

Figure 1:

## 1 Problem 1

Fig. 1 gives the results to problem 1.

## 2 Problem 4

The evolution of the ionization fraction as a function of temperature is given in Fig. 2. Recombination is defined as the point at which  $x = 0.5$ , and is given as  $T_{rec} = 3740$  K for  $\eta = 5.5 \times 10^{-10}$ , as shown by the solid black line in the plot. Photon decoupling and the surface of last scattering occur at the same time/redshift/temperature, as the surface of last scattering exists because photons decoupled from matter. This occurs when  $H = \Gamma$ , which is at a redshift of  $z = 1100$  and a temperature of about  $T = 3000$  K, shown by the black dashed line. For  $\eta = 5.5 \times 10^{-10}$ , this occurs at  $x = 4.33 \times 10^{-3}$ .

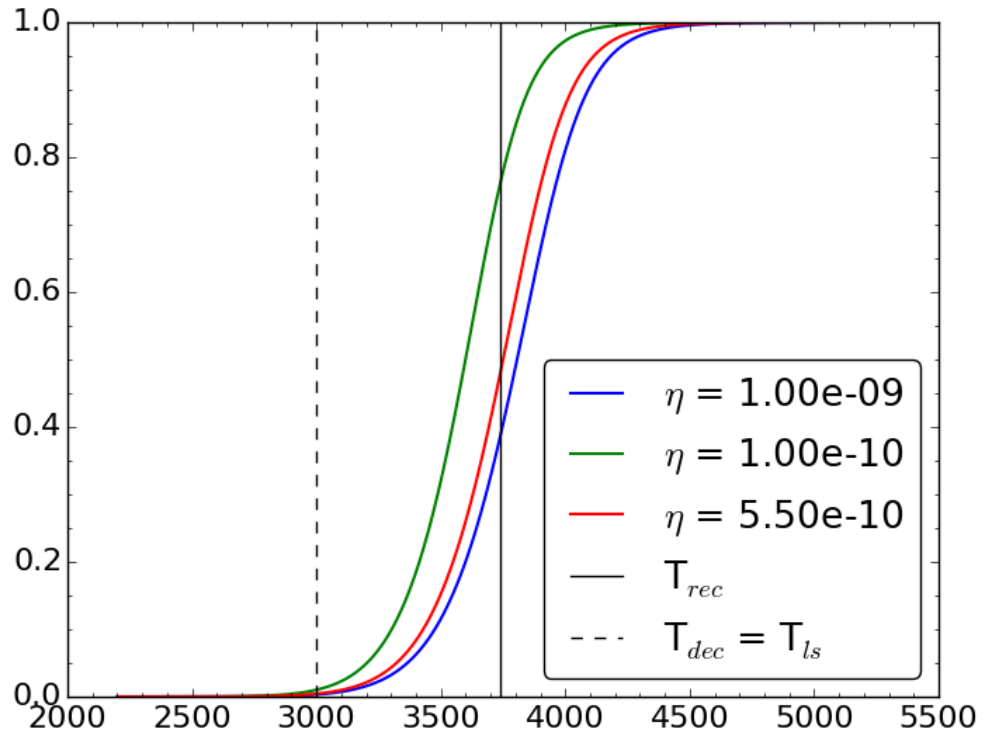


Figure 2: Ionization fraction of Hydrogen as a function of temperature in the universe.