Fitting turbulent and convective parameters for one-dimensional core-collapse supernova simulations

Advanced Computational Research Experience for Students

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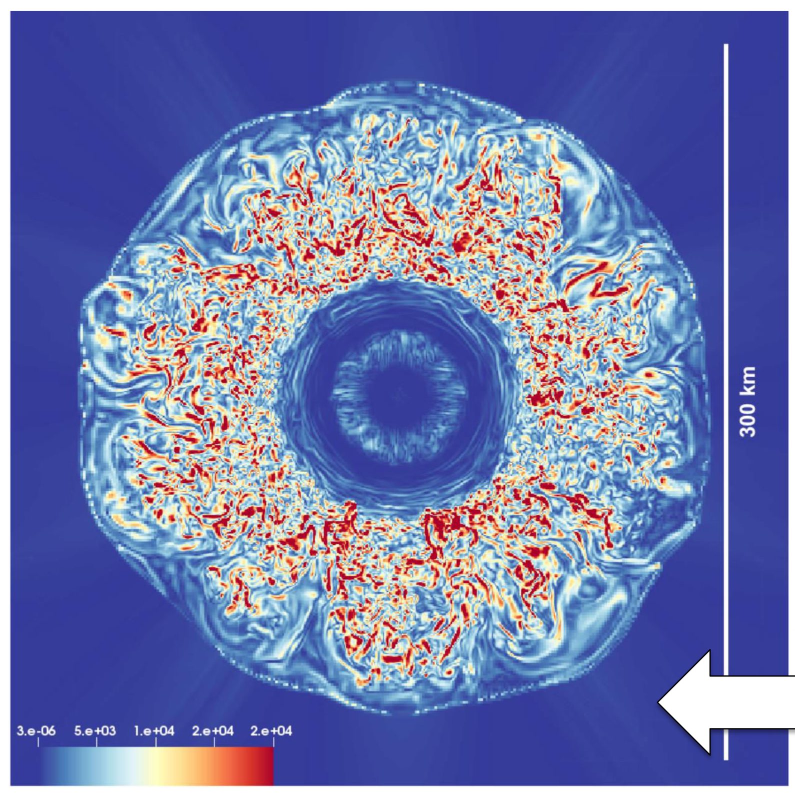
Background

Core-collapse supernovae (CCSNe) are cosmic explosions caused by the gravitational collapse of stars with mass greater than eight solar masses (>8 $M_\odot$). Running **computer simulations** of supernovae can give valuable insight into the physical processes that cause these phenomena. While three-dimensional (3D) simulations are the most physically accurate models, they are extremely computationally expensive. To save computing power, **1D simulations** are often used instead.

1D simulations cannot naturally exhibit phenomena of **convection** and **turbulence**, which are inherently multidimensional. Instead, we introduce these effects artificially based on the **Navier-Stokes Equations**. The equations require the correct convective **mixing-length parameter** and **turbulent mixing parameters** to produce 1D simulations that run smoothly and evolve in a similar way as 3D simulations.

This study tested simulations with different parameters in order to best fit 1D simulations to 3D sample simulations.



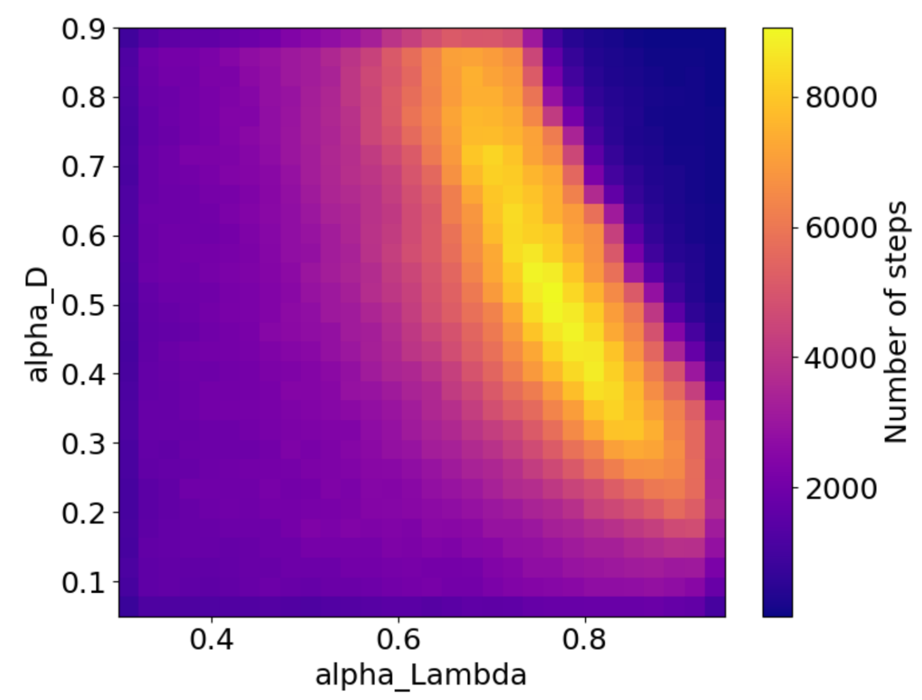
Methods

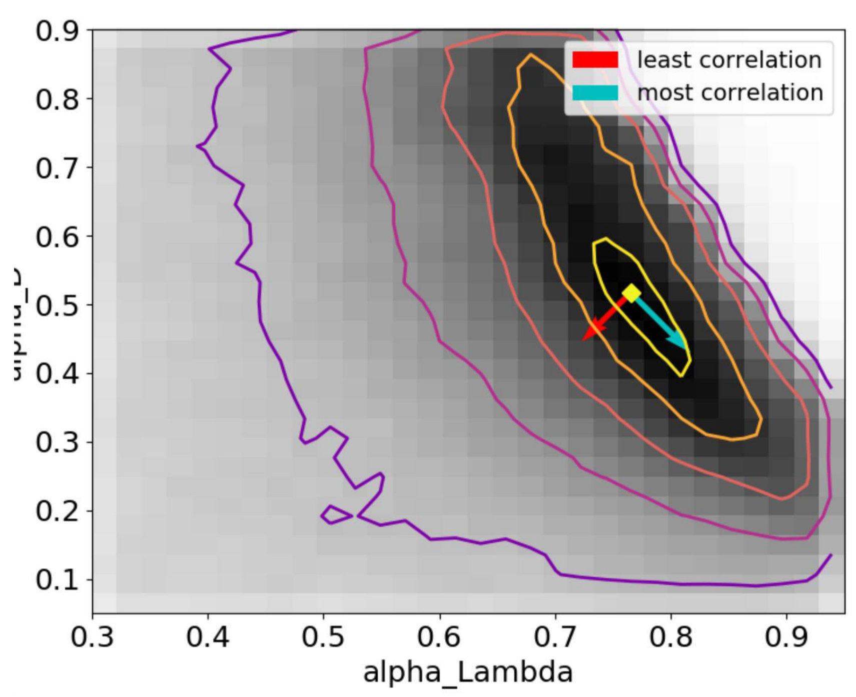
The parameters being varied were the mixing-length parameter α_Λ and the turbulent mixing parameter α_D. There are, in fact, 4 separate α_D's, but in the first phase of this study, we assume they are equal.

This study used **Markov Chain Monte Carlo (MCMC)** techniques to determine the best-fit parameters. In these methods, one or more "walkers" are placed somewhere in the parameter space, and are allowed to take "steps" in various directions. Each walker bases these steps on the goodness of fit of the new and old sets of parameters. The best fits correspond to the areas where the walkers spend the most steps. The 1D profiles at each step were provided by a **Gaussian process emulator** that interpolated from sample points.

The first phase of this study used a two-dimensional parameter space, while the second phase used five parameters: α_Λ; $\alpha_{D,\nu}$; $\alpha_{D,Ye}$; $\alpha_{D,E\,int}$; $\alpha_{D,E\,turb}$

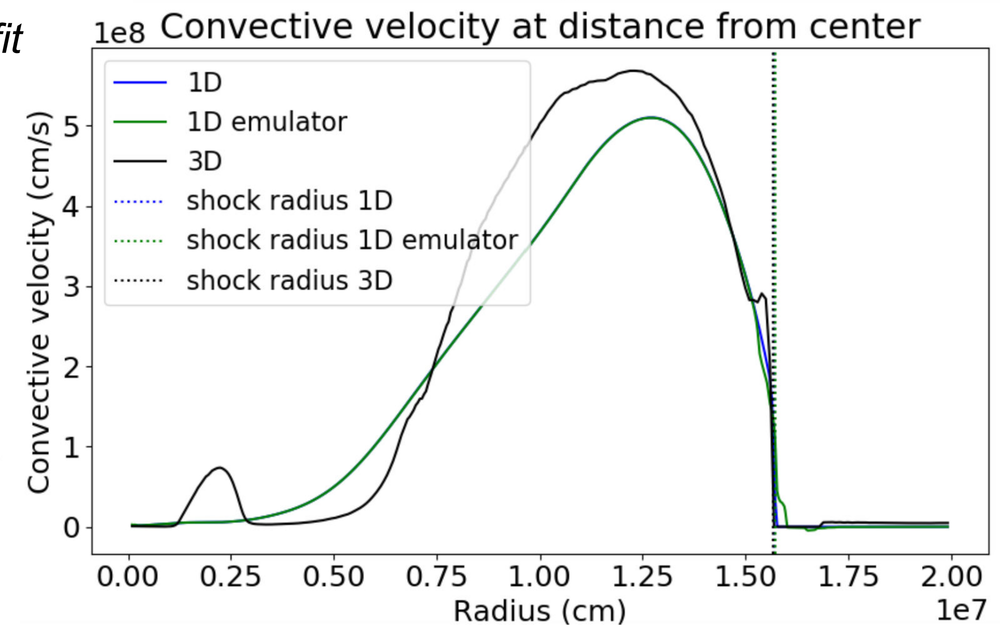
2-parameter results

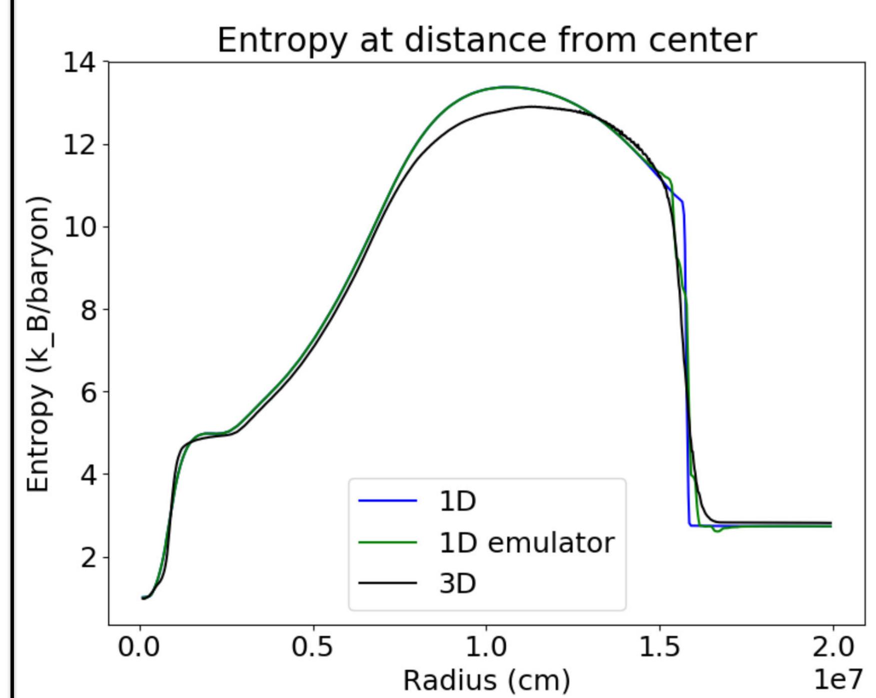




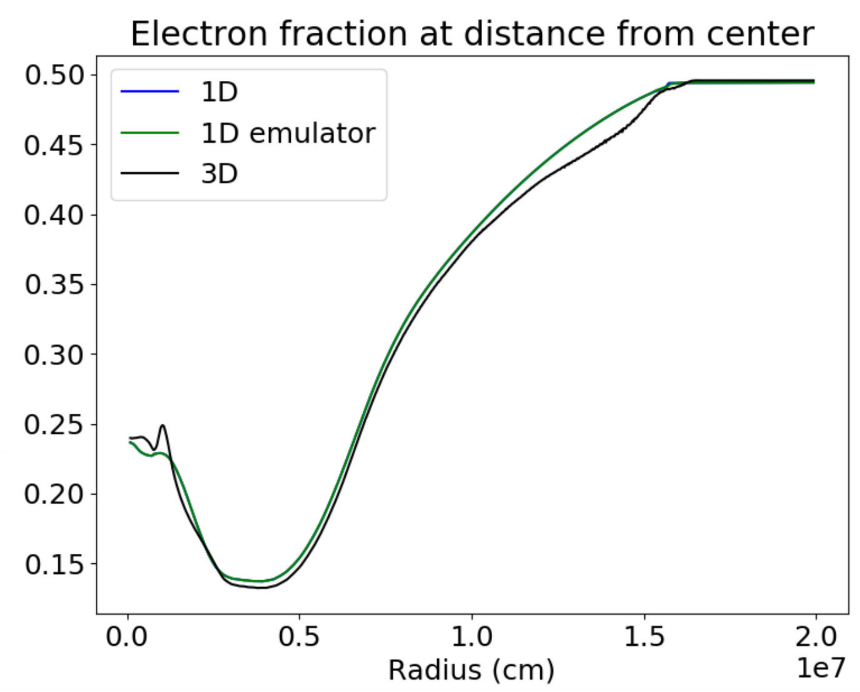
Above, *The 2-parameter trial located best-fit parameters of α_Λ = 0.77 and α_D = 0.5*

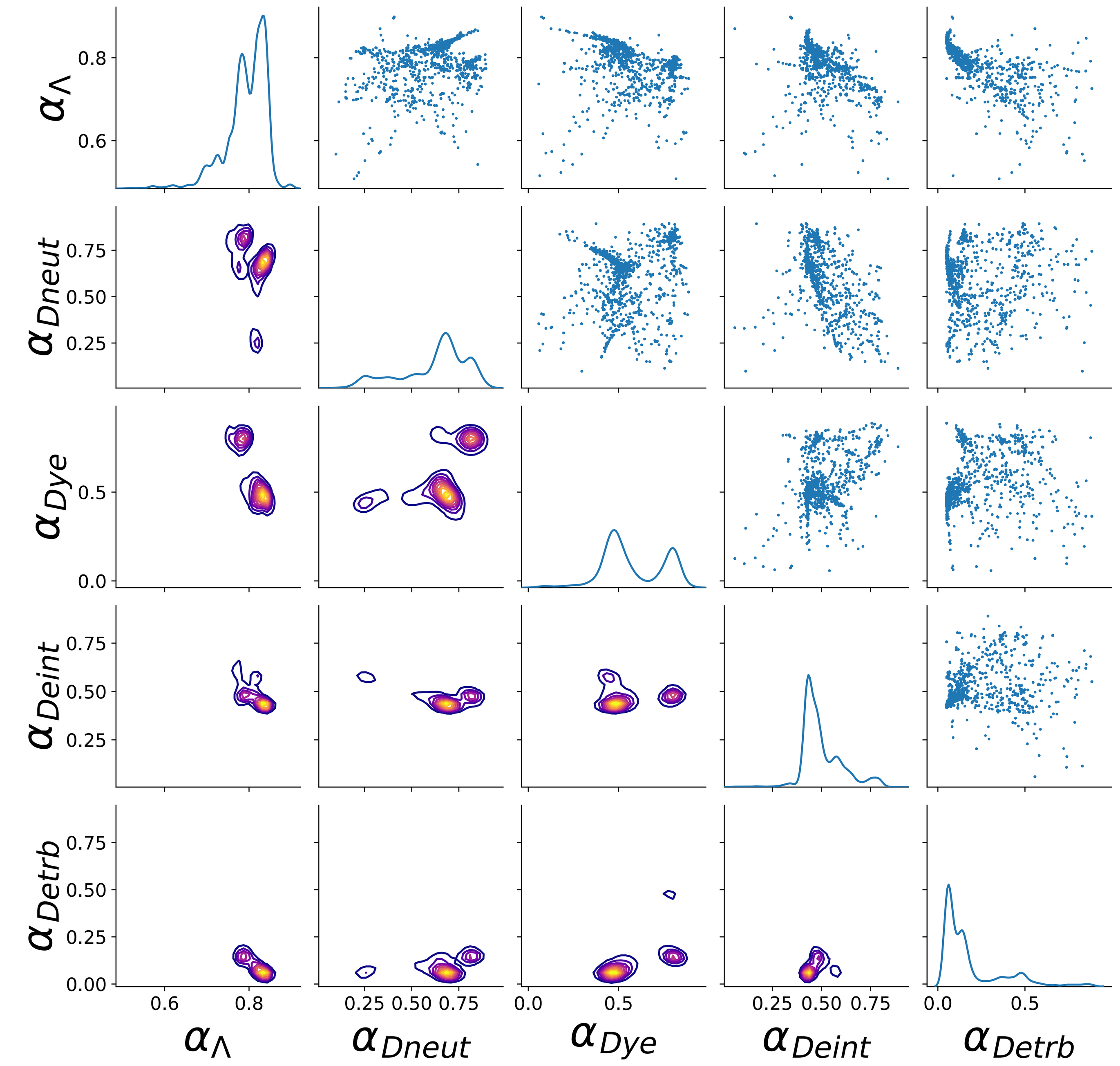
Below and right, *the results of a 1D simulation made using the best-fit parameters are compared to the results from the 3D simulation.*



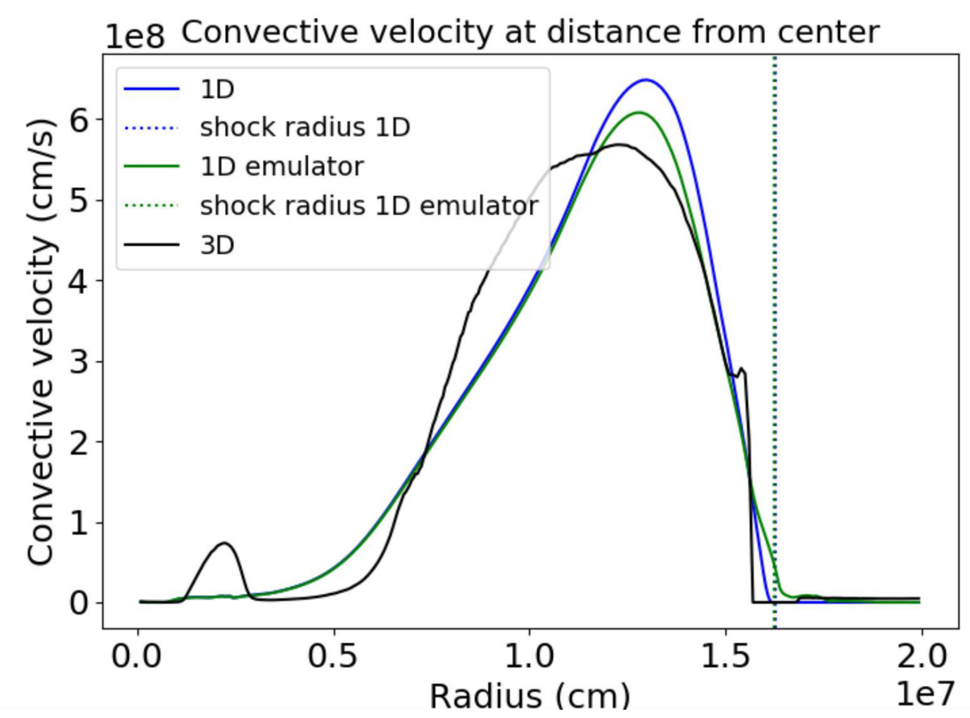


Left, *a vorticity plot from a 3D core-collapse supernova simulation.*

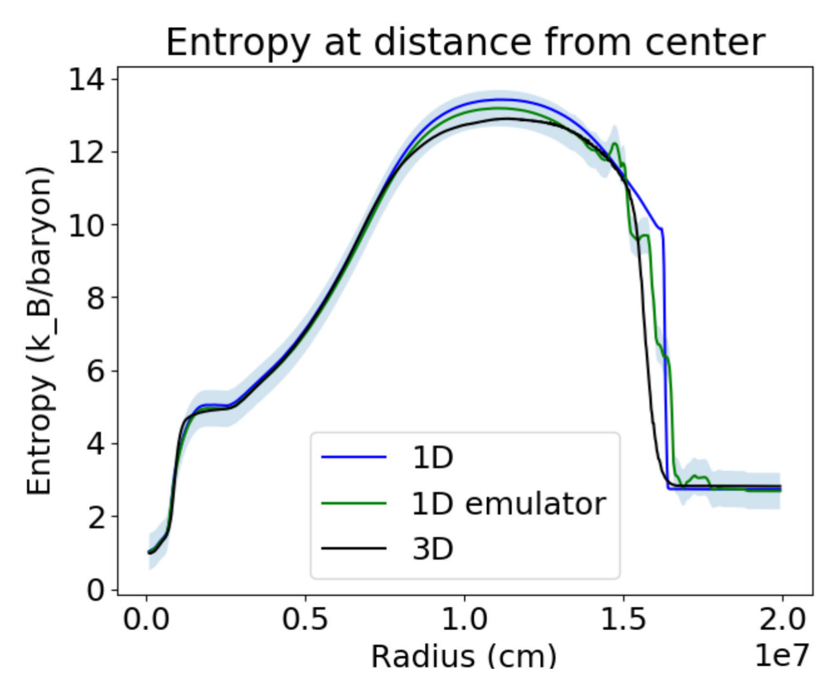


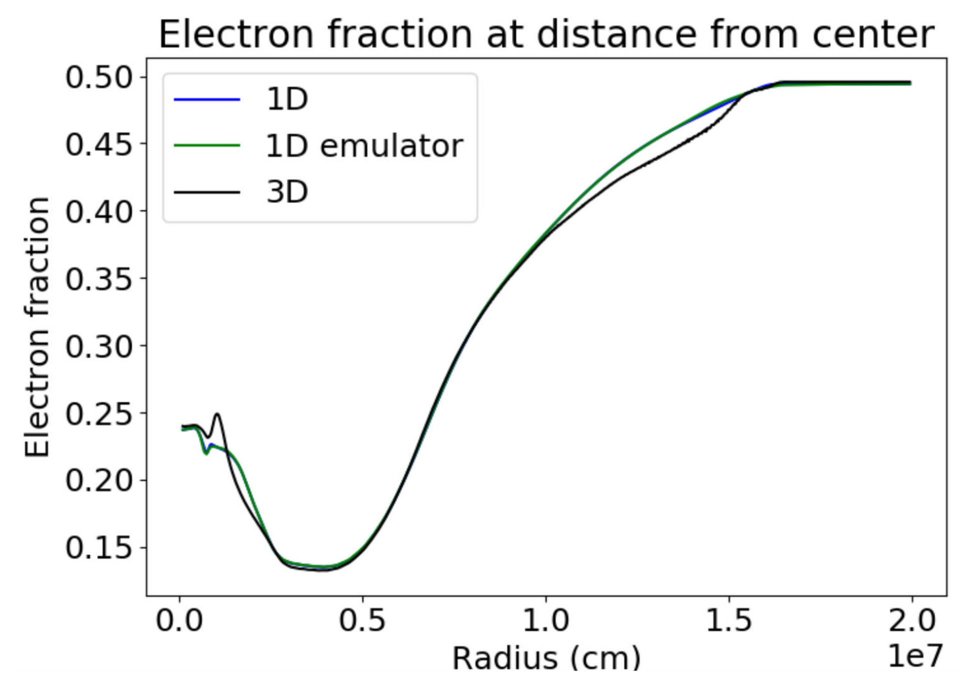


Above, *the distributions of Markov chain steps in a 5-parameter run. Each off-diagonal facet plots one of the five parameters against another.*
In the upper triangle, scatter plots of the steps.
On the diagonal, the distribution of each individual parameter.
In the lower triangle, contour plots of the step distribution.
Right, *the entropy and electron fraction profiles from the best-fit 1D simulation*



5-parameter results





Above, *the entropy and electron fraction profiles from the best-fit 1D simulation from the 5-parameter trial, compared to the 3D simulation*

Conclusions

The 5-parameter trial results produce best-fit parameters of:

α_Λ	$\alpha_{D,\nu}$	$\alpha_{D,Ye}$	$\alpha_{D,E\,int}$	$\alpha_{D,E\,trb}$
0.87	0.83	0.26	0.43	0.06

Under the 2-parameter trial's assumption that all α_D mixing parameters are equal, the best-fit parameters become:

- α_Λ = 0.77
- α_D = 0.5

In future trials, this method will be applied to other 3D simulation data to corroborate these results.

Acknowledgements

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