Formation of ices in the protosolar nebula and implications for the composition of outer planets

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The presence of Jupiter, Saturn, Uranus and Neptune in our solar system raises the question of how they formed in the framework of the standard theories of planetary formation, namely the *core accretion* and the *disk instability* models. The direct or indirect measurements of the volatiles abundances in the atmospheres of these four giants (see Figure 1) are key to decipher their formation conditions in the protosolar nebula. So far, only the composition of Jupiter's atmosphere has been (partly) explored, thanks to the in situ measurements performed by the Galileo probe and the ongoing investigation of the Juno spacecraft. A giant planet formed in the framework of the *disk instability* model implies that oxygen, carbon, nitrogen, sulfur, argon, krypton and xenon elements should (*in principle*) all be enriched by a similar factor relative to their protosolar abundances in its envelope, depending on the extent of photoevaporation in the envelope and settling of dust grains prior to mass loss. A giant planet formed in the framework of the *core accretion* model will present enrichments in volatiles whose characteristics depend on their trapping conditions in the PSN. Because the trapping efficiencies of C, N, S, Ar, Kr, and Xe volatiles are similar at low temperature in amorphous ice, the delivery of such solids to a growing giant planet should be also consistent with the prediction of homogeneous enrichments in volatiles in the envelopes. On the other hand, if the volatiles were incorporated in clathrate structures in the PSN, then their enrichment values in the giants atmospheres should strongly vary from a species to another. An alternative scenario is built upon the ideas that i) Ar, Kr and Xe were homogeneously adsorbed by icy grains in the cold outer part of the PSN midplane and that ii) the disk experienced some chemical evolution. In this scenario, Ar, Kr and Xe would have been supplied in supersolar proportions with the PSN gas to the forming giant planets. Interestingly, recent formation models based on disk's photoevaporation, formation of giants via pebbles and gas accretion suggest that the measured volatiles enrichments can be explained in the four giants. These models deserve to be examined from close to identify the key assumptions that make them consistent (or not) with the other scenarios. In any case, future in situ measurements performed by planetary probes will be mandatory if one wants to disentangle between the different volatiles delivery scenarios to the giants of our solar system.

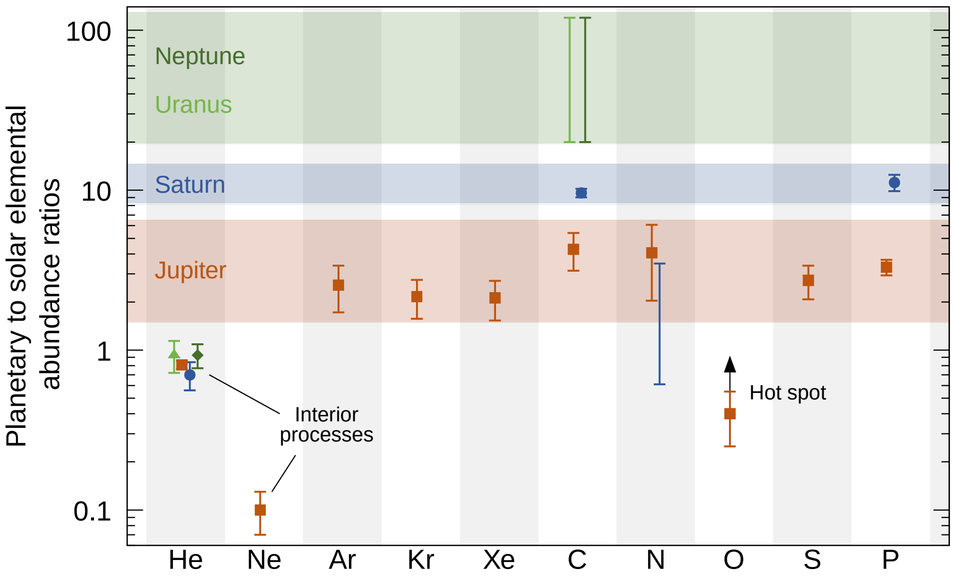

Figure 1: Volatiles enrichments (with respect to their solar abundances) measured in the envelopes of the four giants of the solar system (figure adapted from Mousis et al. 2017).

References

[1] Mousis, O., et al.: Scientific rationale for Uranus and Neptune in situ explorations, Planetary and Space Science, in press.

Short Summary

The presence of Jupiter, Saturn, Uranus and Neptune in our solar system raises the question of how they formed in the framework of the standard theories of planetary formation, namely the core accretion and the disk instability models. The measurements of volatiles atmospheric abundances are key to decipher their formation conditions in the protosolar nebula.