NARROW QUASAR ABSORPTION LINES AND THE HISTORY OF THE UNIVERSE

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Abstract:

In order to get an estimation of the parameters of the cosmological model the statistics of narrow absorption lines in quasar spectra is evaluated. To this end a phenomenological model of the evolution of the corresponding absorbers in density, size, number and dimension is presented and compared with the observed evolution in the spectral density of the lines and their column density seen in the equivalent width. Inspite of the wide range of possible models, the Einstein-deSitter model is shown to be unlikely because of the implied fast evolution in mass.

1 Narrow quasar absorption lines

The narrow absorption lines shortward of the redshifted Lyman-alpha emission in quasars indicate a homogeneous and comoving population of intervening absorbers. They are not connected with the quasar, but uniformly distributed. Therefore, it is necessary to test their property of being a standard for geometric evaluation.

The basic observation is the varying number of lines per redshift interval $N[z]\mathrm{d}z$ and the distribution $f[W,z]\mathrm{d}W$ of the column density W of these lines, which has to be evaluated from the intrinsic equivalent width. We have to compare the observation with

- 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),

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

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

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 [**?**]. 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 ($d = 0$) [**?**].

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

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

in the case of non-evolving dimension

$$n[z]h[z] = m[z]r^{-1}[z]s^{-1}[z] = a[z]s^{2-d}[z], \tag{4}$$

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

$$h^2[z] = \lambda_0 - \kappa_0(1+z)^2 + \Omega_0(1+z)^3 \tag{5}$$

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, $S[z](1+z)^{-1}$:

$$W[z] \propto R[z]S[z](1+z)^2. \tag{6}$$

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

$$n[z]h[z]w[z] = m[z](1+z)^2 \tag{7}$$

The total column density till redshift z may be estimated by

$$W = \int_0^z N[z]W[z]\mathrm{d}z = \int_0^z M[z](1+z)^2 \frac{\mathrm{d}z}{h[z]}. \tag{8}$$

2 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 $w[z] = (1+z)^{\omega}$.

[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 $h[z] = (1+z)^{\chi}$.

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 [**?**]:

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

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 [**?**]. 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

$$N^*[z] = N[z] W^\beta[z]. \tag{9}$$

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

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

have to be evaluated now.

- No evolution in physical size, physical density, and number yields $\omega = 0, \mu = 0, \chi \approx -0.5$, i.e. a Friedmann-Lemaître universe with positive curvature and cosmological constant.
- No evolution in total mass, together with an Einstein-deSitter model for the universe yields $\nu + \omega = 0.5$, with $\nu + \beta\omega = 2.5$ this implies $\omega \approx 3$. If we assume in addition constant physical density, we get $sigma \approx 1$ and $\alpha \approx d - 3$, which corresponds to an extremely fast fragmentation of the absorbing units.
- The main conclusion is that about the evolution of mass. If we accept the assumption of $\omega = 0$, an Einstein-deSitter universe yields $h[z] = (1 + z)^\chi, \quad \chi = \frac{3}{2}$, and we get $M[z] \approx M_0(1 + z)^\mu, \quad \mu = 1.75\ldots 2.25$. Because of the formula

$$\frac{1}{\tau_M} = \frac{1}{M}\frac{\mathrm{d}M}{\mathrm{d}t} = H_0\ h[z]\ \mu, \tag{10}$$

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 which we might consider tell the same in this point.

3 The question of an universal void structure

The void structure found in the galaxy distribution in our neighborhood of $z < 0.05$ should be seen as a 100 Å-structure in the forests of absorption lines. No such structure has been found for sure [**?**], [**?**], [**?**]. Only in exceptional cases objects like the much disputed Crotts void [**?**] have been found. Now we have reasons to assume the void structure to be more prominent in the past, and to interpret the supercluster structure as the result of a permanent collapse from 2-dimensional (pancake) structure to filament network and finally vertices [**?**]. This is the reason why it seems natural to insist on a universal void structure also in the redshift interval, where the absorption forests can be seen, i.e. for $1.8 < z < 4.5$. If the cuts of the line of sight through the bubble walls are not represented by comparatively narrow redshift intervals with higher line density, these cuts have to be identified with the lines itself. This is the bubble-wall interpretation of the absorption lines proposed by Hoell and Priester 1991 and evaluated by Liebscher, Priester and Hoell 1992. Hoell and Priester interpret the absorption forest as result of a bubble structure like that seen for small redshifts in the galaxy distribution. In this case the dimension is $d = 2$, and the equation for the evolution of structure, eq.(**??**), is reduced to

$$n[z]h[z] = a[z]. \tag{11}$$

The number of walls in a comoving foam does not change, $a[z] = 1$. Supposing this and a counting the lines with a low limit of equivalent width ($W_{\mathrm{obs}} > 100$ mÅ, only expecting the traces of the assumed bubble structure) one gets the result of [**?**], [**?**], [**?**], i.e. a Friedmann-Lemaitre universe with positive cosmological constant and curvature, characterized by the redshift of minimum expansion rate $z_{\mathrm{min}} \approx 3.5$ and the minimum $h^2_{\mathrm{min}} \approx 0.5$ itself. Its curvature radius is about three times the Hubble radius. Liebscher, Priester and Hoell invoke dissolving walls, i.e. evolution in d and $A[z]$, to account for the now lower than extrapolated line density in the HST spectra.

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 $z \approx 3.5$ [?],[?]. 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 [?].

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 [?]. We have to put $d = 1$.

4 The evolution in configuration

Before attacking that task, we have to remember the fact, that the evolution of mass, eq.(**??**), is independent of any evolution in density, size, number or dimension of the absorbers. We now try to model an evolution in configuration by a varying effective dimension $d[z]$ by

$$\begin{aligned} n[z]h[z] &= a[z]s^{2-d}[z](\frac{L}{S_0})^{d-d_0}, \\ m[z] &= a[z]r[z]s^{3-d}[z](\frac{L}{S_0})^{d-d_0}, \\ w[z] &= r[z]s[z](1+z)^2. \end{aligned}$$

This is equivalent to

$$\frac{m[z]r^2[z]}{a[z]w^3[z]}(1+z)^6(\frac{L}{S_0})^{d_0} = ((1+z)^2\frac{r[z]L}{w[z]S_0})^d$$

The dimension may evolve as

$$d(\log(\frac{L}{S_0}) + \log((1+z)^2\frac{r[z]}{w[z]})) = d_0\log(\frac{L}{S_0}) + \log((1+z)^6\frac{m[z]r^2[z]}{a[z]w^3[z]})$$

If the evolution in dimension begins at $z_{\rm i}$ with dimension 2, and ends at $z_{\rm f}$ with dimension 0, we get the relation

$$d = \frac{\log(\frac{f[z]}{f[z_f]})}{\log(\frac{g[z]}{g[z_i]}) + \frac{1}{2}\log(\frac{f[z_i]}{f[z_f]})}$$

with

$$f[z] = (1+z)^6 \frac{m[z]r^2[z]}{a[z]w^3[z]}, \quad g[z] = (1+z)^2 \frac{r[z]}{w[z]}$$

A sensible model requires $L > S_0$, that is $2 + \mu - \alpha - \omega > 0$. It yields an average dimension falling with time if $6 + \mu + 2\varrho - \alpha - 3\omega > 0$. The simple case is $\alpha = 0$: The number of walls, edges and vertices does not differ in order of magnitude. Contraction in physical size and constant effective mass is bound to a Friedmann-Lemaître universe. Only for fast evolution in mass ($\mu > 1.8$) a contraction in physical size is compatible with Einstein-deSitter evolution and so on.

5 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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