A Massive Star Odyssey, from Main Sequence to Supernova
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Model atmospheres of massive zero-metallicity stars

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Abstract. We have calculated detailed, fully non-LTE, model atomospheres for massive zero-metal stars. We find the atmospheres of massive primordial stars become unbound due to radiation pressure on lines and continua over a much larger fraction of their evolution than previously expected.

1. Introduction

The first stars in the universe formed from the primordial gas containing only hydrogen, helium, and a trace of lithium. The larger effective temperatures, higher initial masses, and greatly reduced atmospheric UV opacity increase the output of hard, ionizing, UV photons relative to metal rich stars, thus massive primordial stars may contribute significantly to the reionization of the universe.

All models were computed in spherical symmetry using the PHOENIX general purpose stellar atmospheres and radiative transfer code (Hauschildt & Baron 1999). The models were computed with H and He in non-LTE and mass fractions $X=0.77$ and $Y=0.23$. The models are constructed for a specific evolutionary track and two grids for $10\,M_\odot$ and $200\,M_\odot$.

2. Atmosphere stability and evolution

The stellar mass loss rate is usually scaled as $\dot{M} \propto Z^{1/2}$. For zero-metallicity stars, this implies zero radiatively driven mass loss. As the luminosity increases, the radiative pressure force exceeds gravity and the atmosphere becomes unbound.

We have determined the radiation pressure stability limit for the two grids of zero-metallicity stars. The differences between the two limits are small when plotted against atmospheric parameters, $\log g$ and $T_{\rm eff}$. We have also calculated the atmospheres for the $4\,M_\odot$ to $100\,M_\odot$ models from the stellar evolution tracks of Marigo *et al.* (2001). They find only the two most massive models, 70 and

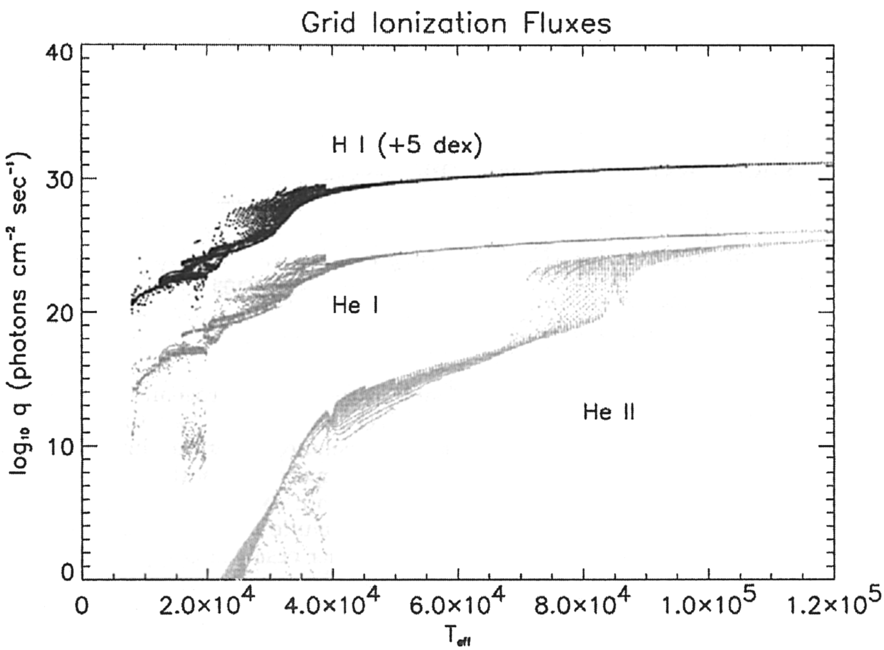

Figure 1. Ionizing photon fluxes per unit surface area, q, of the two grids.

$100\,M_\odot$, briefly exceeding the Eddington luminosity just before the red giant branch. We found that all models above $30\,M_\odot$ become, and remain, unstable much earlier in their post-main sequence evolution, typically near the start of helium burning. This difference is most likely due to the interaction of the non-grey opacity and the non-Planckian radiation field in our model atmospheres.

3. Ionizing photons

The H^0 and He^0 ionizing photon flux is fairly constant for $T_{\rm eff} > 40\,000$ K, with little scatter from different surface gravities. For $T_{\rm eff} < 40\,000$ K, there is a noted decrease in the photon flux and an increase in the scatter. For the He^+ ionizing photons, the flux falls a few dex near $T_{\rm eff} \approx 80\,000$ K, where the He^{++} begins to recombine and the He^+ absorbs some of the He^+ ionizing photons, reducing the emitted total. Below 40 000 K, the helium is singly ionized throughout the atmosphere and nearly all He^+ ionizing photons are absorbed and the energy redistributed to the red. The scatter is much larger in He^+ ionizing photons than the others. The exact cause of the large scatter is not yet known.

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