A constraint on the universal baryon density from the abundance of ^{7}Li

THE observed interstellar abundance of ^{2}H has been used[1,2] to estimate the mean baryon density (ρ_b) of the Universe. This follows, because (1) there is no plausible source for ^{2}H other than the primordial big bang and (2) the production of ^{2}H in a standard big bang decreases rapidly with increasing ρ_b. If one then assumes that all ^{2}H was formed in a big bang, the observed abundance[2] of this nuclide requires a value of ρ_b sufficiently low[1] that, for a cosmological constant $\Lambda = 0$, the present expansion of the Universe will continue forever and the Universe is open. A major weakness in this argument is that another source of ^{2}H may be found. It has been suggested, for example, that ^{2}H could be made in shock waves accompanying a supernova explosion; this now seems unlikely[3], but other mechanisms will certainly be suggested, so that it is important to obtain confirmation of the above conclusion. The predicted production of ^{7}Li in a big bang[2] varies rapidly with ρ_b and could be used to estimate ρ_b if the fraction of the observed ^{7}Li made in the big bang were known. Unfortunately there are many possible sources[4] of ^{7}Li and such estimates must be regarded with scepticism. In this note we point out that ^{7}Li can be used to place an upper limit on ρ_b, even if other production mechanisms are important, and that this limit also strongly favours an open universe. This possibility arises because the big bang production of ^{7}Li increases with increasing ρ_b (for $\rho_b > 10^{-31}$) so that an upper limit is obtained by attributing all of the observed ^{7}Li to the big bang.

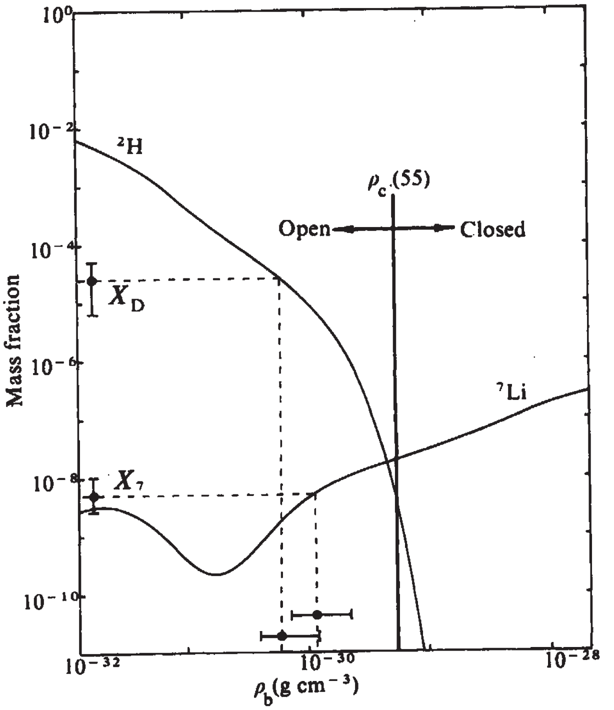

Fig. 1 Abundances of ^{2}H and ^{7}Li produced in a standard big bang (adapted from ref. 8. The present black body temperature is taken to be 2.90 K, see ref. 9.) The vertical line labelled ρ_c (55) is the density necessary to close a Friedman universe with $\Lambda = 0$, if $H_0 = 55$ km s^{-1}-Mpc^{-1} (in general $\rho_c = 5.7 \times 10^{-30} (H_0/55)^2$). The point labelled X_7 is the mass fraction of ^{7}Li corresponding to the abundance given by Boesgaard[5], while that labelled X_D is the mass fraction of ^{2}H from the summary of ref. 2. (This latter value is smaller than that used by Gott *et al.*[1], mostly because they include an estimate of the effects of astration). The uncertainty indicated for X_7 is a factor of two in either direction while that for X_D covers the range from a factor of four smaller to a factor of two larger[10]. Corresponding values of ρ_b and their uncertainties are also shown. The value of ρ_b determined from the ^{7}Li abundance is only an upper limit if there are significant sources of ^{7}Li other than the big bang.

We have adopted here Boesgaard's[5] value of the Li abundance which yields[6] a fractional abundance by mass of ^{7}Li, $X_7 = 5 \times 10^{-9}$. Assuming the big bang must not synthesise more than this amount leads to $\rho_b \leq 1.1 \times 10^{-30}$ g cm^{-3}. As is shown in Fig. 1, this is substantially less than the critical value ρ_c necessary to close a $\Lambda = 0$ Friedman universe.

The uncertainty in X_7 is perhaps a factor of two; the meteoritic value[6], for example, is $X_7 = 8 \times 10^{-9}$. Substantially larger values have been seen[5] in a small number of red giant stars, but these values presumably reflect a local production mechanism. Allowing for a factor of two uncertainty gives an upper limit closer to ρ_c, but still favouring an open and forever expanding universe.

The existence of mechanisms which destroy ^{7}Li weakens the limit on ρ_b since the big bang may then have made more ^{7}Li than is now observed; conversely, discovery of additional sources of ^{7}Li strengthens the limit. Astration of primordial material is presumably the most important destruction process. Estimates of the fraction of matter which has passed through stars are rather uncertain but are typically about 0.5. It has been pointed out[4,7], however, that infall of primordial material from the galactic halo may be significant and would tend to compensate for the effects of astration for those nuclei produced in the big bang. Other sources of ^{7}Li are generally rather speculative[4], except for production in the cosmic rays which yields roughly 10% of the observed ^{7}Li. Since these various effects tend to offset each other, the observed value of X_7 seems reasonable but subject to uncertainty.

If it is a good approximation to ignore both astration and sources of ^{2}H and ^{7}Li other than the big bang, their observed abundances each separately determine the density. An estimate based on the ^{2}H abundance X_D is shown in Fig. 1, and is in good agreement with the density obtained from ^{7}Li. Effects of astration would tend to worsen this agreement. Thus when other possible contributions to ^{7}Li are better understood, the requirement that the big-bang contribution to X_7 and X_D yield the same value of ρ_b may be a strong constraint on allowable astration.

We assumed above that the cosmological constant $\Lambda = 0$. While this is consistent with the available data, a non-zero value cannot be excluded, except on aesthetic grounds, and its effects must be considered. It has been found[11] that for reasonable values of Λ, the limits on ρ_b from the ^{2}H and ^{7}Li abundances are essentially unchanged. But, the simplest relationship between ρ_b and the curvature and evolution of the Universe is no longer valid[11].

In summary, the simplest and most straightforward assumptions concerning the origin of ^{7}Li and the nature of the big bang expansion require an upper limit for the present universal density of $\rho_b = (1.1\ [+1.1 \text{ or } -0.4]) \times 10^{-30}$ g cm^{-3}. Given that the Universe is indeed a Friedman universe with zero cosmological constant, the agreement between the present limit and that based on ^{2}H strongly supports the conclusion of Gott *et al.*[1] that the Universe is open and will continue to expand forever.

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Note added in proof: It has come to our attention that conclusions similar to those reached here have been discussed by G. Steigman at the Harvard Neighborhood Meeting on Cosmology, October 1975.

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