The Earliest Stars in the Universe: Evolution of High-Mass Population III Stars

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Abstract

Having never been observed, our knowledge of the structure and evolution of the earliest stars derives entirely from calculation. With the expectation that the launch of new telescopes will allow for their observation, we present evolution calculations for massive population III stars. The models include 50 $M_\odot$, 60 $M_\odot$, 70 $M_\odot$, and 80 $M_\odot$ stars with $Z = 1 \times 10^{-14}$, H = 0.765 and He = 0.235 for comparison. We also analyze the changes in the surface and central abundances for the stars and include a preliminary light curve for a 40 $M_\odot$ model corrected for cosmological redshift.

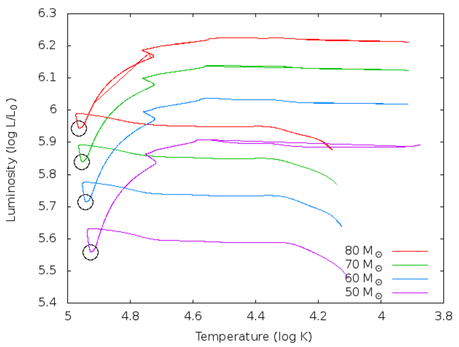

Figure 1: H-R diagram of 50 $M_\odot$, 60 $M_\odot$, 70 $M_\odot$, and 80 $M_\odot$ stars. The models show an increase in temperature associated with an increase in mass, as we should expect.

Introduction

Taking advantage of reduced light pollution due to wartime blackouts in 1944, Walter Baade, then working at Wilson Observatory, was able to resolve stars in the center of the Andromeda galaxy, M31, for the first time (Baade, 1944). He noted that blue stars are confined to the galaxy's disc, while red stars were concentrated around the galactic center and the nuclear bulge. From these observations, he proposed dividing the stars in that galaxy into two populations: the younger population I stars (blue) and the older population II stars (red).

Over the years, the divisions were revised to reflect the composition of the stars. Population I stars have more metals than population II stars—metals being defined as all elements heavier than helium.

But because both classes of stars have metals present, and the big bang did not produce a significant amount of metals (Iocco et al., 2009), there must have existed another type of star, population III, that was entirely devoid of metals. It is a purely theoretical population, having never been observed. But its stars must have been the earliest in the universe, composed entirely of H and He. They would have produced the first metals, from which the first population II stars formed.

Population III stars are unusual stars, very different from any stars around today. They would have been quite large, possibly several hundred solar masses. In addition, because they formed in an environment devoid of metals, they are much simpler in composition than other stars and are well-suited to computer simulation.

Mass ($M_\odot$)	Luminosity ($L/L_\odot$)
30	134 896.2883
40	190 546.0718
50	361 909.5139
60	517 892.9511
70	691 321.3988
80	879 285.6794

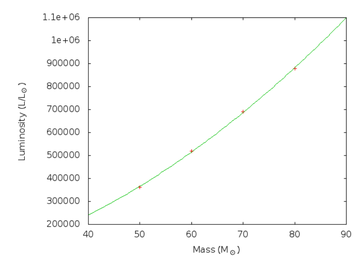

Figure 2: We indicate the luminosity of each star at the beginning of the main sequence (as shown circled in Figure 1 as a function of initial mass. The plot fit gives a mass-luminosity relationship given by $L/L_\odot = 244.189M^{1.8695}$, while for modern day stars of comparable mass it is approximately $L/L_\odot \approx M$.

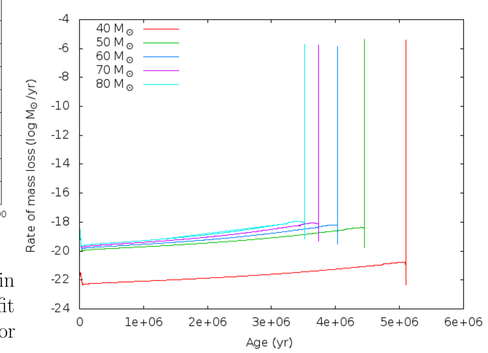

Figure 3: Here we show the rate of mass loss for each model. The solid green and red lines are the 40 $M_\odot$ and the 50 $M_\odot$ models, and have been evolved to a later stage than the 60–80 $M_\odot$ models, but it is still clear that the more massive stars experience a higher rate of mass loss. This is due to the greater surface heavy metal abundances in the more massive stars, dregged up by convection. This produces stronger stellar winds.

40 $M_\odot$

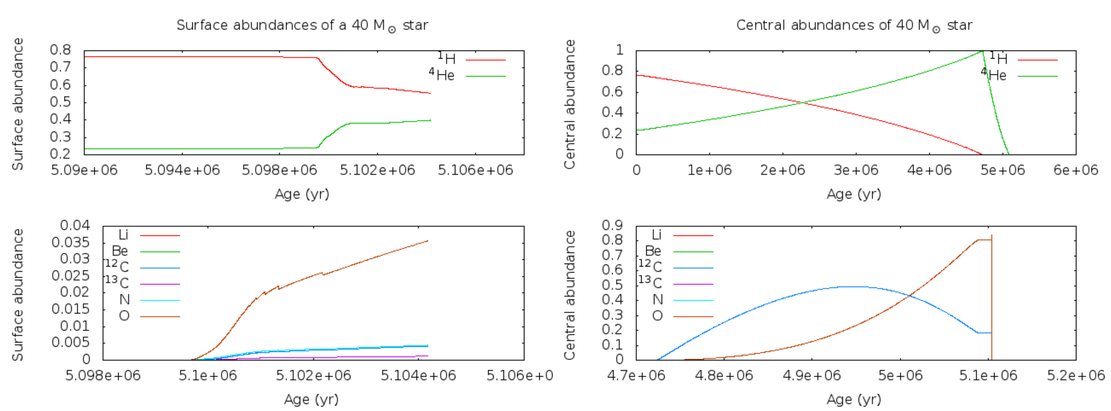

Figure 4: The central and surface abundances of a 40 $M_\odot$ model. In the top left panel we show the evolution of the surface abundances for hydrogen and helium, which are present in much greater quantities. In the bottom left panel we show the evolution of surface metals, which are not as abundant. In the top right we show the evolution of the central abundances for hydrogen and helium, and in the right bottom panel we show the evolution of surface metals. The abundance of metals begins to become more significant during the final stages of evolution.

50 $M_\odot$

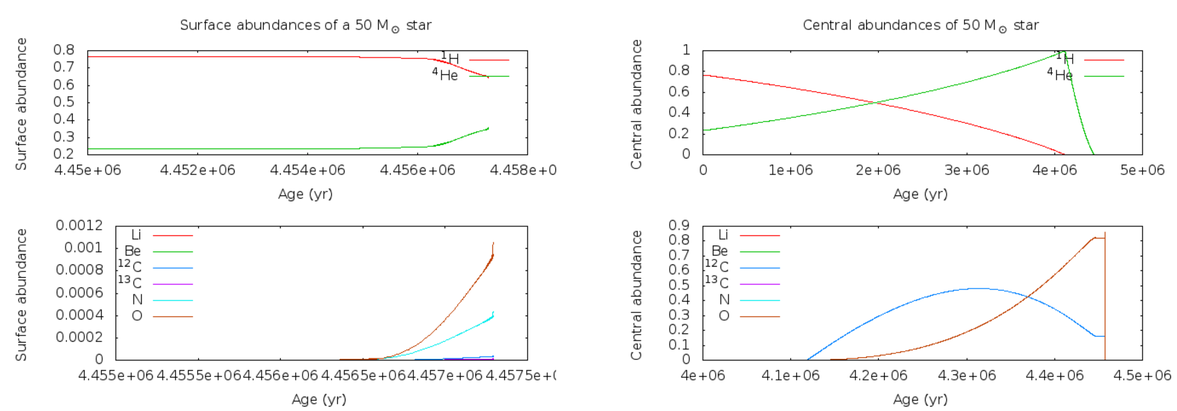

Figure 5: The central and surface abundances of a 50 $M_\odot$ model. In the top left panel we show the evolution of the surface abundances for hydrogen and helium, which are present in much greater quantities. In the bottom left panel we show the evolution of surface metals, which are not as abundant. In the top right we show the evolution of the central abundances for hydrogen and helium, and in the right bottom panel we show the evolution of surface metals. The abundance of metals begins to become more significant during the final stages of evolution.

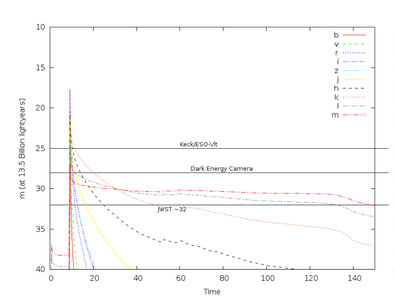

Figure 6: (Taken from Lawlor et al., 2013) Here we present preliminary light curves in a number of bands for a 40 $M_\odot$ model adjusted for cosmological redshift and with K-corrections. We hope to be able to use plots like these (more will be computed for other masses, as this is a work in progress) to compare with possible supernovae observed by new advanced telescopes, such as the James Webb Space Telescope, with the hope of being able to determine the nature of that exploding star from our models. The horizontal lines show the sensitivity limits for the James Webb Space Telescope, the Dark Energy Camera and the Keck Telescope.

References

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