UNIVERSITY OF TORONTO
Faculty of Arts and Science

APRIL/MAY 2009 EXAMINATIONS

AST320H1S

Duration: 3 hours

No Aids Allowed

Marks: All three questions have equal weight. All subitems of questions have equal weight.

1. Luminosity of a radiative star.

   (a) Use the stellar structure equations to show that for a star supported by thermal pressure and with an opacity κ that is independent of density and temperature (e.g., electron scattering), the luminosity scales as,
   $$L \propto \frac{\mu^4}{\kappa} M^3. \tag{1}$$

   (b) In the above, you did not have to consider how energy is generated. Why is this the case? What will happen to a star if nuclear fusion does not provide enough energy to balance the energy loss given by Eq. 1, and, conversely, what will happen if fusion provides more energy than is lost?

   (c) Now suppose energy generation by fusion balances the radiative losses. For this case, we can also constrain the radius; explain physically why this is the case and derive how radius scales with mass for stars fusing by the CNO cycle (you can assume that the rate has a power-law dependence on temperature with index $\nu = 13$; also assume that the fraction of the star involved in fusion is independent of mass).

2. Nuclear fusion in the Early Universe.

   (a) Write down the reactions by which Helium is formed in the Early Universe.

   (b) How do the conditions differ from those in cores of stars, and how does this influence the chain of reactions that is used?

   (c) In Fig. 1 (see page 2), predicted abundances of the light elements are shown as function of baryon-to-photon ratio η. Describe briefly why the Helium abundance has only a slow dependence on η over much of the range shown, but a rapid decline towards low values of η.

3. Type Ia supernovae.

   (a) In a type Ia supernova, all the material in a carbon-oxygen white dwarf is burnt explosively. Describe in what type of progenitor systems type Ia supernovae occur, what triggers nuclear fusion, and why all type Ia supernovae have approximately equal luminosity.

   (b) Give physical arguments why the start of nuclear fusion leads to an explosion and not to steady nuclear burning.

   (c) Type Ia supernovae have been used to infer that the expansion of the universe is accelerating. Describe how was this done. To help your explanation, sketch the expected brightness as a function of z for a flat, matter-dominated ($\Omega_{\rm tot} = \Omega_m = 1$) and for our actual universe ($\Omega_{\rm tot} = 1$, $\Omega_m \simeq 0.3$ and $\Omega_\Lambda \simeq 0.7$).

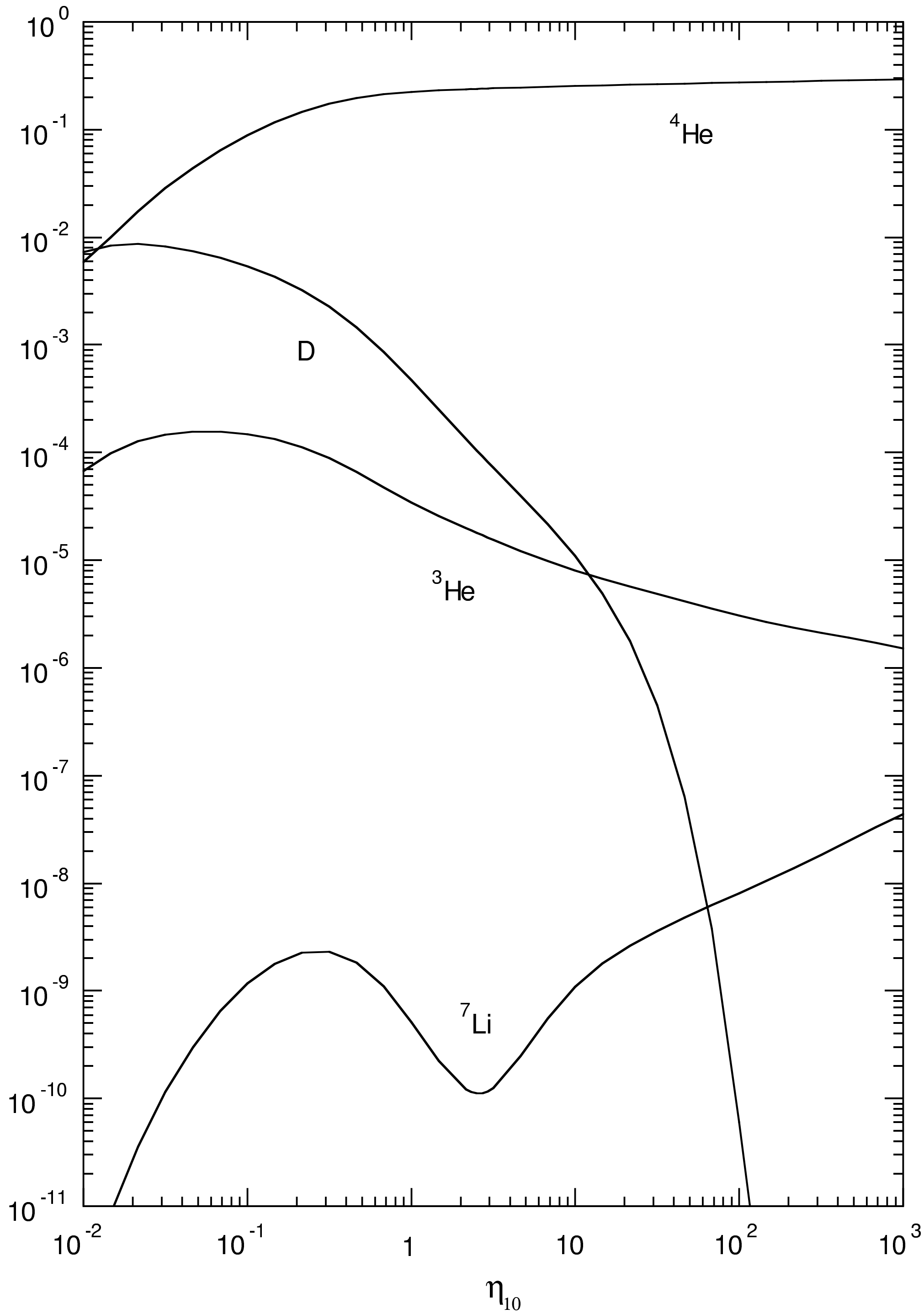

Figure 1: Expected abundances for the light elements as a function of baryon to photon ratio (in units of 10^{-10}). From Mukhanov (2003, astro-ph/0303073).