VOLATILES ENRICHMENTS AND COMPOSITION OF JUPITER. Y. Alibert[1] , O. Mousis[1,2] and W. Benz[1], [1]Physikalisches Institut, Universität Bern Sidlerstrasse 5, CH-3012 Bern, Switzerland (Yann.Alibert@phim.unibe.ch, Willy.Benz@phim.unibe.ch); [2]Observatoire de Besançon, CNRS-UMR 6091, 41 bis, avenue de l'Observatoire, BP 1615 Besançon, France (Olivier.Mousis@obs-besancon.fr),

Introduction: Detailed internal structure models of Jupiter matching many observational constraints have been constructed recently [1]. From this modeling, the mass of the core of the planet and the total amount of heavy elements present in the planet, the latter being of the order of 42 $M_{\oplus}$. Note that the inferred present day core mass can differ significantly from the one at the end of the formation process depending upon the extent of core erosion [1]. The total amount of heavy elements present in Jupiter, on the other hand, is not affected by this process.

Abundances of volatile species in Jupiter's atmosphere have been measured using the mass spectrometer on-board the Galileo probe [2]. These measurements reveal that the giant planet's atmosphere is enriched by a factor of ~3 in Ar, Kr, Xe, C, N and S compared to solar abundances.

Based on the classical core-accretion scenario [3], Gautier et al. [4] suggested that these enrichments result from the trapping of volatile species by water ice in form of clathrate hydrates or hydrates. However, the large amount of water ice required to trap the volatile species in these models implies a total heavy element content in Jupiter incompatible with the internal structure constraints [1].

In the present paper, we show that the core accretion scenario extended to include migration and disk evolution [5] can lead to the formation of a Jupiter-like planet which accounts for both the constraints set by internal structure models of this planet and the measurements of the abundances of volatiles in its atmosphere.

Jupiter formation: The Jupiter formation model we consider [6] is based on the extended core-accretion formation approach [5]. These models extend the classical core-accretion scenario [3] to take into account the migration of the protoplanet, and the evolution of the protoplanetary disk. The disk evolution results from viscosity (calculated in the framework of the α-formalism) and photoevaporation. The thermodynamical properties of the disk as a function of position and time are calculated by solving the vertical structure equations [5], and are used to determine the composition of the ices incorporated in the planetesimals. These extended core-accretion models allow the formation of giant planets in a few million years, a timescale compatible with typical disks lifetimes.

In the model we consider, Jupiter forms from an embryo originally located between ~9 AU and ~ 15 AU (depending on the migration rate which is still poorly constrained), which migrates inwards and stops at the current position of Jupiter at the time the disk disappears, after ~3 million years.

Composition of planetesimals: We assume that volatiles have been trapped during the cooling of the nebula in planetesimals either in form of pure condensates or in form of hydrates or clathrate hydrates [4]. Once condensed, ices are assumed to decouple from the gas, to be incorporated into growing planetesimals which may subsequently be accreted by the forming Jupiter. The figure shows cooling curves of the nebula at 5 and 15 AU derived from our disk model, as well as the condensation curves for the various ices considered in this work [7,8]. The thermodynamical conditions at which the different ices are formed correspond to the intersection between the cooling curve and the stability curve of the different condensates.

We assume that in the solar nebula gas phase the elements are in solar abundance [9]. Note that we also assume that the amount of water ice is sufficient to trap all volatiles. This corresponds to an abundance of water relative to H_2 in vapor phase in excess of the solar value. Sedimentation and drift due to gas drag on the icy grains could explain this overabundance of water [10]. Moreover, C is present under the form of CO_2, CO and CH_4 , with CO_2:CO:CH_4 = 30:10:1, values compatible with ISM measurments [11,12], and N is present under the form of N_2 and NH_3, with N_2:NH_3 = 1. Finally, due to its condensation curve, CO_2 condenses as a pure ice and not as a clathrate. This has a considerable influence on the total amount of water required to explain the enrichments in volatiles.

Enrichments in volatiles: In our Jupiter formation model, planetesimals are accreted between the starting location of the embryo, and the final location of Jupiter. Knowing, for each distance to the sun, the amount of accreted planetesimals and their composition, the final enrichment in volatiles is deduced.

Ar, Kr, Xe, C, N and S are enriched respectively by a factor of about 2.3, 2.4, 2.9, 3.3, 2.9 and 2.4 compared to their solar values. These values, which require the accretion of at least ~ 25.6 $M_\oplus$ of ices, are compatible (within error bars) with the in situ measurements made by the Galileo probe [2]. The mean ices/rocks ratio (I/R) of accreted planetesimals must be greater than 1.6 (depending upon the efficiency of the trapping process). Other assumptions on the initial ratios of CO_2:CO:CH_4 and N_2:NH_3 can lead to slightly different results, but without changing the main conclusions [13].

We note that if we ignore the presence of pure CO_2 ice but assume that C is trapped in form of CO and CH_4 only [4], we were capable to match the measured enrichments while remaining compatible with internal structure models [1] only if we assumed the accretion of pure ice planetesimals (I/R = ∞).

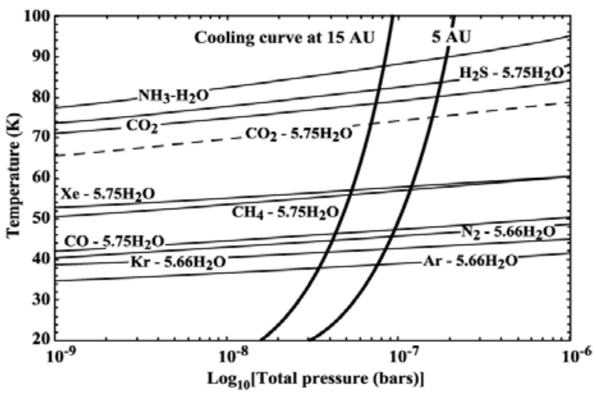

Figure 1: Stability curves of the condensates considered in the present work, and evolutionary tracks of the nebula at 5 and 15 AU. Abundances of various elements are solar, with CO_2:CO:CH_4 = 30:10:1 and N_2:NH_3 = 1 in vapor phase. The condensation curve of CO_2 pure condensate (solid line) is shown together with that of the corresponding clathrate hydrate (dashed line). Species remain in the vapor phase as long as they stay in the domains located above the curves of stability.

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