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The upper atmosphere of Venus: Model predictions for mass spectrometry measurements

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Abstract

We use an exosphere model to predict the neutral density profiles of all major species and of the noble gases in Venus' upper atmosphere. We compare the results to other models and existing observations and put the outcome into the context of future missions to Venus. Special consideration is given to noble gases and their detection possibility with mass spectrometers.

1. Introduction

Venus is the closest and most similar planet to Earth in the whole solar system, yet, basic measurements are missing. The atmospheric composition has been studied to some extent with the Pioneer Venus Orbiter mission [5] and the more recent Venus Express, however, the concentration of many species and their isotopic ratios are not yet known with satisfying accuracy. This holds true in particular for heavy noble gases such as Kr and Xe. These elements form a key link to the reconstruction of the atmospheric evolution, which would provide crucial information on the formation of Earth-like bodies. Knowing the abundances of the noble gases may allow us to answer the question why Venus did not evolve to a potentially habitable planet like its neighbour Earth.

2. Our exosphere model

The exosphere model we use for the Venus atmosphere is based on a Monte Carlo simulation originally developed for Mercury and the Moon [7, 8]. The model therefore applies directly only to the atmospheric region where collisions are negligible, i.e., to the exosphere. The simulations are performed for all known atmospheric species plus some that may become detectable on future missions to Venus. The simulations start at the exobase, which is located at around 210 km on the dayside and drops to around 154 km on the nightside because of the cooling by IR emission from the CO_2 atmosphere [5, 6]. The altitudes between the homopause and the exobase are covered by analytic extensions. This is necessary for some species and illumination conditions if we want to relate our model densities to observations made at homopause altitudes or below.

In our exospheric model, collisions as well as other processes which take place above the homopause as e.g. sputtering, charge exchange or photolysis are not addressed. However, we focus on the noble gases, which do not undergo photochemical dissociation and have a lower cross section for ionisation and charge exchange than non-noble gases. The major exospheric species C, H, N, and O are modeled as combination of a thermal and a hot population.

3. Results

We calculated the number density profiles for all known and expected species of the Venusian atmosphere, comparing our results to other models [4, 5] and to existing observations [1, 2, 6]. The results for the thermal component of the exosphere are displayed in Fig. 1. For the reliable detection of noble gases (third panel) a spacecraft must reach low altitudes, ideally down to 120 km. This altitude may be reached during aerobreaking maneuvres.

In Fig. 1 two lines are shown, assuming a performance of an instrument that was developed for lunar research [9], for integration times of 1 s and 10^4 s, respectively. Figure 1 also shows that the heavy noble gas xenon is hardly detectable by the mass spectrometer for a integration time of 1 s, corresponding to a signal-to-noise ratio of about 3. On the other hand, an integration time of 100 s (realistic for an aerobreaking trajectory like the one planned for EnVision) would imply a signal-to-noise ratio ≈ 30 for xenon.

From these calculations, we predicted mass spectra for possible future Venus missions, as for example for the EnVision mission and for the Venus flyby of ESA's JUICE mission. The results and their wider implications have been published recently [3].

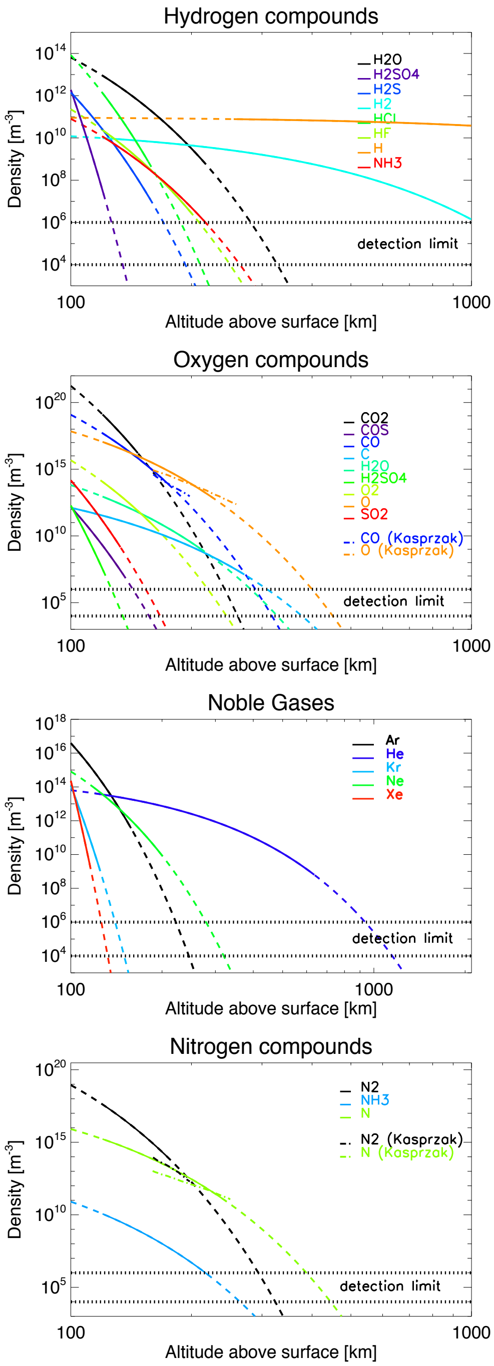

Figure 1: Modeled neutral density profiles of the Venus atmosphere. From top to bottom: hydrogen molecules, oxygen-bearing molecules, noble gases, and nitrogen-bearing molecules.

4. Conclusions

We have modeled density profiles of all major species and of the noble gases in the upper atmosphere of Venus. Our model predictions compare well with existing measurements and other models. Our calculations show that the heavy noble gases xenon and krypton might be detectable with state-of-the-art mass spectrometers. The EnVision mission planned by ESA offers the perfect opportunity for these fundamental measurements. During its Venus flyby, JUICE might also be able to measure the hot oxygen and hydrogen populations important for planetary escape.

Acknowledgements

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