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Water on Venus: Implications of theEarly Hydrodynamic Escape

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Abstract

In order to study the evolution of the primitive atmosphere of Venus, we developed a time dependent model of hydrogen hydrodynamic escape powered by solar EUV (Extreme UV) flux and solar wind, and accounting for oxygen frictional escape

We study specifically the isotopic fractionation of noble gases resulting from hydrodynamic escape. The fractionation's primary cause is the effect of diffusive/gravitational separation between the homopause and the base of the escape. Heavy noble gases such as Kr and Xe are not fractionated. Ar is only marginally fractionated whereas Ne is moderately fractionated.

We also take into account oxygen dragged off along with hydrogen by hydrodynamic process. In that case, most of the available energy is consumed by oxygen and the amount of energy available for the escape of hydrogen is reduced by one order of magnitude. We find nonetheless scenarios that are compatible with present-day Ne and Ar fractionation in Venus atmosphere.

We suggest that the early hydrodynamic escape pumped volatiles out of the magma ocean to fuel its mechanism and that it lasted less than 100 Ma on Venus, stopping when there was no more hydrogen to escape. At the same time the atmosphere thinned and cooled, which was the cause of the freezing of the magma ocean.

1. Introduction

The atmospheres of Venus and the Earth are quite similar, despite the different ways the planets evolved. Their compositions show an impressive similarity, if we take into account the fact that for the Earth oxygen has been produced by photosynthesis and that CO_2 has been trapped into carbonate deposits, as they are mostly composed of CO_2, nitrogen and noble gases. This similitude points toward a common origin for those three atmospheres and a usual theory is that these atmospheres are secondary, created by the degassing of volatiles from the bodies that constituted the early planet. The atmosphere of Venus could then represent a primitive state of the evolution of terrestrial. Moreover, Mars and the Earth possess reservoirs of water at present-day whereas Venus seems to be dry. The early evolution of terrestrial planets and the effects of hydrodynamic escape might explain this observation by the removal of most of the initial water on Venus.

2. Results and Scenario

We study the evolution of the primitive atmosphere of Venus and investigate the possibility of an early habitable Venus with a possible liquid water ocean on its surface. We therefore developed a time dependent model of hydrodynamic escape of hydrogen during the first few hundred million years. Oxygen is the second major species in the early atmosphere and we study it through its linked escape with hydrogen. We follow a theory from Hunten et al. (1987) [1] and developed by Chassefière (1996) [2]. The energy powering the escape comes from solar EUV (Extreme UV) and solar wind and decreases with time. It is directly converted into upward translation energy and is consumed by both H and O, with oxygen using most of it, due to its higher mass, thus reducing the escape flux when it is dragged along by hydrogen.

We track the loss of hydrogen over time and relate it to the equivalent amount of "initial" water it represents. We apply the same principle to the slower escape of oxygen. This enables us to compare the losses to the initial global water content of the planet. Most of the escape takes place during the first few hundred million years. We also study specifically the isotopic fractionation of noble gases resulting from hydrodynamic escape. The fractionation's primary cause is the effect of diffusive/gravitational separation between the homopause and the base of the escape. We compare the $^{20}Ne/^{22}Ne$ and $^{36}Ar/^{38}Ar$ ratios to the Venera data available in order to constrain our scenarios [3]. Heavy noble gases such as Kr and Xe are not fractionated. Ar is only marginally fractionated whereas Ne is moderately fractionated.

Our model suggests that during the first 100 Myr of the evolution of Venus, the content of approximately five terrestrial oceans (5 TO) of water have been lost to space, while reaching present day values for the fractionation of noble gases. Our preferred scenario shows that around 60% of the oxygen contained in this water (3 TO) was left behind in the atmosphere. This is consistent with the expected scenarios for the primordial water endowment of Venus [4]. Longer escape times would neither fit with isotopic data (noble gases would be too fractionated) nor with the plausible amount of water available early in the evolution of the planet (only several terrestrial oceans of water). Moreover, it would leave an increasing amount of molecular oxygen in the atmosphere that would difficult to remove.

We argue that hydrodynamic escape could have controlled the solidification rate of the magma ocean during the end of the accretion period by pumping the water out of the magma. As long as there is enough water vapor in the atmosphere the surface temperature is buffeted at 1500K and the atmosphere is at equilibrium with the magma (i.e. 1 TO of water in the atmosphere for 5 in the magma ocean). When volatiles are lost, the magma ocean freezes progressively and releases water vapor, which stabilizes the surface temperature. This way, the atmosphere would have been able to maintain a pressure of around 300 bar despite losses. After most of the water in the magma has been extracted, the atmosphere progressively dried up, and the magma ocean crystallized, leading to a final collapse of the hydrodynamic escape around 70-100 Myr after the beginning of the accretion. This timing is consistent with the end of the magma ocean phase on Earth (before 160 Ma) and Mars (roughly 100 Ma).

We propose that the dissolution of oxygen in the magma ocean as been able to efficiently remove large amounts of oxygen from the atmosphere. From 100 Myr to 500 Myr, the hydrogen delivered by a late veneer of comets could have been removed by continued thermal escape. The energy available then would have been insufficient to allow oxygen to be escape significantly. At 500 Myr, on Venus would be left with a dense molecular oxygen atmosphere of around 10 bar. The amount of water that would have been brought to the surface by volcanism and bombardment over the late evolution of Venus would correspond to a global equivalent layer of several meters. At later times non-thermal mechanisms may have removed most of the remaining hydrogen and led to the present D/H ratio. The 10 bar of oxygen may have been lost to crustal oxidation if the resurfacing and oxidation rates have been high enough during the last past 4 billion years.

3. Summary and Conclusions

The scenario we propose with this contribution should be considered a possible and globally self-consistent scenario for the evolution of water on Venus. It suggests that most of the evolution was decided very early by the action of hydrodynamic escape of H and O. This process efficiently removed the light volatiles from the atmosphere and the magma ocean. When it exhausted the available reservoirs, it progressively shut down and led to a thinner atmosphere and the freezing of the magma ocean. At that point the isotopic ratios for the noble gases are set. It also created a transient molecular oxygen atmosphere that was subsequently lost. Given the timing of the events, if this scenario is true, it is unlikely that Venus ever had a water ocean as the only time when large amounts of water are present corresponds to high surface temperature. When the surface cools, it is a direct consequence of the loss of the available water and it is doubtful there was enough left to create a habitable environment.

References

[1] Hunten, D.M., The escape of light gases from planetary atmospheres. J. Atmos. Sci. 30, 1481–1494. 1973.

[2] Chassefière, E.,. Hydrodynamic escape of oxygen from primitive atmospheres: applications to the cases of Venus and Mars. Icarus 124, 537–552. 1996

[3] Wieler, R., Noble gases in the solar system. In: Porcelli, D., Ballentine, C.J.,Wieler, R. (Eds.), Noble Gases in Geochemistry and Cosmochemistry, pp. 21–70 (Geochemical Society, Mineralogical Society of America). 2002.

[4] Raymond, S.N., Quinn, Lunine, J.I., High-resolution simulations of the final assembly of Earth-like planets. I. Terrestrial accretion and dynamics. Icarus 183, 265–282. 2006.