MSUCL-245
June 1977

A Constraint on the Mean Baryon Density of the Universe from the Abundance of ^{7}Li*

Sam M. Austin and C.H. King

Cyclotron Laboratory and Physics Department
Michigan State University
East Lansing, MI 48824

Abstract

Because the amount of ^{7}Li produced in a standard big bang increases with increasing mean baryon density ρ_b (for $\rho_b > 10^{-31}$ g/cm^{-3}), the observed abundance of ^{7}Li can be used to place an upper limit on ρ_b, whether or not ^{7}Li is also made by other processes. This limit favors an open universe.

*Research supported by the U.S. National Science Foundation.

The observed interstellar abundance of ^{2}H has been used[1,2] to estimate the mean baryon density ρ_b of the Universe. This estimate follows from the facts (1) that there is no plausible source for ^{2}H other than the primordial big bang and (2) that 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. For example, it has been suggested that ^{2}H could be made in shock waves accompanying a supernova explosion. This particular mechanism now seems unlikely[3], but others will certainly be suggested, so that is is important to obtain confirming evidence for the above conclusion. We show here that the observed abundance of ^{7}Li can be used to place an upper limit on ρ_b, whether or not ^{7}Li is also made by other processes. This limit also favors an open universe.

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 skepticism. 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 favors an open universe. This possibility arises because the big bang production of ^7Li <u>increases</u> with increasing ρ_b (for $\rho_b > 10^{-31}$) so that an upper limit is obtained by attributing all of the observed ^7Li to the big bang.

For the present argument we have adopted Boesgaard's[5] value of the Li abundance which yields[6] a fractional abundance by mass of ^7Li, $X_7 = 5 \times 10^{-9}$. Assuming the big bang must not synthesize more than this amount then leads to $\rho_b \leq 1.1 \times 10^{-30}$ g/cm^2. 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 favoring an open and forever expanding universe.

The existence of mechanisms which destroy ^7Li weakens the limit on ρ_b since the big bang may then have made more ^7Li than is presently observed; conversely, discovery of additional sources of ^7Li 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 typically about 0.5. On the other hand, it has been pointed out recently[4,7] 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 ^7Li are generally rather speculative in nature[4], except for production in the cosmic rays which yields

roughly 10% of the observed ^7Li. Since these various effects tend to offset each other, using the observed value of X_7 seems reasonable.

If it is a good approximation to ignore both astration and sources of ^2H and ^7Li other than the big bang, their observed abundances each separately determine the density. An estimate based on the ^2H abundance X_D is shown in Fig. 1, and is in good agreement with the density obtained from ^7Li. Effects of astration would tend to worsen this agreement. Thus when possible contributions to ^7Li of other sources 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 have 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 ^2H and ^7Li abundances are essentially unchanged. However, the simple 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 ^7Li and the nature of the big bang expansion require an upper limit for the present universal density of $\rho_b \doteq (1.1 {}^{+1.1}_{-0.4}) \times 10^{-30}$ gm/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.

This research was supported by the U.S. National Science Foundation.

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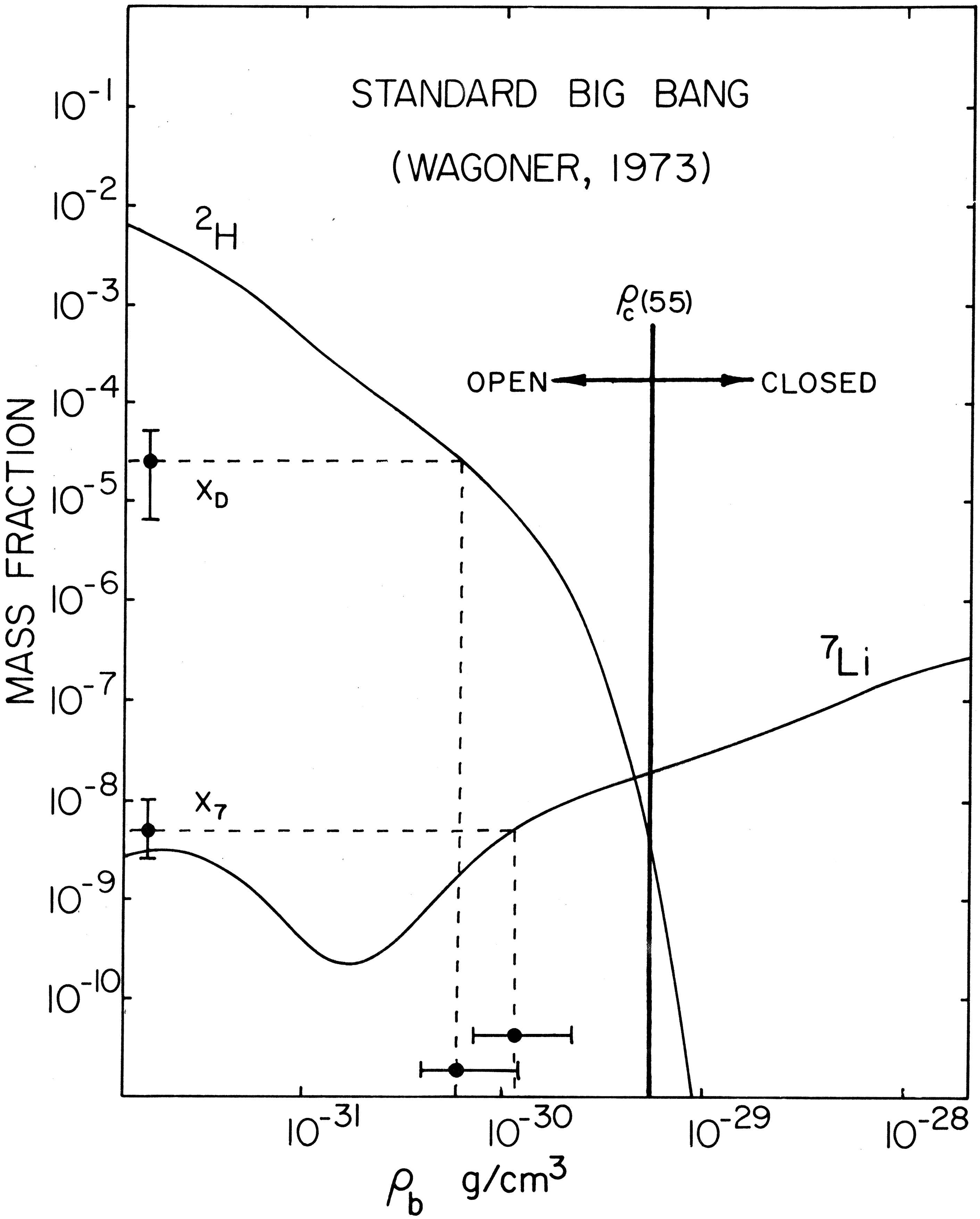
Fig. 1. Abundances of ^{2}H and ^{7}Li produced in a standard big bang (adapted from Wagoner[8]. The present day black body temperature is taken to be 2.90 K, see ref. 9.) The vertical line labeled $\rho_c(55)$ is the density necessary to close a Friedman universe with $\Lambda = 0$, if $H_o = 55$ km/sec-Mpc (in general $\rho_c = 5.7 \times 10^{-30} (\frac{H_o}{55})^2$). The point labeled X_D is the mass fraction of ^{7}Li corresponding to the abundance given by Boesgaard[5], while that labeled 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 2 in either direction while that for X_D covers the range from a factor of 4 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.



STANDARD BIG BANG
(WAGONER, 1973)
MASS FRACTION
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
2H
7Li
XD
X7
ρc(55)
OPEN
CLOSED
10^-31
10^-30
10^-29
10^-28
ρb g/cm3