Simulating the Structure and Evolution of Main Sequence Stars

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Motivations

Main Sequence Stars are the most common types of stars in the universe. It usually takes billions of years for their evolution. During this process, they experience changes in their internal structure which also affect their other properties such as luminosity, temperature, and chemical composition.

In this project, I decide to make multiple plots to show the structure and evolution of main sequence stars, including their internal mass, pressure, temperature and luminosity through the radius and time. I believe this model can help readers understand the inner structure for general main sequence stars in an effective way and it can provide a logical flow for star evolution to help readers know the energy change through the interior of main sequence stars.

Required Input Physics

Through Radius

$$\frac{dM_r}{dr} = 4\pi r^2 \rho$$

$$\frac{dP}{dr} = -\frac{GM_r\rho}{r^2}$$

$$\frac{dT}{dr} = -\frac{3}{16}\frac{\kappa L_r P}{4\pi r^4 \sigma T^3}$$

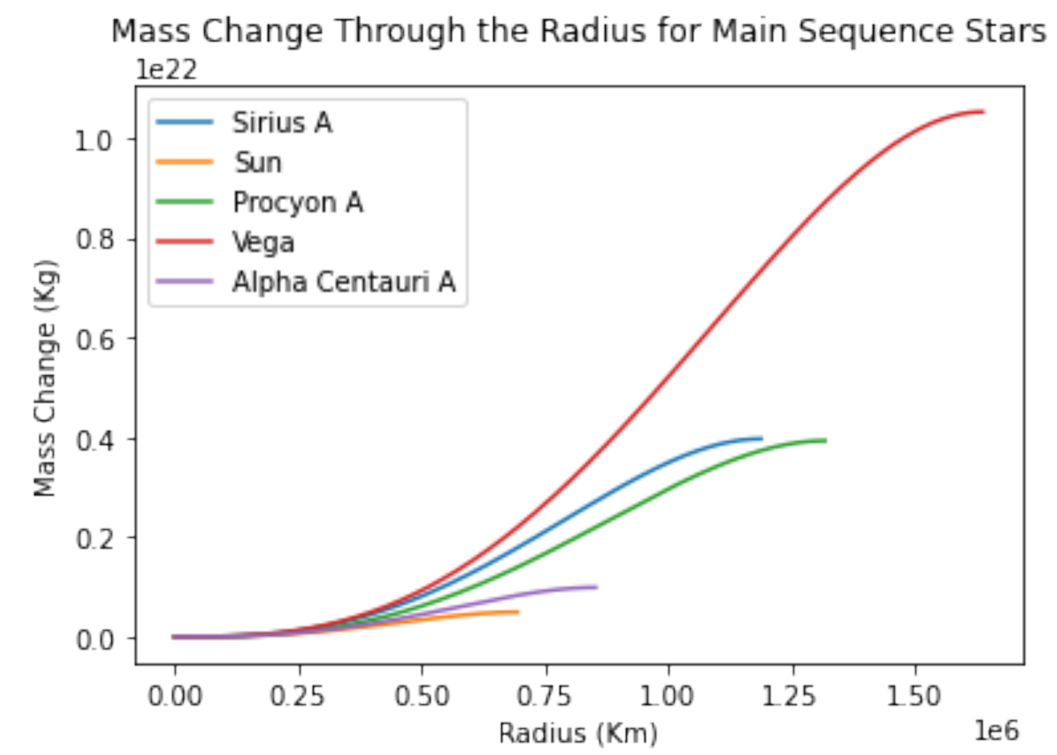
$$\frac{dL_r}{dr} = 4\pi r^2 \rho \epsilon$$

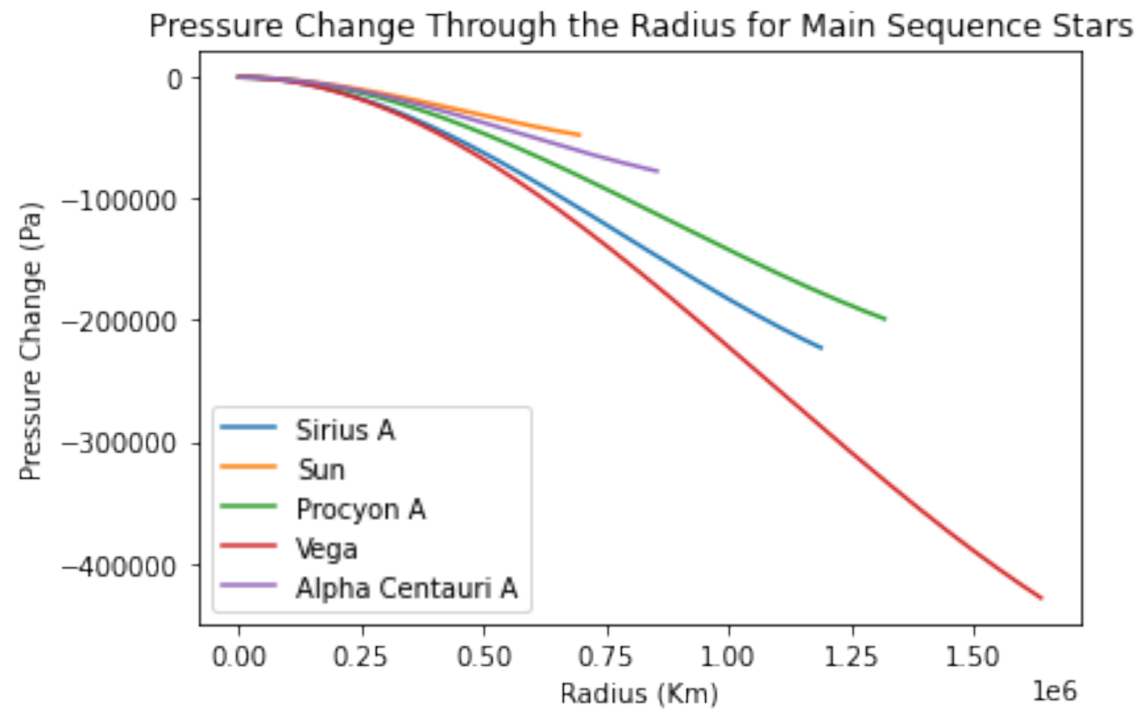
Through Time

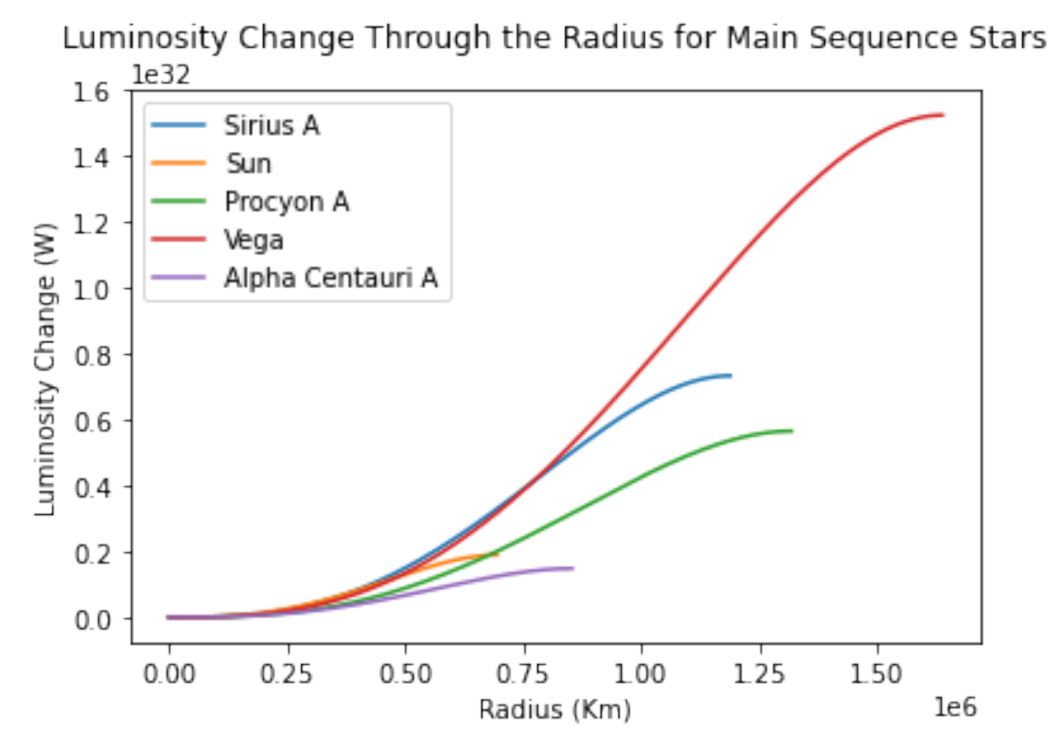
$$\frac{dM_r}{dt} = -\frac{\eta L_r}{c^2}$$

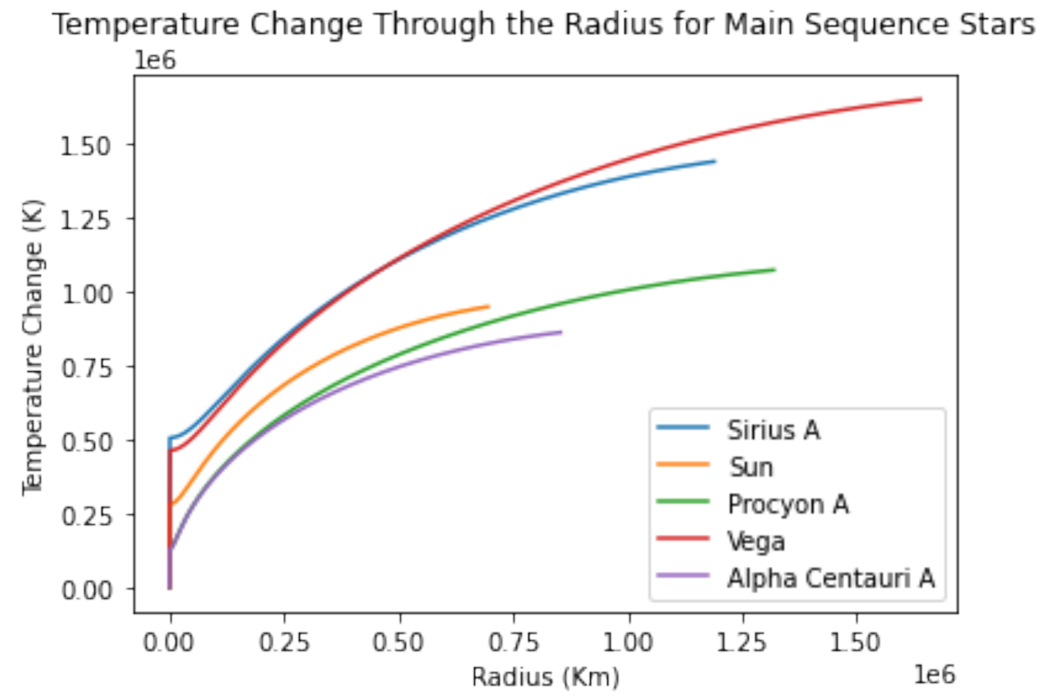
$$\frac{dT}{dt} = -\frac{3acL_r}{4M_r T^3}$$

Result Graphs (Through Radius)

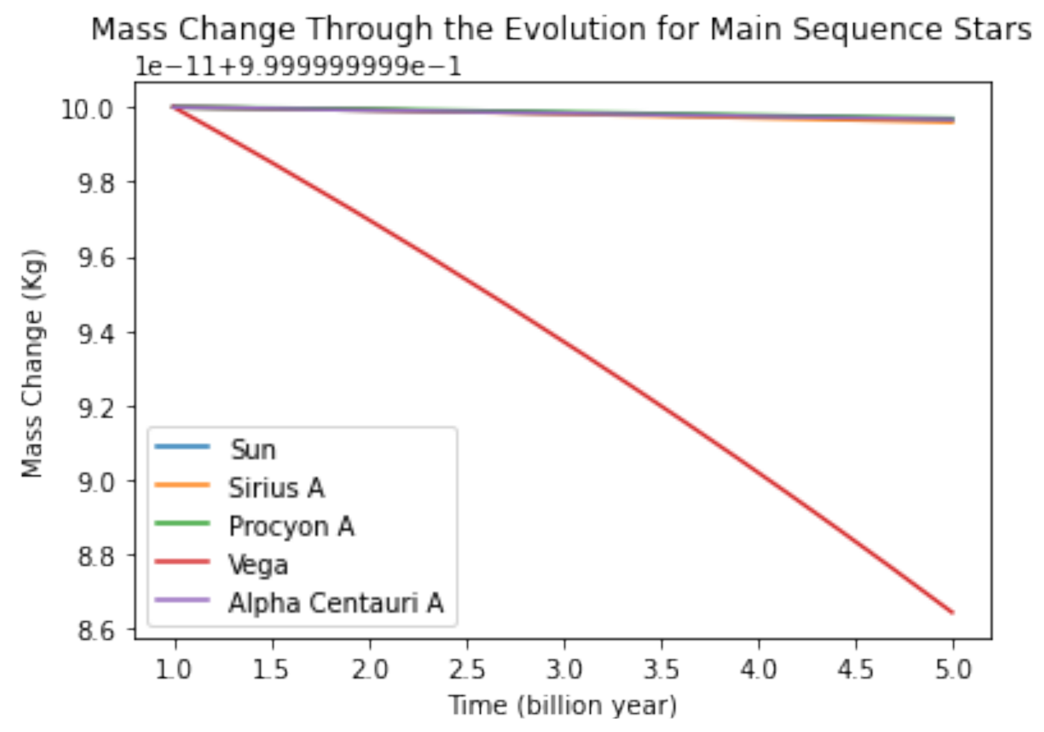


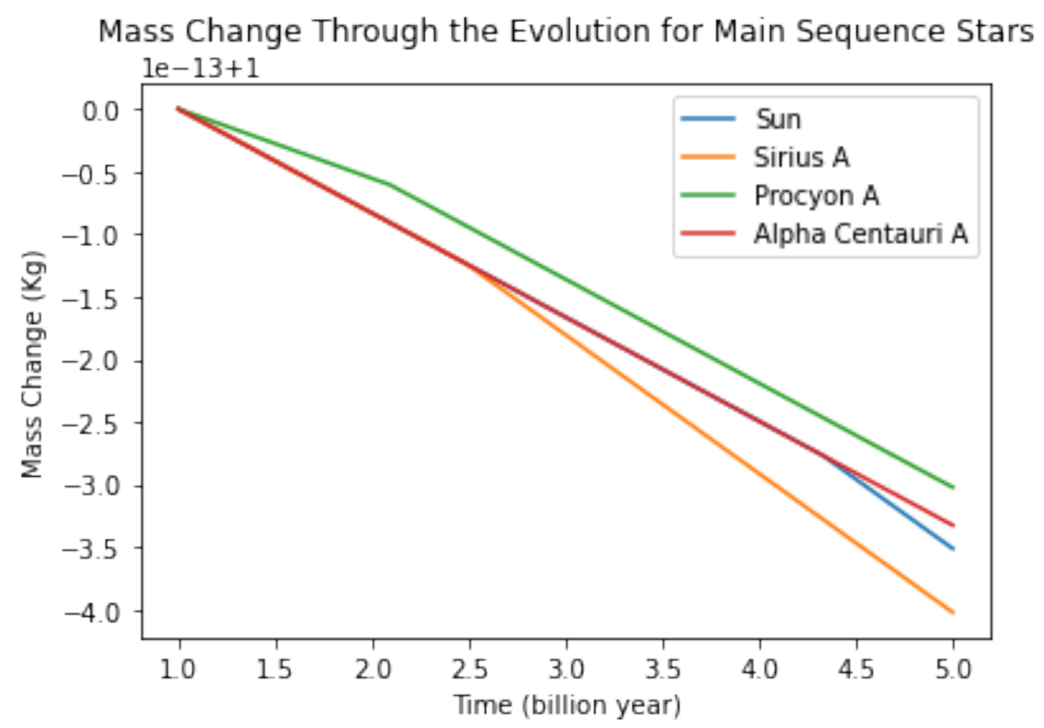


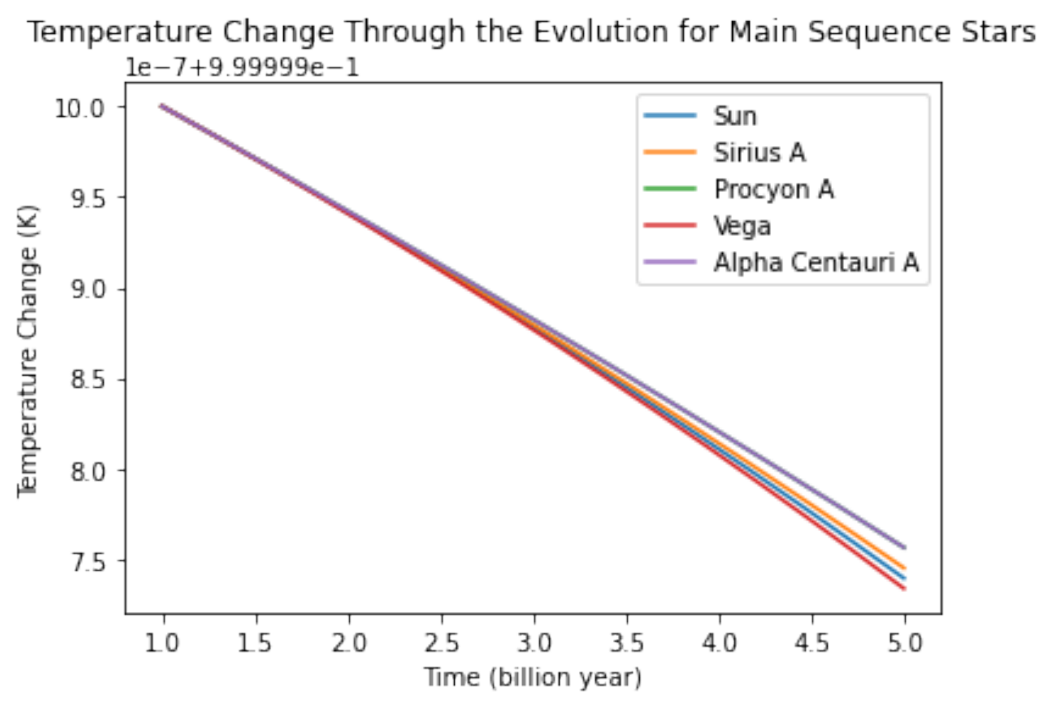




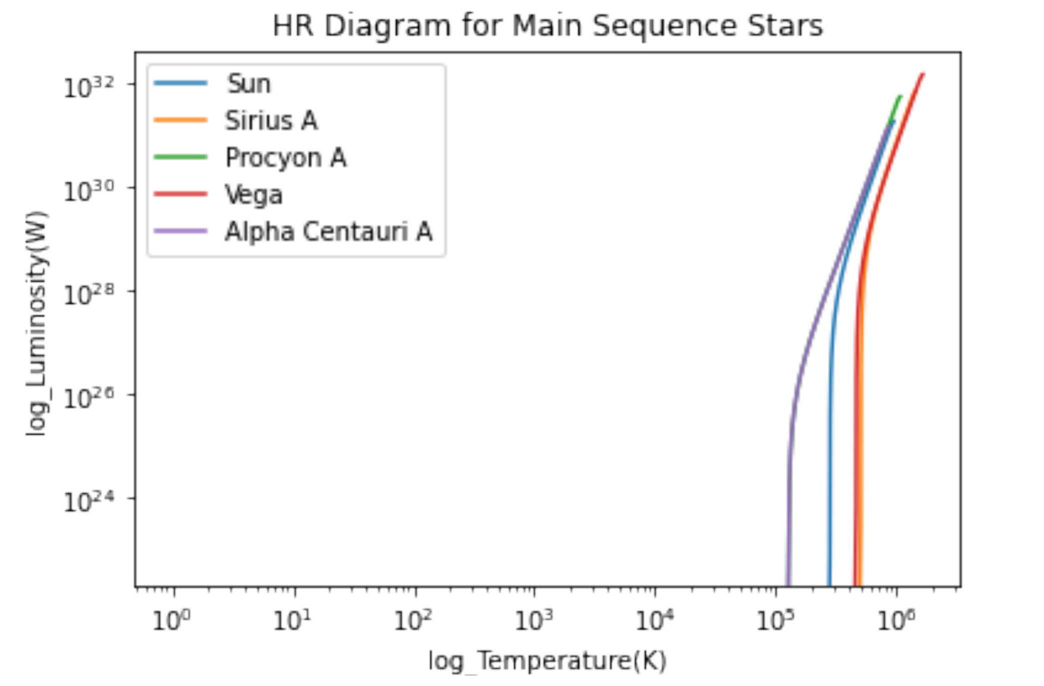
Result Graphs (Through Time)





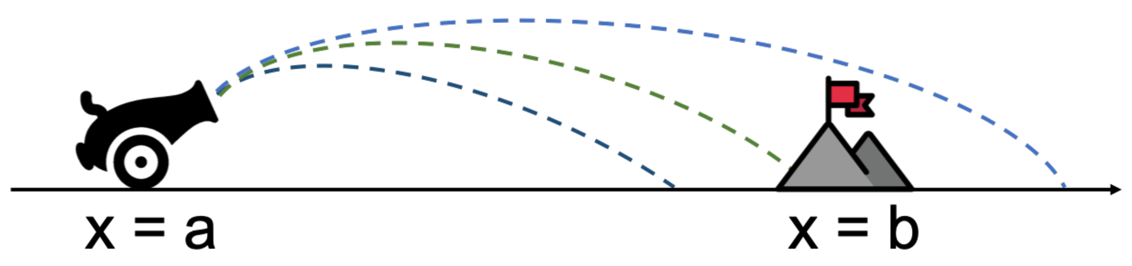


Applications (HR Diagram)



Methods

$$K_1 = hf(x_n, y_n)$$
$$K_2 = hf(x_n + \tfrac{h}{2}, y_n + \tfrac{k_1}{2})$$
$$K_3 = hf(x_n + \tfrac{h}{2}, y_n + \tfrac{k_2}{2})$$
$$K_4 = hf(x_n + h, y_n + k_3)$$
$$y_{n+1} = y_n + k_1/6 + k_2/3 + k_3/3 + k_4/6 + O(h^5)$$



Result Analysis

Mass and Luminosity increase through the radius non-linearly while Pressure profile decrease through the radius non-linearly. The changing gradient is relatively small compared to its initial value.

Mass and temperature decrease with almost linear trend through the evolution time. However the changing gradient is super small compared to its initial value.

Further Studies

More types of stars to simulate: White Dwarfs, Giants, Subgiants and Supergiants

More complex cases: chemical reactions during the evolution, the effects of rotation and magnetic fields and more complicated boundary conditions

References

Evolution of Stars and Stellar Populations, Maurizio Salaris and Santi Cas- sisi, ISBN-13 (2005)

Stellar Interiors, Carl Hansen and Steven D. Kawaler, second-edition (2004)

Stellar Evolution and Nucleosynthesis, Sean G. Ryan and Andrew J. Norton, Cambridge University Press (2010)