\varrho$, $s[z] = (1+z)^\sigma$, $m[z] = (1+z)^\mu$, $a[z] = (1+z)^\alpha$, and $h[z] = (1+z)^\chi$.

which we might consider tell the same in this point.

The bubble-wall interpretation ($d = 2$) makes equation (8) independent of the evolution in the thickness $s[z]$ of the walls, as it was already mentioned. The absorption line catalogues taken as they are, one gets an increasing number density in redshift, and this inevitably leads to a Friedmann-Lemaitre universe with positive curvature and positive cosmological constant. Accepting the value of baryon density resulting from primordial nucleosynthesis calculations, everything seems to fit for a Hubble number of $H \approx 100$ km/s/Mpc and no additional dark matter.

Two additional facts have to be mentioned. First, the number density of lines seems to have a maximum at $z \approx 3.5$ [8],[16]. This contradicts the power laws used in Einstein-deSitter models. Second, we can infer the present size of the bubbles assumed to produce the absorption lines by their walls. It is about the size of the bubbles in the CfA survey, and this is remarkable, because it connects features observed with very different methods, and for different classes of objects. We only mention the possible connection between the ephemeral periodicities in redshift catalogues and the bubble structure. Nearest to the mean wall separation $0.009 < \Delta z < 0.005$ expected by Hoell and Priester is the result of Kruogovenko and Orlov [9].

Apart from the bubble-wall interpretation, there are also good reasons for a model based on filaments: the fact, that caustics of the primordial velocity field (possibly necessary to solve the time problem of primordial structure formation) always define one-dimensional structures. Other models with filamentary structures can be found in [10]. We have to put $d = 1$, if this filamentary structure is dominant. However, we have to keep in mind, that the original interpretation is to take the filaments as constituents of the walls, which remain the primary structure.

2 Conclusion

The evaluation of the line catalogues indicates a Friedmann-Lemaître universe with positive curvature. The evolution of equivalent width and line density, combined with the assumption of a slow or zero increase of absorbing mass, $\mu \leq 0$, prevent an evolution of the expansion rate fast enough to be compatible with the Einstein-deSitter universe. The present value of the quantum vacuum energy density or the cosmological constant is essential. Hence the dark matter necessary to fill the gap between the critical density and the matter density (baryonic and dark) measured in the galaxy and cluster distribution is probably vacuum, not exotic particles.

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