How different are massive star models from different simulations?

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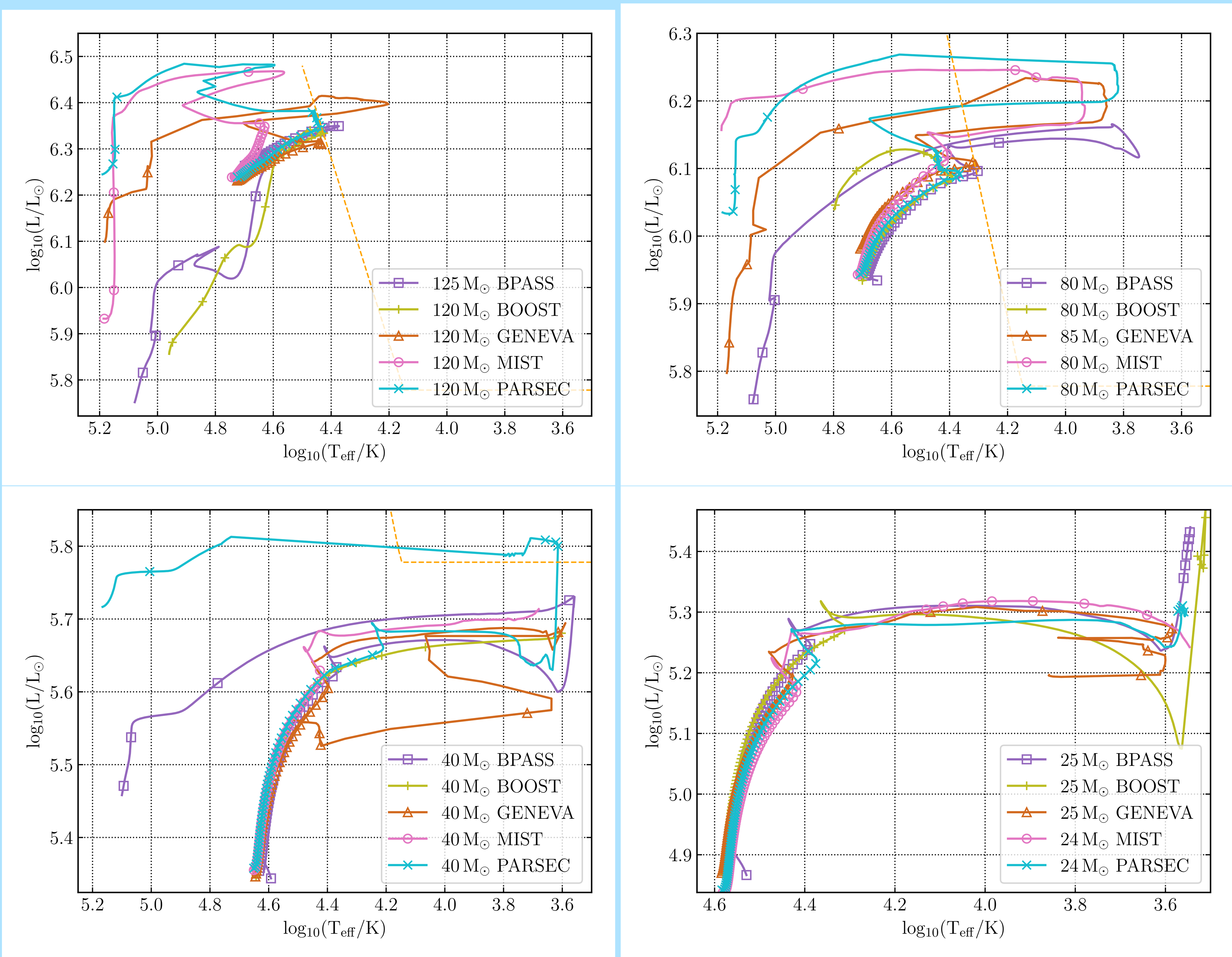
Massive stars from various simulations: why so different?

The evolution of massive stars is the basis of several astrophysical investigations, from predicting gravitational-wave event rates to studying star-formation and stellar populations in clusters. However, 1D simulations of massive stars, especially those above 40 $M_\odot$, are subject to serious uncertainties. **We present a comparison between five published sets** of stellar models from the **PARSEC, MIST/MESA, Geneva, BPASS and BoOST/Bonn** simulations at near-solar composition. The different methods adopted by the stellar evolution codes when the Eddington-limit is exceeded inside massive stars can result in up to ~18% difference in terms of ionizing radiation coming from stellar populations. For the same reason, the mass of the **black-hole** can vary up to ~20 $M_\odot$ between various sets of models. **These differences are important, as they can lead to strikingly different results in explaining observations of stellar populations such as gravitational-wave event rate predictions.** We conclude that any set of massive star models should be applied with caution, keeping in mind that evolutionary predictions for stars ≳40 $M_\odot$ have not yet reached a scientific consensus.

Hertzsprung–Russell diagrams



Figure's original: **Agrawal, Szécsi et al. (2022, MNRAS).**

Hertzsprung–Russell diagrams of the massive single star models analysed in our work. All models have near solar composition. Symbols mark every 10^5 years of evolution. Only core-hydrogen- and core-helium-burning phases are plotted. Thin grey lines marks the approximate position of the observational Humphreys–Davidson limit where relevant. The higher the mass, the more varied the tracks become.

This is mainly because the codes apply various treatments for the numerical instabilities associated with the Eddington-limit proximity.

All the stellar models used in oue work are publicly available (click for the links): **PARSEC – MIST (MESA) – Geneva – BPASS – BoOST (Bonn).**

Quantifying the differences:

total ioning flux emitted from a stellar population:

up to 18% difference!

mass of the black hole remnant:

up to 20 $M_\odot$ difference!

Stellar models can reach a point where self-gravity is over come by radiation pressure inside their envelopes. When this happens, the so-called Eddington limit is reached. If a stellar model approaches the Eddington limit, the simulation can become numerically challenging. Various codes deal with these challenges in various ways, leading to differences between the 1D models especially when it comes to very massive stars (≳40 $M_\odot$, see Figure).

Questions? Contact me!

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Related publication: **Agrawal, Szécsi et al. (2022, MNRAS).**