Atmospheric signatures of amorphous water ice delivery

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The delivery of enriched icy grains has been proposed as a mechanism to explain the enrichment of Jupiter with noble gases [1]. The enrichment with noble gases imposes constraints on the formation temperature of these grains, with Ar in particular only adsorbing to amorphous ice below 30K [2]. While significant consideration has been given to the formation conditions of the ices, the release of species as the grain migrates inward toward the forming planets has been given less thought. The desorption of the noble gases Ar, Kr and Xe trapped in amorphous ice occurs largely below 80K [3], while Jupiter formed at a temperature of 130K. [4] The composition of the icy grains thus changes from formation to deposition. The accretion and release processes are visualised in Figure 1.

The accretion and subsequent desorption of noble gas species alongside water into an enriched icy grain has been simulated using a Monte Carlo model. Assuming a tetrahedral structure of amorphous water ice, particles are deposited onto a predefined grid at temperatures sufficiently low to retain Ar. The temperature is subsequently increased up to 150K, capturing the temperature range relevant for giant planet formation. Previously reported experimental measurements of evaporation rates are used to benchmark the model and constrain the diffusion and evaporation rates of each noble gas species. The accretion and heating phases are shown in Figure 2, alongside the relevant physical processes. The desorption of each species from the ice is tracked during heating, and used to compute the temperature-dependent enrichment profile of the grain.

The Ar/Xe ratio of an icy grain simulated to form at 20K and heated up to 150K is shown in Figure 3. The higher thermal velocity of Ar causes the grains to initially be excessively enriched with Ar relative to the other noble gases at deposition. The ratio of 1.6 upon delivery to Jupiter at 130K is in line with atmospheric probe measurements conducted by Galileo, shown as the shaded green area. For icy particles accreted from gas reservoirs with a limited water budget, a distinct dip in the Ar/Xe ratio is observed in the 30K-70K range in which the ice giants formed. In this temperature range, Ar readily desorbs from the ice while Xe is retained. The atmospheric signature of the amorphous ice delivery mechanism could thus differ for Neptune in particular, with a depletion of Ar relative to Jupiter a possibility. This feature can be taken into account during the interpretation of potential future composition measurements of ice giant atmospheres. In addition, the results suggest the delivery of 0.1-0.5m\textsuperscript{⊕} of enriched ice is sufficient to provide the measured Jovian enrichment.
Figure 1: Overview of the processes leading to enriched icy grain delivery to Jupiter. The evolution of ice grain composition between epochs 1 and 2 has been studied.

Figure 2: Monte Carlo approach used to study ice grain composition evolution. Water and noble gas particles are shown in blue and orange, respectively. The processes of (1) accretion, (2) diffusion and (3) evaporation are labelled.

Figure 3: Evolution of the Ar/Xe enrichment ratio of an icy grain formed at 20K with an H2O:Ar ratio of 1:1 (violet) and 1:1 (red). The formation temperature of the giant planets are indicated. The dashed green line is the value measured by Galileo, the shaded area is the range of measurement uncertainty [9].
References:


