A Heuristic Model of Chemical Evolution Into the Reionization Era

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ABSTRACT
We develop a model of chemical evolution of the early universe under the influence of Population III (Pop. III) stars into the reionization era. Solving photoionization rate equations for primordial atomic and molecular species subject to the Cosmic Background Radiation (CBR), we predict the fractional abundances of these species as a function of redshift (z). The CBR, however, eventually becomes negligible after the birth of Pop. III stars. To extend a recombination era model, we simulate the formation of stars within a halo according to z-dependent stellar formation rates and constrained by the Initial Mass Function (IMF). Each star is assigned mass dependent properties and distributed across the halo. A spherical grid is defined within the space and the chemical evolution induced by the nearby stars for each point is calculated. A volume average over the cloud provides the chemical evolution and reionization behavior for the modeled primordial halo. Iterating over many halos of varying masses, we are able to predict the reionization behavior of the early universe.

Key words: astrochemistry – stars: Population III – dark ages, reionization, first stars

1 INTRODUCTION

To expand upon the previous models of the recombination era in Gay (2010)(MORE REFERENCES?), we simulate the birth of Population III stars within early galactic halos and model the chemical evolution of various points within the halos in order to track the reionization and chemical evolution of the entire region.

2 METHODS, OBSERVATIONS, SIMULATIONS ETC.

Each halo is assigned a total mass M_H and a z-value corresponding to the collapse of the halo into stars z_H, which further determines what fraction of the halo's total mass ends up contained within stars, M_S (Hartwig et al. (2015)). The z-dependent early universe recombination code from Gay (2010) is run up to z_H in order to model recombination and determine the number density of particles within the halo, allowing us to determine an accurate radius R_H for the halo. This total stellar mass M_H is then distributed into stars with mass M_s according to the Salpeter IMF, and these stars are assigned mass-dependent lifetimes τ_s, effective temperatures T_s, ionizing photon fluxes $Q_s(\mathrm{H}^0)$, and radii R_s, according to Schaerer (2002).

Using these assigned values, we model the stars within the early universe code. Setting the blackbody radiation temperature to T_s and tracking the number density of H^0 within the ionized region, we model the ionization front for each star and track its radius, as provided by Osterbrock & Ferland (2006):

Table 1. A sample of stellar masses and associated properties provided by Schaerer

Mass ($M_\odot$)	Lifetime (years)	Q(H^0)	Luminosity ($L_\odot$)
25	6.459×10^6	5.446×10^{48}	$10^{4.890}$
120	2.521×10^6	1.069×10^{50}	$10^{6.574}$
400	1.974×10^6	5.573×10^{50}	$10^{6.984}$

$$R_F\,(t) = \frac{3Q(\mathrm{H}^0)}{\alpha_B n^2}(1 - e^{-\alpha_B n t}) \qquad (1)$$

where α_B is the H^0 case B radiative recombination rate coefficient, n is the region's number density of H^0 in cm^{-3}, and t is the time in seconds since the birth of the star. The stars are then spherically dispersed throughout the halo with a r^{-2} distribution; to avoid excessive clumping near the center, the entire core of the halo, with a radius $r \leq R_C/4$, is assigned the same probability density as its outer shell.

To model a star's influence on a nearby point, we run the early universe code, setting the blackbody temperature to T_s, and scaling the consequent photoionization rates with a radial geometric dilution factor d based on $D_{\{s,p\}}$, the distance from the star to the

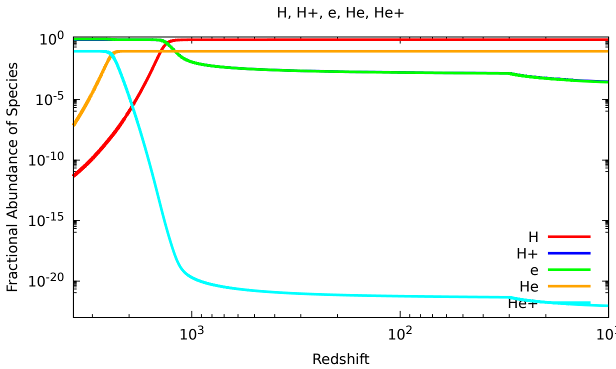

Figure 1. This is an example figure. Captions appear below each figure. Give enough detail for the reader to understand what they're looking at, but leave detailed discussion to the main body of the text.

point, since much of the emitted radiation is not incident on our region of concern:

$$d = D^{-2}_{\{s,p\}} \tag{2}$$

With this diluted photoionization rate, we are able to simulate the evolution of the region radiated by the star. Further, we can sum various photoionization rates induced by each nearby star in order to model the effect of multiple stars.

We define a spherical grid within our halo, the points of which serve as our points of measurement. For each point, the ionization fronts that reach the point and their associated dilution values are determined. The early universe code is run for this grid point, and as each ionization front reaches the point, their corresponding photoionization rate is added. The result is a total, z-dependent evolution of the point under the influence of multiple stars.

Each point of our grid represents the chemical evolution of an element of spherical space within the halo. Taking a volume average over all of the evaluated points, we produce an average chemical evolution and reionization history for the entire halo. This process is iterated over numerous halos of varied mass, allowing for a comprehensive model of the reionization process.

2.1 Maths

Simple mathematics can be inserted into the flow of the text e.g. $2 \times 3 = 6$ or $v = 220\,\mathrm{km\,s^{-1}}$, but more complicated expressions should be entered as a numbered equation:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}. \tag{3}$$

Refer back to them as e.g. equation (3).

2.2 Figures and tables

Figures and tables should be placed at logical positions in the text. Don't worry about the exact layout, which will be handled by the publishers.

Figures are referred to as e.g. Fig. **??**, and tables as e.g. Table 2.

Table 2. This is an example table. Captions appear above each table. Remember to define the quantities, symbols and units used.

A	B	C	D
1	2	3	4
2	4	6	8
3	5	7	9

3 CONCLUSIONS

The last numbered section should briefly summarise what has been done, and describe the final conclusions which the authors draw from their work.

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