The Effects of Rotation on The First Stars

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Abstract

Using the Geneva stellar evolution code, we have developed a new grid of zero-metallicity models for masses 9-120M_{sun} including models with initial rotation of 40% of critical velocity. We analyse the evolution of the interior structure, energy generation, angular momentum transport, as well as the surface properties, identifying unique evolutiionary features of the first stars. This sheds new light on the behaviour of the first stars and how they may have impacted their environments.

Results

Rotation modifies the structure of the star, mixing of chemical species, and angular momentum transport, so understanding the effects of rotation are crucial to understand how the first stars lived and died.

From Fig 1 we see that rotation strongly affects the surface properties of the first stars. This occurs through two main effects. Rotational mixing increases the core size, which increases luminosity. This is evident in Fig 1 in how luminosity increases more steeply for rotators on the main sequence (MS), and the higher luminosity of rotators at the end of He-burning. Secondly, the transport of heavy elements by rotational mixing during He-burning causes a boost in energy of the H-burning shell, which changes the effective temperature.

Another important property that is impacted by rotation is metal enrichment. Rotational mixing helps transport more heavy elements to the H-shell, however, we have found that this can trigger an earlier CNO boost at higher masses. This early CNO boost causes the core to retract and limits further transport of heavy elements, thus hindering enrichment. H-He shell interactions at late phases also cause variations in Nitrogen enrichment. These processes explain the complex trends seen in Fig 2.

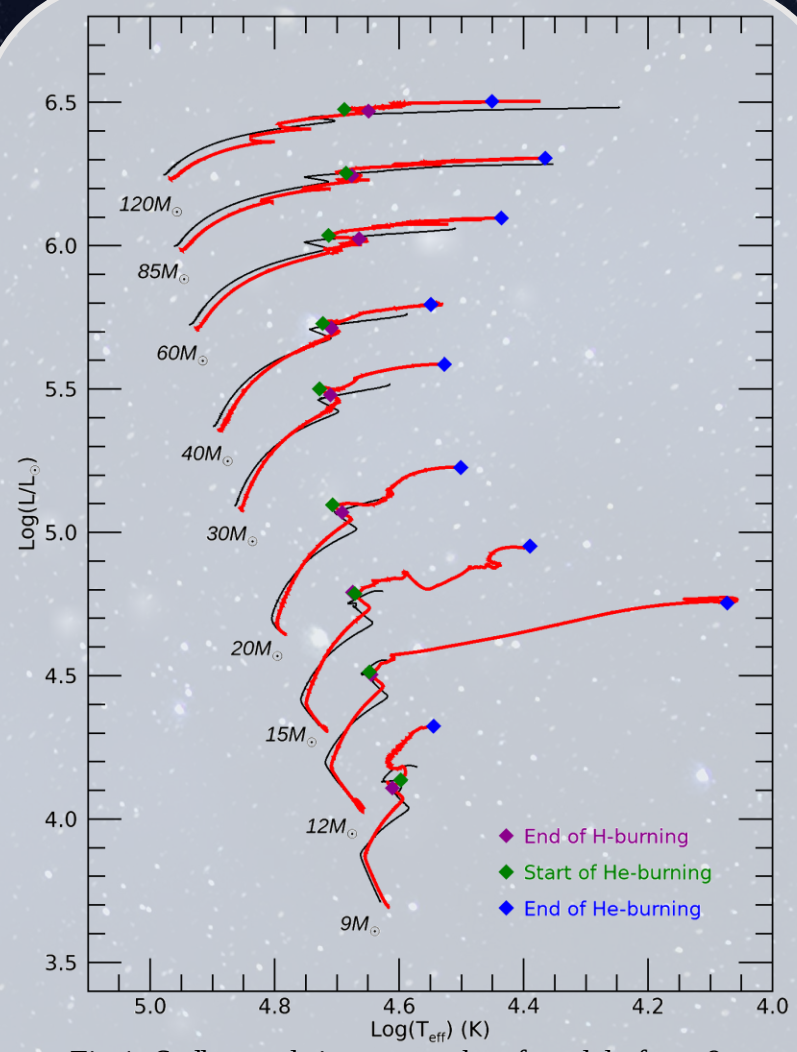

Fig 1: Stellar evolutionary tracks of models from 9-120M_{sun} on the HR diagram, luminosity vs. surface temperature, with rotating and non-rotating models given in red and black respectively. Key evolutionary stages are indicated.

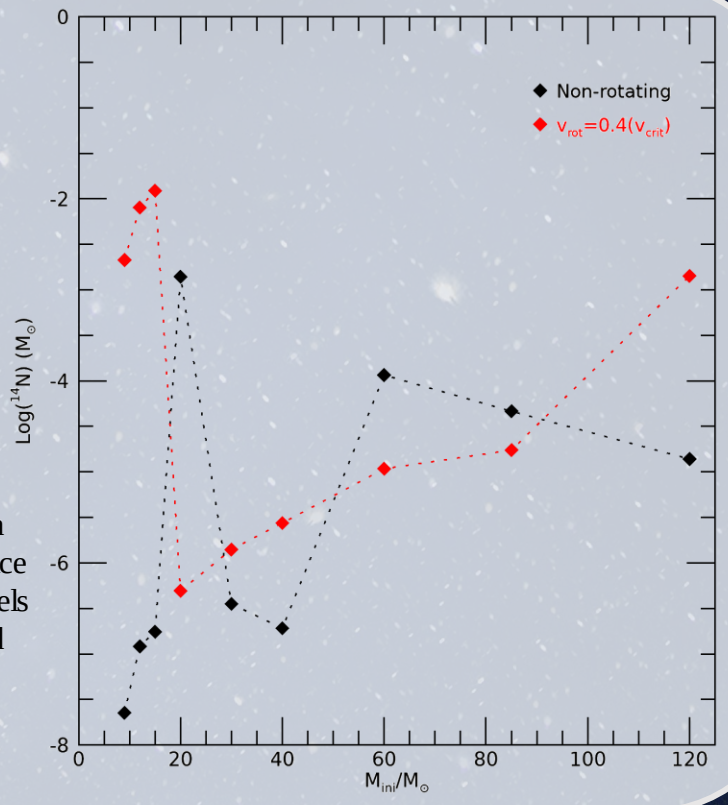

Fig 2: Final Nitrogen abundance for models with and without rotation.

Key Points

1. Rotation significantly affects evolution of surface properties, rotational mixing increases the core size which increases luminosity and also boosts the H-shell during He-burning which affects the surface temperature.
2. Rotational mixing aids transport of He-burning products, but gives an earlier CNO boost which may hinder enrichment. Further variation in N-enrichment may arise due to H-He shell interactions at late burning stages.
3. Our most massive rotating models (>60M_{sun}) reach critical rotation on the MS and subsequently experience mass-loss, this may form a decretion disk which would impact the observable signatures as well as the nature of the final fate.
4. This work is part of a paper 'Grids of stellar models with rotation: V. Models from 1.7M_{sun} to 120M_{sun} at zero metallicity' which is due to be submitted soon.

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