Astrophys Space Sci (2012) 337:651–663
DOI 10.1007/s10509-011-0898-0

ORIGINAL ARTICLE

# First stars. II. Evolution with mass loss

**D. Bahena · P. Hadrava**

Received: 11 February 2011 / Accepted: 18 October 2011 / Published online: 23 November 2011


**Abstract** The first stars are assumed to be predominantly massive. Although, due to the low initial abundances of heavy elements the line-driven stellar winds are supposed to be inefficient in the first stars, these stars may loose a significant amount of their initial mass by other mechanisms.

In this work, we study the evolution with a prescribed mass loss rate of very massive, galactic and pregalactic, Population III stars, with initial metallicities $Z = 10^{-6}$ and $Z = 10^{-9}$, respectively, and initial masses 100, 120, 150, 200, and 250 $M_\odot$ during the hydrogen and helium burning phases.

The evolution of these stars depends on their initial mass, metallicity and the mass loss rate. Low metallicity stars are hotter, compact and luminous, and they are shifted to the blue upper part in the Hertzprung-Russell diagram. With mass loss these stars provide an efficient mixing of nucleosynthetic products, and depending on the He-core mass their final fate could be either pair-instability supernovae or energetic hypernovae. These stars contributed to the reionization of the universe and its enrichment with heavy elements, which influences the subsequent star formation properties.

**Keywords** First stars · Stars: models · Evolution · Mass loss

D. Bahena (✉) · P. Hadrava
Astronomical Institute of the Academy of Sciences,
Boční II 1401, 14131 Praha 4, Czech Republic
e-mail: bahen@hotmail.com

P. Hadrava
e-mail: had@sunstel.asu.cas.cz

## 1 Introduction

It is widely accepted that the so called Population III stars, i.e. the first stars formed from the primordial gas with an extremely low metallicity, have played an important role in the evolution of the universe. The first stars are assumed to be predominantly very massive and they were responsible for reionization of the universe and its enrichment by heavy elements.

The formation of the first stars and hence also their Initial Mass Function (IMF) is significantly influenced by the low metallicity of the protostellar material. Due to its low opacity, its gravitational attraction can not be effectively opposed by radiative pressure and the continuing accretion gives rise to more massive stars.

Numerical hydrodynamic simulations of star formation generally confirm the tendency to higher masses of the first stars, although quantitatively the results differ considerably.

Bromm and Larson (2004) found the masses of the first stars between $10^2$ and $10^3$ $M_\odot$, Omukai and Palla (2003) followed the evolution of accreting protostars and found $\sim 600$ $M_\odot$ as the upper limit for massive stars. According to Abel et al. (2002), the final masses are uncertain because a single molecular protostar seed of $\sim 1$ $M_\odot$ at the centre of a $\sim 100$ $M_\odot$ core of a protogalaxy is formed. The cores may fragment into clusters of massive (MS) or very massive stars (VMS). Nakamura et al. (1999) found 3 $M_\odot$ as the mass of the first stars which may grow up to $\sim 16$ $M_\odot$ by the accretion. The IMF of Population III could thus be bimodal with peaks at $\sim$ 1–2 $M_\odot$ and $\sim 10^2$ $M_\odot$ (Nakamura and Umemura 2001). Tumlinson et al. (2004) defined *strong VMS hypothesis* ("The first generation were exclusively VMS") and the *weak VMS hypothesis* ("The first generation included VMS in addition to MS with $M \lesssim 50$ $M_\odot$").

The structure, evolution and properties of the first stars have been modelled in several studies including the Paper I