Modeling the Effect of a Faint Young Sun on Venus' Cloud Structure

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1. Science Question

What is the effect of a Faint Young Sun on Venus' Cloud Structure?

2. Background

Clouds of sulfuric acid completely cover Venus today. The production of this sulfuric acid is caused by a photochemical reaction that consumes sulfur dioxide, water vapor, and sunlight. This reaction occurs in the photochemical cloud. The photochemical cloud is driven by the active supply of acid and the condensational cloud is driven by a reservoir of acid below the cloud.

Venus has been exposed to varying amounts of solar intensity throughout its history due to a fainter young Sun. It is believed the sun was 29% less luminous 4.7 billion years ago. This becomes a paradox as young Earth and Mars should have been frozen but there is geological evidence proving Earth had liquid water.[1] A younger Sun also has an effect on Venus' cloud structure through its photochemical production.

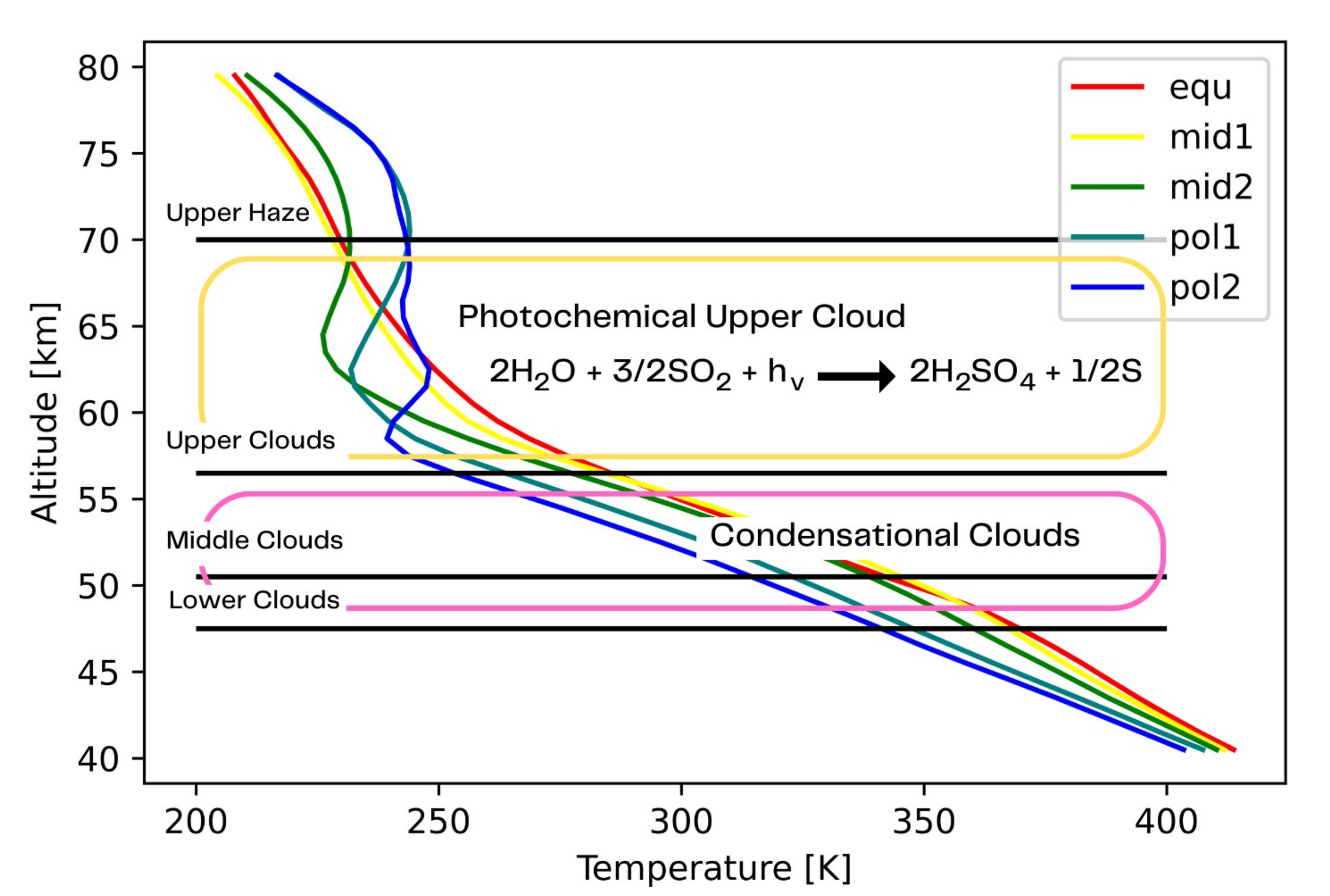

Figure 1: Schematic of modern day Venus' temperature profile and cloud structure at different latitudes (equ = ± 30° with other latitudes increasing by increments of 15°). The photochemical cloud encompasses the upper clouds and the condensational cloud encompasses the middle and lower clouds.

3. Model & Methods

PlanetCARMA is a model for planetary atmospheres that simulates physical processes, including nucleation, condensation, and evaporation in a column of atmosphere.[2] We verified that the model was consistent by reproducing previous Venus simulations[3] that are consistent with observational data. We mimicked the effects of the Faint Young Sun across the entirety of Venus' cloud structure by scaling the photochemical production rate and the bottom boundary of the sulfuric acid mixing ratio. The photochemical production rate affects the photochemical cloud and the bottom boundary affects the condensational cloud.

These parameters were scaled according to Endal and Shattens equation for the luminosity of the Sun over time, where t is the elapsed time since the formation of the Sun.[4]

$$\text{Luminosity of Sun over Time} = 0.71L_{sun} \cdot \left[1 + 0.412\left(1 - \frac{t}{4.7 \cdot 10^9}\right)\right]^{-1}$$

4. Assumptions & Parameters

Within PlanetCARMA there are certain assumptions:

- Fixed altitude of photochemical production in PlanetCARMA

Additional Parameters:

- Changing only luminosity of a faint young Sun
- Modeled only at equatorial latitudes
- Assuming bottom boundary of the sulfuric acid mixing ratio scales according to luminosity
- 2 year run time in model time

5. Results

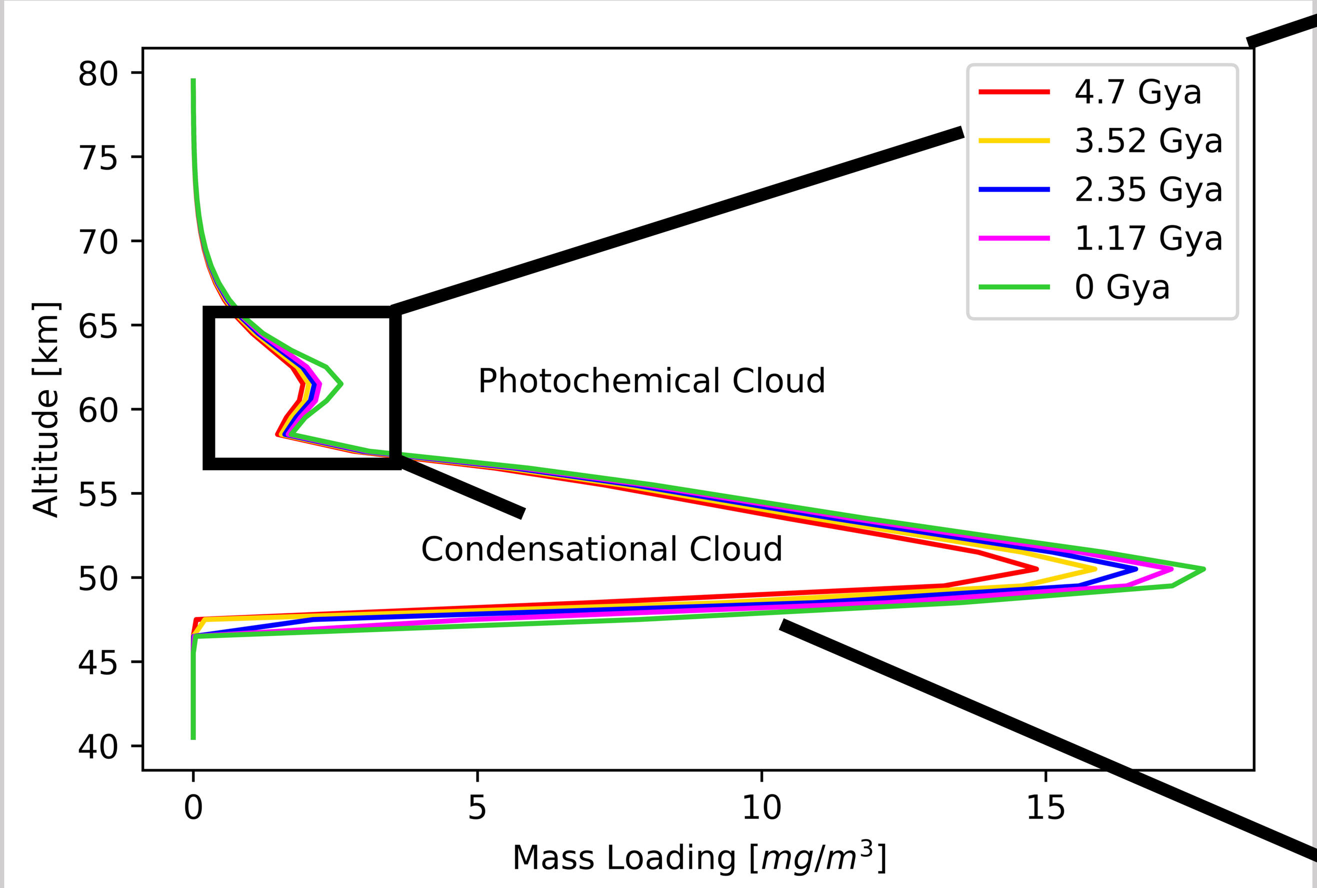

Figure 2: Mass loading plot showing the condensational and photochemical clouds over 4.7 billion years.

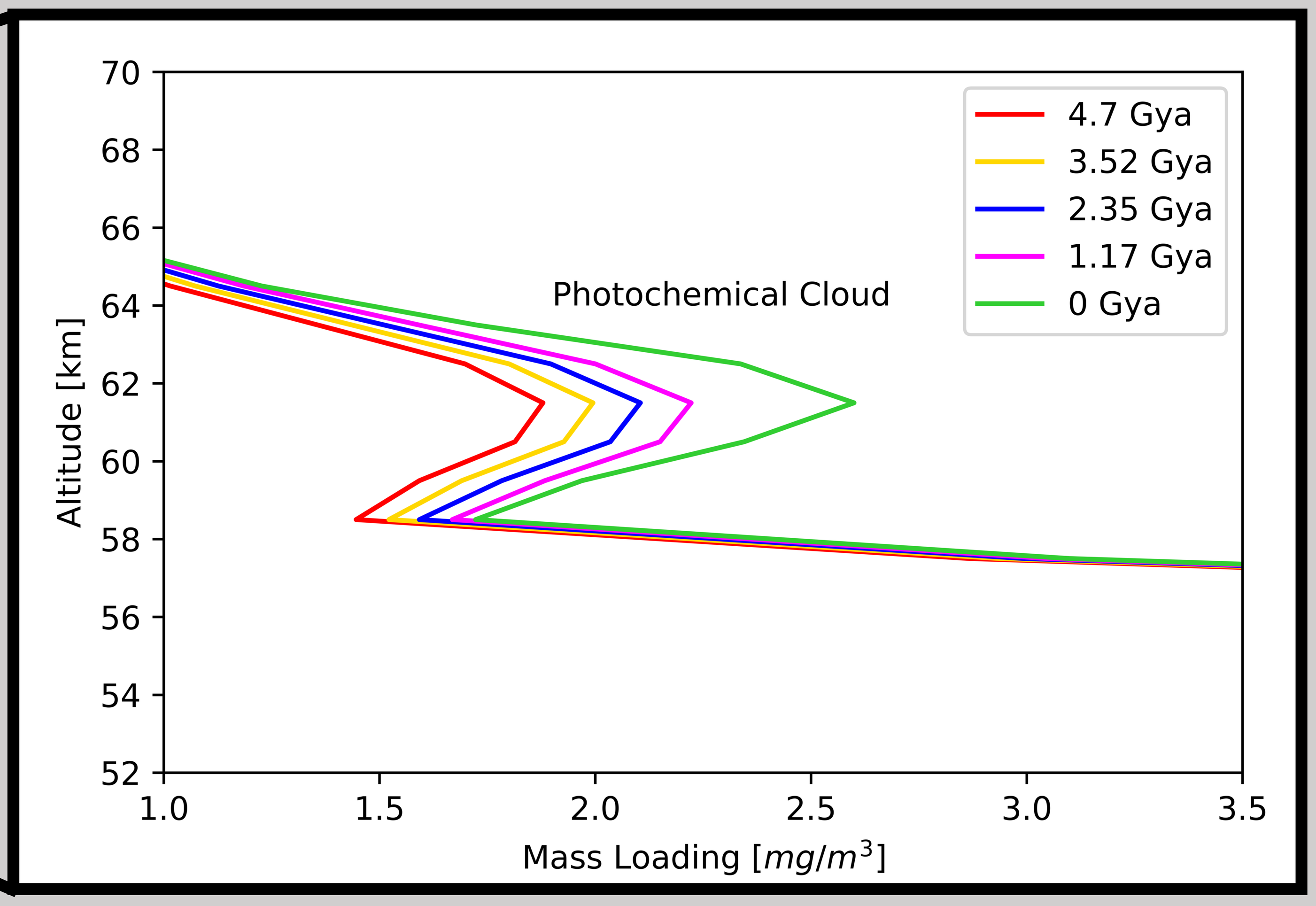

Figure 3: Close up of the photochemical cloud in the mass loading plot.

In Figure 2, the mass in the condensational cloud (47-56 km) decreases steadily as the luminosity of the Sun decreases. The condensational clouds decrease is driven by the bottom boundary of the sulfuric acid mixing ratio. Figure 3 shows that the photochemical cloud (56-70 km) does not decrease consistently. The loss in magnitude between today's Venus and 1.17 Gya Venus is larger than between any other run. This is because the Sun's luminosity increased 59% in the second half of the Sun's lifetime.[4]

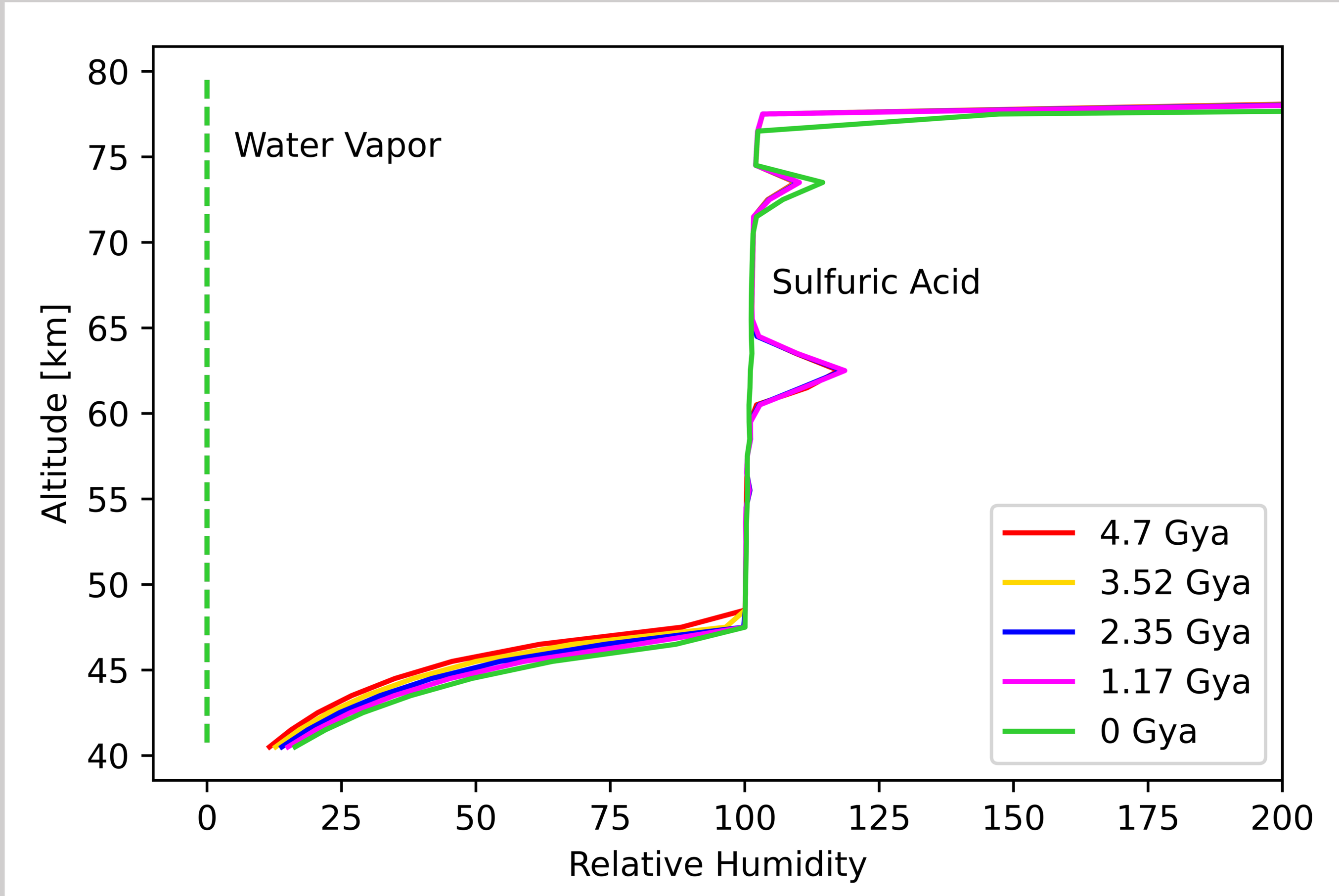

Figure 4: Relative humidity plot showing that the 4.7 Gya, 3.52 Gya, 2.35 Gya, and 1.17 Gya lines are stacked on top of each other.

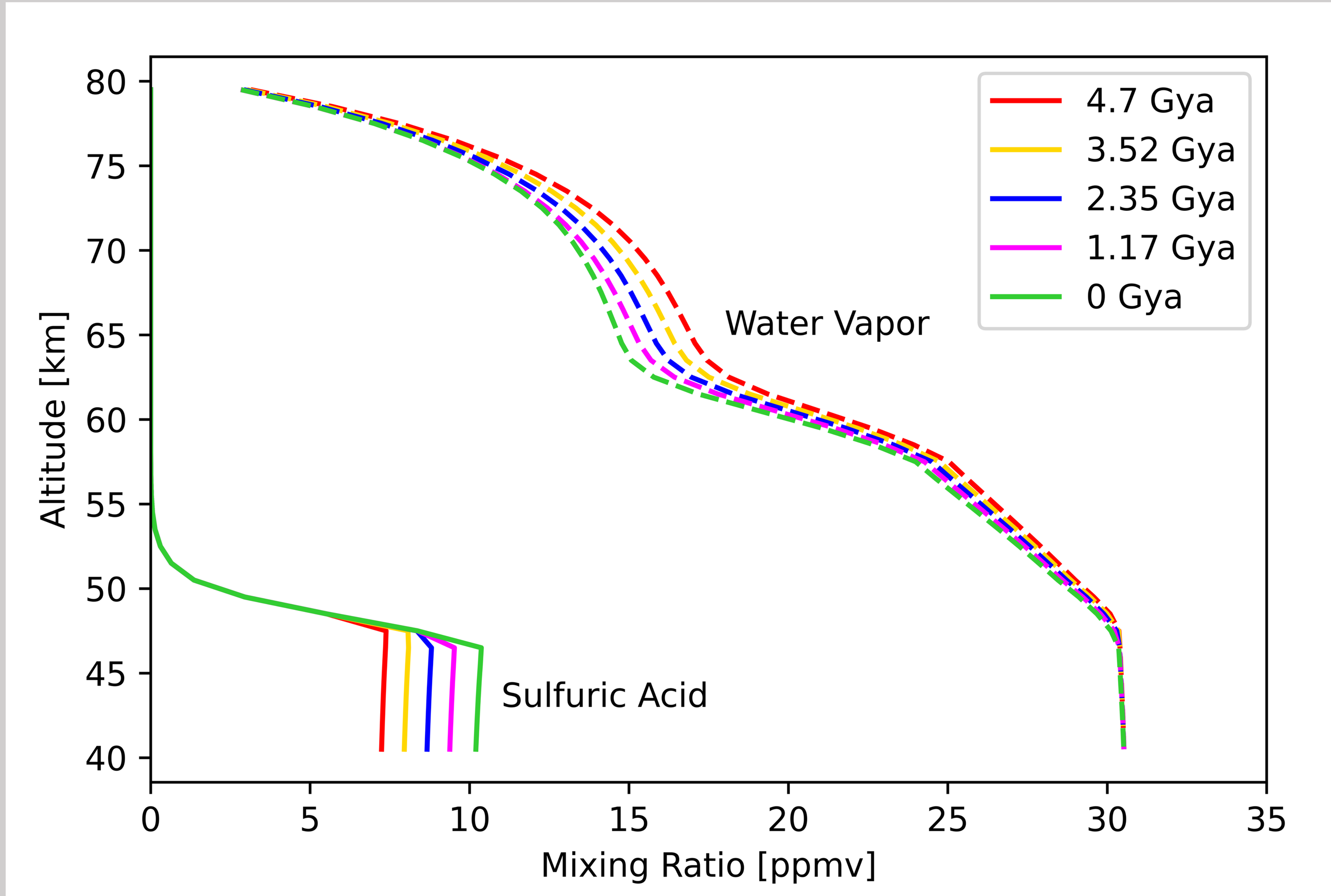

Figure 5: Water Mixing Ratio and Sulfuric Acid Mixing Ratio over 4.7 billion years.

In Figure 4, Today's Venus is the only line that does not have a spike in relative humidity at 61 km. In Figure 5, the sulfuric acid mixing ratio shows the different bottom boundaries of the sulfuric acid reservoir. Additionally, the water mixing ratio increases in the photochemical cloud (56-70 km) as the luminosity of the Sun decreases. In Figure 6 (below), the effective radius plot shows only minor changes in the effective radius across time in the condensational clouds, meaning that the structure of the clouds are largely the same across time.

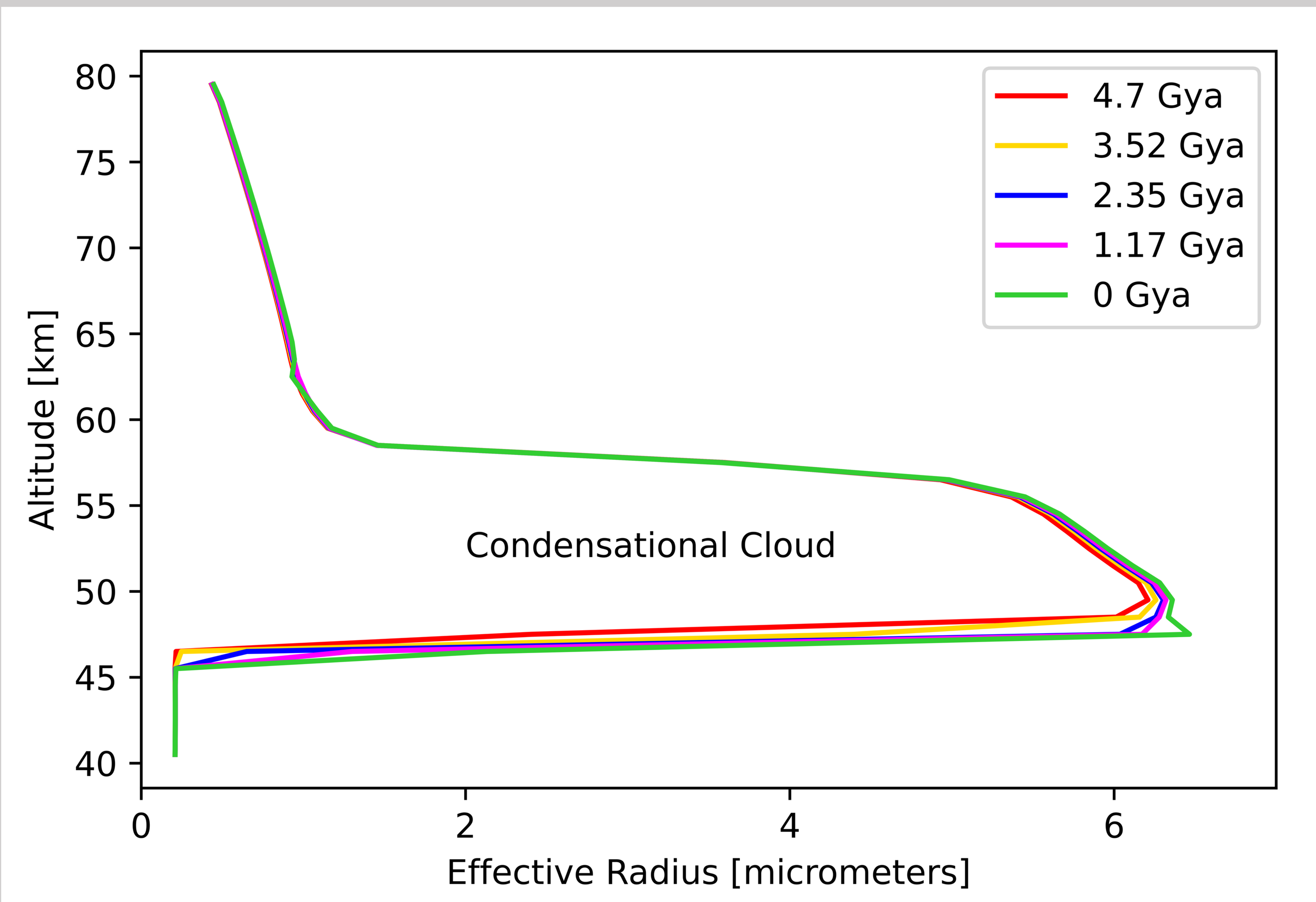

Figure 6: Effective radius plot showing over a range of 4.7 billion years.

6. Conclusions

Our simulations indicate that a faint young Sun would have an impact on Venus' cloud structure, most prevalently in the last billion years. This is most clear in Figures 2 and 3 with a larger change in the mass loading of the photochemical cloud (56-70 km) between 1.17 Gya and today's Venus than any other run.

Further extensions to this project include using the effective radius in Figure 6 to calculate the optical depth of the clouds and the extinction coefficient.

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7. References

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