QUASAR ABSORPTION LINES
AND THE PARAMETERS OF THE FRIEDMANN UNIVERSE

DIERCK-E.LIEBSCHER
Astrophysikalisches Institut Potsdam
D – 14482 Potsdam

and

WOLFGANG PRIESTER
Institut für Astrophysik und extraterrestrische Forschung der Universität Bonn
D – 53121 Bonn

ABSTRACT

We consider the elementary consequences of the distribution in redshift and column density of narrow quasar absorption lines.

1. Introduction

The evolution of the expansion rate of the universe is subject to the Friedmann equation,

$$\frac{1}{R^2}(\frac{\mathrm{d}R}{\mathrm{d}t})^2 = H^2[z] = H_0^2(\lambda_0 - \kappa_0(1+z)^2 + \Omega_0(1+z)^3) = H_0^2 h^2[z]\ . \tag{1}$$

The normalized cosmological constant λ, the normalized curvature κ, and the density parameter Ω have to be determined from the evolution of the population of homogeneously distributed objects whose intrinsic evolution is known. The same observation can be used to get the intrinsic evolution of these objects, if the cosmological model is given. In the simplest case, the number of objects in a spherical shell between the redshifts z and $z + \mathrm{d}z$ is given by

$$N[z]\frac{\mathrm{d}z}{\mathrm{d}\chi}\mathrm{d}\chi = A[z]R_0^3 4\pi r^2[z]\mathrm{d}\chi, \tag{2}$$

where the functions $r[z]$ and $\chi[z]$ are defined as usual by the line element $\mathrm{d}s^2 = c^2\mathrm{d}t^2 - R^2[t](\mathrm{d}\chi^2 + r^2[\chi](\mathrm{d}\theta^2 + \sin^2\theta\mathrm{d}\varphi^2))$ and the redshift relation

$$\mathrm{d}\chi = \frac{R_H}{R_0}\frac{\mathrm{d}z}{h[z]}.$$

The function $A[z]$ describes the evolution of the comoving density of the population in question. The evolution can be in number (by merging or fragmentation) or in the property defining the membership to the population. Hence,

$$N[z]h[z] = A[z]4\pi r^2[z]R_0^2 R_H$$

describes the relation between the evolution of the expansion rate, $h[z]$, and the evolution of the population, $A[z]$, if the number per redshift $N[z]$ is given by observation. If we denote this property by the value L of some observable, we can define a distribution

$$N[z, L]h[z]\mathrm{d}L = A[z]R_0^2 R_H 4\pi r^2[z]p[L, \alpha[z]]\mathrm{d}L.$$

Intrinsic evolution is now split into the evolution of the total number $A[z]$ per comoving volume and the evolution of the parameters $\alpha[z]$ of the distribution of L.

2. Quasar absorption lines

Quasar absorption lines indicate a homogeneous population of absorbers. The number of lines per redshift interval is correspondingly given by

$$N[z]h[z] = A[z]R_H Q[z]. \tag{3}$$

The comoving surface $4\pi R_0^2 r^2[z]$ in equation (2) had only to be substituted by the comoving cross-section $Q[z]$ of the absorbers. For instance, the cross-section of a cloud of physically constant size evolves like $Q[z] = Q_0^2(1+z)^2$. The evolution of the size is related to the evolution of the expansion rate, if $N[z]$ is given by observation.

Quasar absorption lines are uncorrelated. This is a strange observation, because one should expect to see the void structure of the galaxy distribution. If the line of sight cuts a wall, the absorption lines are expected to be denser than in the redshift interval corresponding to the voids itself. Such density variations are not seen at the level of equivalent width $EW > 0.1$ Å. Our hypothesis is to identify the isolable lines by the walls itself and the redshift distance between two lines with the voids. We assume the walls to be densely populated by clouds and filaments of Ly-α absorbing hydrogen, so that each wall-crossing of the line of sight produces one absorption line. This hypothesis leads to a constant comoving A and Q, because the foam structure can only expand with the universe. The walls are dense down to some critical redshift z_{crit}. Below that redshift, the dilution reduces the probalility of a line from 1 to smaller values. As long as the walls remain dense, the product AQ is constant, and the observation of $N[z]$ determines $H[z]$ up to the factor H_0. Because of the Friedmann equation, eq.(1), the function $h^2[z]$ can show a decrease in z only if the normalized curvature κ_0 is positive. In fact, $N[z]$ is increasing between the redshifts 2 and 4. Counting identifiable lines, one gets an only slow increase of $N[z]$, resulting in[4,5]

$$\lambda_0 = 1.080, \quad \Omega_0 = 0.014\ , \quad \kappa_0 = \lambda_0 + \Omega_0 - 1\ .$$

The errors lie in the position of the minimum of the expansion rate $h[z]$ ($z_{\mathrm{min}} \approx 3.5$, $h^2_{\mathrm{min}} \approx 0.5$) and trandform in only small errors of λ_0 and Ω_0.

How to compare this result with the hypothesis of a homogeneous distribution of individual clouds? Individual clouds produce line densities depending on the evolution of their size. The no-evolution approximation is $Q[z] = Q_0(1+z)^2$, because we have to assume the clouds to be confined and not expanding with the universe. Observationally, we have to introduce a minimum intrinsic equivalent width $EW_{\rm min}$ for counting lines. The observed width goes as $EW_{\rm observed} = EW_{\rm intrinsic}(1+z)$. To get a constant intrinsic minimum over the total range of redshift $z = 2 \ldots 4$ it is necessary to choose $EW_{\rm min} \approx 0.3$ Å, i.e. we can count only the larger clouds. One gets[6]

$$N[z] \propto (1+z)^{\gamma}, \quad \gamma \approx 2.5 \ .$$

With the void structure in mind, the larger clouds are comparatively rare positions on the walls and do not allow to see the walls in total. The result with no evolution is now $h[z]N[z] \propto (1+z)^2$. Curiously enough, we get the same values[2] of λ_0 and Ω_0 as in the case of the narrower lines and $h[z]N[z] = \mathrm{const.}$

3. Column density evolution

The assumed minimum intrinsic equivalent width characterizes a constant-member population of clouds only in the case of no evolution in column density of the indvidual cloud. This is generally assumed to be the case[9,8]. However, if we find only a power-law part of the distribution of column densities, we are not allowed to make such a statement independent of a hypothesis of the number evolution. We will discuss this point later. For the moment, we include the possibility of an evolution of the typical column density $W[z]$, which is the product of the physical density of Ly-α absorbing hydrogen in the absorbers, $\mu_A[z](1+z)^3$, with the physical column length $S[z](1+z)^{-1}$. The total absorbing mass per comoving volume is now given by

$$\mu_{\rm total} = \mu_A[z]S[z]Q[z]A[z] \ .$$

Substituting equation (3) yields

$$N[z]h[z]W[z] = R_H \mu_{\rm total}(1+z)^2 \ .$$

This equation relates the evolution of the expansion rate of the universe with the evolution of the total mass of Ly-α absorbing hydrogen. The relation does not depend on the behaviour of the individual cloud (expansion, contraction, merging, fragmentation) or of the configuration of the absorbers (clouds, filaments, walls) and its evolution. Using the data of Lu et al.[6], i.e. $N[z] \approx N_0(1+z)^{2.5}$ and $W[z] \approx W_0$, we obtain

$$h[z]N_0W_0 \approx \mu_{\rm total}(1+z)^{-0.5} \ .$$

Again, if $\mu_{\rm total}$ evolves slowly, a universe with positive curvature is the consequence. A universe with $\lambda = \kappa = 0$ results in $\mu_{\rm total} \propto (1+z)^2$, which indicates a very short lifetime for the Ly-α absorbing state of the hydrogen:

$$\tau_{\rm Ly\alpha} = \frac{\mu_{\rm total}}{\frac{d\mu_{\rm total}}{dt}} \approx 0.06 H_0^{-1} \ .$$

Such a short lifetime is only produced by a model, in which the Lyman-alpha clouds are more or less primordial condensations at $z \approx 10$, which are merging to form galaxies, so that the population observed in the redshift range of $z = 2 \ldots 4$ is only the remainder of a much richer population fading out by merging and star formation fast[7]. However, one has now to argue for a secondary population of Ly-α absorbing clouds, which are seen in the HST spectra of comparatively nearby quasars[1]. There are too many lines in the spectra for a simple extrapolation from the redshift range $= 2 \ldots 4$ in the ($\lambda = \kappa = 0$) universe. in our hypothesis, the evolution of μ_{total} is slow, and the lines seen in the HST spectra are more sparse than expected from the extrapolation. This is due to the existence of a redshift z_{crit}, denoting the time when the walls become transparent and the clouds and filaments cannot cover them totally any more.

4. Conclusions

- If we can approximate a distribution between some limits as a power law, we only know that the accessible region does not contain the essential part of the distribution: any expectation value including the normalization depends on the limits irreducibly. For instance, if the distribution of column densities is a power law, the typical equivalent width is not defined. Instead, we may write

  $$N[z, W]\mathrm{d}W\mathrm{d}z = A[z](\frac{W}{W_0[z]})^{\beta}\mathrm{d}W\mathrm{d}z \; .$$

  The observations then tell us only the change of the quantity

  $$A^*[z] = \frac{A[z]}{W_0^{\beta}[z]} \; .$$

  The argument about $\mathrm{d}M/\mathrm{d}t$ is weakened.

- Star formation and merging are considered already.

- Usually inflation is believed to predict vanishing curvature. Inflationary models with curvature nevertheless can be constructed. Their main problem lies in the inflation period being too short for cooling enough the perturbations in order to suppose zero-point oscillations at the first crossing of the Hubble radius of the larger scales. Nevertheless, curvature should not always set to zero before evaluating the observations.

- A cosmological term and curvature, which matter in the recent epoch are both very small at the end of inflation, and are named fine-tuned. If $\Lambda c^2/3$ is of the order of H_0^2, the corresponding temperature is about 0.1...1 eV. This is the order of magnitude of a so-called late-time phase transition[10]. Hence zero Λ would be a fine-tuned cancellation of all contributions to the vacuum energy by the weaker than GUT interactions, which are still stronger than any cosmological term requires today. There is no argument against including Λ in the evaluation of astrophysical observations.

- Conventional dark matter, inferred from rotation velocities and velocity dispersions is at best marginally consistent with the extremely low density of a closed Friedmann-Lemaître universe with minimum expansion rate at $z \geq 3$.
- Exotic dark matter is inconsistent with such a universe.
- If the interpetation of the bulk velocities discussed by A.Yahil (this volume) is correct, the Friedmann-Lemaître universe is in serious trouble, if our position in the universe is not peculiar by its depth of gravitational potential.
- The Hubble constant may be inferred from the analysis by identifying the density with the baryon density allowed by the primordial nucleosynthesis. One gets a value of $H_0 \approx 90$ km/s/Mpc. Our argument favours the high value of the Hubble constant.
- There is no age problem in a Friedmann-Lemaître universe with minimum expansion rate at $z \geq 3$. The actual age of such a universe is at least 3 times the Hubble age. This large correction for the age helpes also the post-recombination growth of perturbations, but not too much[3].

5. References

1. Bahcall,J.N., Bergeron,J., Boksenberg,A., Hartig,G.F., Jannuzi,B.T., Kirhakos,S., Sargent,W.L.W., Savage,B.D., Schneider,D.P., Turnshek,D.A., Weymann,R.J., Wolfe,A.M. *Astrophys.J.Suppl.Ser.* **87** 1-43.
2. Hoell,J., Liebscher,D.-E., Priester,W. *Astron.Nachr.* **315** 89-96.
3. Hoell,J. .
4. Liebscher,D.-E., Priester,W., Hoell,J. *Astron.Astroph.* **261** 377-381.
5. Liebscher,D.-E., Priester,W., Hoell,J. *Astron.Nachr.* **313** 265-273.
6. Lu,L.M., Wolfe,A.M., Turnshek,D.A., Lanzetta,K.M. *Astrophys.J.Suppl.Ser.* **84** 1-38.
7. Mo,H.J., Miralda-Escudé,J., Rees,M.J. *Monthly Notices R.A.S.* **264** 705-711.
8. Sargent,W.L.W. *in: Observational cosmology, ed. A.Hewitt, G.R.Burbidge, L.Z.Fang* 777-790.
9. Sargent,W.L.W., Young,P.J., Boksenberg,A., Tytler,D., *Astrophys.J.Suppl.Ser.* **42** 41-81.
10. Schramm,D.N. *in: Primordial Nucleosynthesis and Evolution of Early Universe, ed. K.Sato, J.Audouze* 225-242.