EPSC Abstracts
Vol. 13, EPSC-DPS2019-989-3, 2019
EPSC-DPS Joint Meeting 2019


EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

# Modelling the performance of Cupid's Arrow, a small satellite concept that would measure noble gases in Venus atmosphere

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## Abstract

Measuring the abundances of noble gases and their isotope ratios in Venus atmosphere is an essential investigation to understand Venus global evolution. We propose a small satellite concept that would skim through Venus atmosphere below the homopause to collect samples that will be analyzed in deep space by a miniaturized quadrupole ion trap mass spectrometer (QITMS).

## 1. Introduction

As thousands of exoplanets are being detected, there is great hope of finding a planet like Earth that harbors life. Venus is often considered as the Earth's twin although the conditions at its surface are much different and do not allow for life to exist. In this context, it becomes increasingly important to understand how Venus and Earth have diverged in their geological evolution so dramatically. Noble gases in planetary atmospheres are tracers of geophysical evolution. They can provide information of processes driving atmospheric composition including the original supply of volatiles from the solar nebula, delivery of volatiles by asteroids and comets, escape rate of planetary atmospheres, degassing of the interior, and its timing in the planet's history. To date, planetary scientists have successfully made these measurements at Earth, Mars, Jupiter and a comet. However, our understanding of Venus' evolution given the elementary and isotopic pattern of noble gases and stable isotopes in its atmosphere, is today poorly known. Specifically, the concentrations of heavy noble gases (Kr, Xe) and their isotopes are mostly unknown, and our knowledge of light noble gases (He, Ne, Ar) is incomplete and imprecise [1]. The Venus Exploration Assessment Group (VEXAG) considered these measurements to be high priority (essential).

We have proposed Cupid's Arrow [2], a small satellite concept that would skim Venus' atmosphere and sample its atmosphere below the homopause [3]. The samples would then be analyzed by the QITMS while the probe is in deep space, leaving plenty of time to measure the amount of noble gases and their isotope ratios. After designing the probe around the miniaturized mass spectrometer [2], activities included demonstration of the sensitivity of the QITMS [4] and numerical simulations to investigate the characteristics of the sampling system and to include these results in a performance model. The numerical simulations are intended to assess the amount of fractionation that would happen during hyper velocity sampling and the accuracy of the measurements.

## 2. Numerical simulations

The Direct Simulation Monte Carlo (DSMC) code SPARTA [5], an open source software package developed by SANDIA National Laboratories, is used in this work. SPARTA, based on Bird's DSMC method [6], is a molecular-level gas-kinetic technique. As SPARTA is able to model hypervelocity reacting flows in strong chemical and thermal non-equilibrium, this software package is well suited to determine relevant flow properties for the Cupid's Arrow mission concept, and to numerically investigate the possibility of elemental and/or isotopic fractionation in the sampled gases. The composition of Venus atmosphere is modeled as a mixture of $N_2$ and $CO_2$ with various amounts of noble gases to investigate the accuracy of the measurements as a function of the amount of noble gases present in the atmosphere. The chemical model includes a number of species such as O, O2, CO, N, and NO with reaction rates derived from laboratory experiments. The effect of different physical modeling assumptions, such as ionization and catalytic versus non-catalytic boundary conditions are currently being investigated. 2D axisymmetric simulations with one sample acquisition tank are used for these sensitivity studies. Preliminary 3D simulations using a representative geometry (Fig. 1) including realistic valves at the inlet and outlet of the sampling system are currently underway.

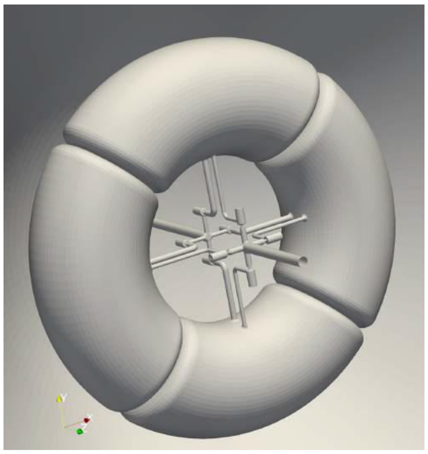

**Figure 1:** *Representative geometry of the Cupid's Arrow sampling system including four tanks that will be used for sample acquisition while skimming through Venus atmosphere below the homopause. Collecting four samples provides flexibility and robustness for the mission concept*

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# 3. Results

The numerical simulations show that fractionation indeed happens during sampling. The ratio Ar/Xe is initially set to 10 numerically in the simulations and is equal to ~7 in the tanks, suggesting that the sampling system may favor the transport of heavier species. However, the 2D simulations do not include a realistic valve with a small orifice, and the influence of this geometry on fractionation results is currently unknown. The statistical error associated with this value increases with decreasing initial concentration of noble gases, while the mean value stays constant, demonstrating that this is a function of the numerical resolution used in the simulations, and not a physical effect. Once final geometry will be agreed upon, running a case with a larger number density of particles will reduce the uncertainty significantly. Similarly, the isotope ratios show an enhancement in the heavier component by about 6% for Argon and 1% for Xe. The difference between these two numbers is well understood as the relative mass difference between Ar isotopes is much larger than that of Xe isotopes. The numerical simulations also provide the nature of the species being present in the chamber. CO and O become more important than $CO_2$ while $N_2$ remains the major N-bearing molecule. They also provide the time required to fill the tanks as the flux is limited by the characteristics of the valves.

# 4. Summary and Conclusions

The numerical simulations demonstrate that the fractionation occurring during sampling can be modeled. This effect will be included in the performance model of the QITMS that has been shown to be precise enough to acquire the values of isotope ratios with the required accuracy.

# Acknowledgements

Parts of this work have been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. The information in this abstract is pre-decisional and is presented for planning and discussion purposes only.

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