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Could Jupiter be a carbon-rich planet?

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Abstract

Motivated by recent spectroscopic observations suggesting that atmospheres of some extrasolar giant-planets are carbon-rich, i.e. carbon/oxygen ratio (C/O) ≥ 1, we find that the whole set of compositional data for Jupiter is consistent with the hypothesis that it be a carbon-rich giant planet. The Jovian oxygen abundance to be measured by NASA's Juno mission en route to Jupiter will provide a direct and strict test of our predictions.

1 Introduction

Data returned by the Galileo probe mass spectrometer in 1995 around the one-bar pressure level in Jupiter's atmosphere has provided carbon, nitrogen, sulfur, argon, krypton and xenon abundances that are relatively well matched by formation scenarios based on solar nebula models assuming solar elemental composition [1, 2]. Below expected water condensation level, the measured oxygen abundance was unexpectedly low, an effect typically attributed to the dynamics of the region within which the probe descended [3], but which we argue here could also partly reflect a bulk abundance lower than predicted by existing formation models.

Here we find that all the observed elemental abundances of Jupiter can be explained consistently within the standard core-accretion model of Jupiter's formation beyond the snow line by only changing the C/O ratio in the formation zone. The resulting O abundance in Jupiter's envelope then becomes moderately enriched compared to solar and is found to be consistent with values predicted by thermochemical models.

2 Modeling approach

Our model is based on a predefined initial gas phase composition in which all elemental abundances, except that of oxygen that is varied, reflect the bulk abundances of the Sun [4] and describes the process by which volatiles are trapped in icy planetesimals formed in the protoplanetary disk [5]. The process of volatile trapping in planetesimals formed in the feeding zone of proto-Jupiter is calculated using the equilibrium curves of hydrates, clathrates and pure condensates, and the thermodynamic path detailing the evolution of temperature and pressure at 5 AU in the protoplanetary disk. The intersection of the thermodynamic paths with the equilibrium curves of the different ices allows determination of the amount of volatiles that are condensed or trapped in clathrates at these locations in the disk following the approach depicted in [2, 6]. This method permits computation of the composition of the volatile phase present in the planetesimals formed in Jupiter's feeding zone. The precise adjustment of the mass of these ices accreted by Jupiter and vaporized into its envelope allows us to reproduce the observed volatile enrichments. The fitting strategy is to match the maximum number of observed volatile enrichments and to determine the uncertainty range corresponding to this matching.

3 Results

Because fractionation occurs at the trapping/condensation epochs of the different volatiles [2], the C/O ratio acquired by planetesimals differs from that in the gas phase. We thus conducted an iterative procedure allowing us to derive an oxygen abundance of $\sim$0.5 times its protosolar value in the nebula in order to get C/O = 1 in Jupiter's building blocks and envelope. Once the composition of plan-

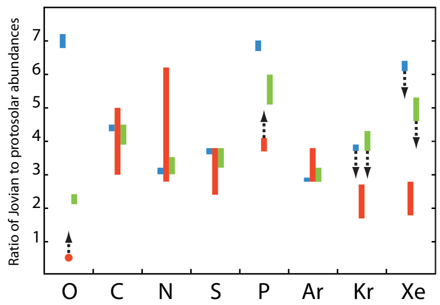

Figure 1: Ratio of Jovian to protosolar abundances. Red bars and red dot correspond to observations. Green and blue bars correspond to calculations based on an oxygen abundance that is 0.5 and 1 times the protosolar value in the disk, giving C/O = 1 and 0.35 in Jupiter, respectively. Arrows up correspond to the possibility that the measured O and P abundances are lower than their bulk abundances and arrows down to the possibility that planetesimals could be impoverished in Kr and Xe.

etesimals has been calculated, we adjusted the mass of heavy elements located in Jupiter's envelope to fit the maximum number of volatile abundances measured by the Galileo probe. Figure 1 represents the superimposition of two fits (case of an oxygen-depleted nebula and case of a protosolar oxygen nebula) with the measured volatile abundances. The figure shows that the same number of elements (carbon, nitrogen, sulfur and argon) is fitted in the two cases. However, the oxygen abundance predicted in Jupiter for an oxygen-depleted nebula is much closer to the measured abundance than the value predicted for a protosolar oxygen abundance. If the former case is correct, this supports the argument that the oxygen abundance in Jupiter derived from Galileo Probe water measurements reflects a bulk interior depletion of O relative to C, and is much less affected by atmospheric dynamical or meteorological processes than in the standard model. Neither calculation matches the observed phosphorus abundance, which is however only expected to provide lower bounds on the bulk abundance. The same remark applies for the observed krypton and xenon abundances but their relatively low values suggest the possibility of systematic error in their determination [1].

4 Discussion

A key observational test is the measurement of oxygen as water below the meteorological layer within Jupiter. A value of water about 2 $\times$ solar deep below the water clouds would confirm that Jupiter is carbon-rich. The Microwave Radiometer aboard the recently launched Juno spacecraft will probe the deep atmosphere of Jupiter at radio wavelengths to measure the planet's thermal emissions. This instrument will obtain measurements of water at pressures down to 100 bars deep in the Jovian atmosphere [7], thereby constraining Jupiter's O/H and C/O ratios.

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