Candidates for the leptonic X^- particle of interest in these models are the spin 0 supersymmetric partners of the standard-model leptons. Such X^- particles (and their antiparticles X^+) would be produced copiously in the hot early universe and subsequently annihilate. Their annihilations, however, would freezeout at some epoch. The residual X^+ particles do not affect BBN because they do not bind to the positively-charged nuclei. It is possible, however, that the decay of both $X^\pm$ particles affect the final light element abundances through electromagnetic and/or hadronic showers. Here, however, we only consider the X-nuclear reactions, and not the effect of subsequent decay.

The binding energies of nuclei bound to X^- particles, i.e., X-nuclei, have been derived by taking account of the modified Coulomb interaction with the nucleus [7] under the assumption that the mass of the X^- particle is much heavier than the nucleon mass.

We performed the detailed network calculation of the catalyzed BBN [7] taking into account both the recombination and ionization of X^- particles with nuclei and thermonuclear reactions and β-decay of normal nuclides and X-nuclei. We adopt all of the new reaction rates from the rigorous quantum many-body dynamical calculations of Ref. [9]. For the $^7\mathrm{Be}_X(p,\gamma)^8\mathrm{B}_X$ resonant reaction through an atomic excited state of $^8\mathrm{B}_X$, rates for different masses of X^- have been published [9]. For our purposes we adopt their rate for an infinite X^- mass. Our results are thus completely different from previous studies without the use of the new cross sections.

We adopt the constraint on the primordial ^{6}Li abundance from the observations in MPSs. The primordial abundances of ^{6}Li and ^{7}Li could be higher than the observed abundances [18] considering the possible effect of stellar depletion of initial surface abundances. The observed abundances should, therefore, be considered a lower limit to the true primordial ones. Since ^{6}Li is more fragile to nuclear burning than ^{7}Li [24], its depletion factors could be larger than those for ^{7}Li. We adopt a conservative limit of a factor of 10 above the mean value of $(^6\mathrm{Li/H})_{\mathrm{MPS}} = (7.1 \pm 0.7) \times 10^{-12}$ [18], and a 3 σ lower limit to the mean value times a factor of 1/3. The limit on the ^{6}Li/H abundance are thus $1.7 \times 10^{-12} \leq {}^6\mathrm{Li/H} \leq 7.1 \times 10^{-11}$.

Figures 1a and 1b show the results of a catalyzed BBN calculation. For these figures the X^- abundance was taken to be 5% of the total baryon abundance, i.e. $Y_X = n_X/n_b = 0.05$, where n_X and n_b are the number densities of the X^- particles and baryons, respectively. Figure 1a shows the evolution of normal nuclei while Figure 1b corresponds to X-nuclei.

The abundances of the normal nuclei are very similar to the standard BBN abundances until the temperature reaches $T_9 \sim 0.5$. The X^- particles then combine with ^{7}Be at $T_9 \sim 0.5$ and subsequently ^{7}Li at $T_9 \sim 0.3$. The $^7\mathrm{Be}_X$ produced by these X^- captures (Fig. 1b) is then destroyed by the $^7\mathrm{Be}_X(p,\gamma)^8\mathrm{B}_X$ reaction, primarily through the atomic excited state of $^8\mathrm{B}_X$ [5], and secondarily through the atomic ground state $^8\mathrm{B}^*(1^+, 0.770\ \mathrm{MeV})_X$ composed of the $^8\mathrm{B}^*(1^+, 0.770$ MeV) nuclear excited state and an X^- particle [6]. We have assumed that $^8\mathrm{B}_X$ inter-converts to $^8\mathrm{Be}^*(2^+, 3\ \mathrm{MeV})_X$ by β-decay with a rate given by the normal ^{8}B β-decay rate multiplied by a correction term $(Q_X/Q)^5$, where Q and Q_X are the Q-values of the standard β-decay and that of β-decay for X-nuclei [7]. The produced $^8\mathrm{Be}^*(2^+, 3\ \mathrm{MeV})_X$ then immediately decays to the three-body channel $\alpha+\alpha+X^-$ [9].

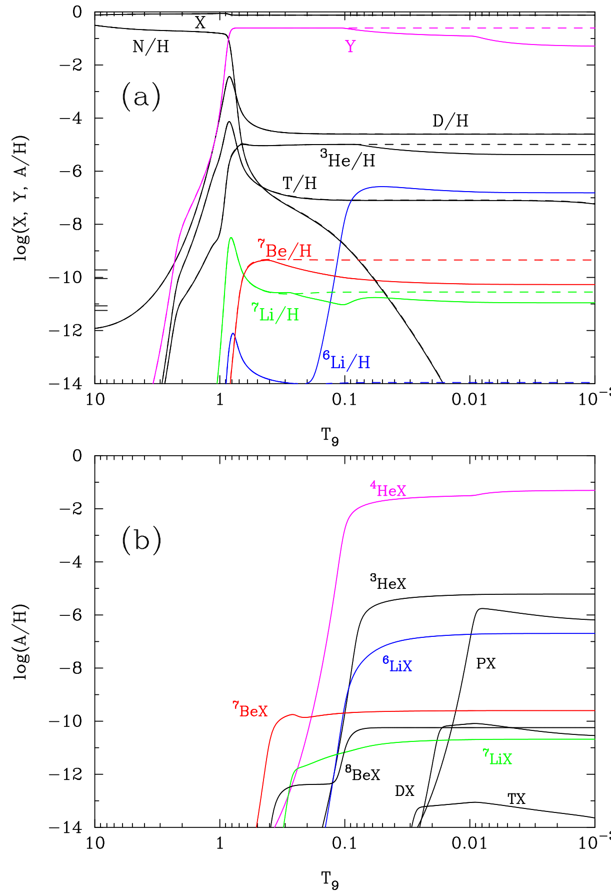

FIG. 1: (color online). Calculated abundances of normal nuclei (a) and X-nuclei (b) as a function of T_9 (solid lines). The abundance and the lifetime of the X^- particle are set to be $Y_X = n_X/n_b = 0.05$ and $\tau_X = \infty$, respectively. The dashed lines correspond to the standard BBN case.

When the temperature decreases to $T_9 \sim 0.1$, the X^- particles bind to ^{4}He. Then, the X^--catalyzed transfer reaction $^4\mathrm{He}_X(d,X^-)$ operates to produce normal ^{6}Li and $^6\mathrm{Li}_X$ (after the recombination). Because of the small binding energies to the X^- (see Table I of Ref. [7]), neutral X-nuclei do not form until late times corresponding to $T_9 \sim 0.03$ (for t_X), $T_9 \sim 0.02$ (for d_X) and $T_9 \sim 0.01$ (for p_X). The neutral X-nuclei then mainly react with ^{4}He nuclei to lose their X^- and to produce $^4\mathrm{He}_X$ (as a result of the precise calculation [9]) so that abundances of neutral X-nuclei are kept low. Nuclear reactions triggered by neutral X-nuclei are thus not important.