FISCHER-TROPSCH CATALYSIS IN A TURBULENT MODEL OF THE JOVIAN SUBNEBULA. O. Mousis[1], Y. Alibert[2], Y. Sekine[3], S. Sugita[4] and T. Matsui[4], [1]Observatoire de Besançon, CNRS-UMR 6091, 41 bis, Avenue de l'Observatoire, BP 1615 Besançon, France (Olivier.Mousis@obs-besancon.fr); [2]Physikalisches Institut, Universitaet Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland; [3]Department of Earth & Planetary Science, Graduate School of Science, University of Tokyo, 7-3-1 Bunkyo, Tokyo, 113-0033, Japan; [4]Department of Complexity Science & Engineering, Graduate School of Frontier Science, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 227-8562, Japan.

Introduction: Fischer-Tropsch catalysis, which converts CO (and CO_2) and H_2 into CH_4 on the surface of transition metals such as iron and nickel, is believed to play important roles in astrophysical environments. In addition to producing large quantities of water in some circumstellar envelopes [1], it has also been showed as a mean to produce hydrocarbons in oxygen-rich regions such as the protosolar nebula [2]. Laboratory experiments to determine CH_4 reaction rates have been recently conducted under the gas-phase conditions of the Saturnian subnebula [3]. From the use of a high pressure and stationary subnebula model [4], it has been concluded that CH_4-rich satellitesimals could be formed in the catalytically active region of the subdisk and thus may have played an important role in the origin of Titan's atmosphere [3]. However, in the context of a time-dependent accretion subdisk model, which provides a more realistic description of the subnebula's evolution than stationary models (the evolution of a time-dependent accretion subdisk model can be ruled by the last sequence of the giant planet formation), the Fischer-Tropsch catalysis may not lead efficiently to the formation of CH_4-rich satellitesimals. Indeed, even if pressure and temperature conditions are initially high enough to permit a rapid production of CH_4 in heterogeneous gas-phase, the accretion of the subnebula's material onto the giant planet may be faster than the cooling time needed to trap CH_4 in satellitesimals formed in the subdisk.

In this work, we examine the production of CH_4 through the Fischer-Tropsch catalysis in the Jovian subnebula and its implications for the composition of produced satellitesimals by using an evolutionary turbulent accretion disk model [5]. The evolution of this model is divided in two phases: an initially dense and warm first phase during which the subnebula's material is provided by the solar nebula and a cold second phase starting at the disappearance of the nebula and whose length corresponds to the time required for the subdisk to empty. From this model, it has been argued that regular icy satellites may have formed from satellitesimals produced either in the solar nebula or in the subdisk [6]. It has also been showed that the chemical composition of ices incorporated in regular satellites is nearly identical in both formation scenarios, due to the inhibition of the homogeneous gas-phase chemistry in the Jovian subnebula [6]. In contrast, assuming that the Fischer-Tropsch catalysis was efficient in the subdisk, we propose here to determine if the composition of satellitesimals produced in the Jovian subnebula can be different from that of solids formed in the solar nebula.

Fischer-Tropsch catalysis: According to laboratory experiments conducted at lower pressures ($2x10^{-2}$ – $5x10^{-1}$ bar) and high H_2/CO (H_2/CO_2) ratio (= 1000) [3], the region where the conversions of CO into CH_4 and CO_2 into CH_4 via Fischer-Tropsch catalysis proceed efficiently is narrow in a subnebula (T ~ 550 K). This is because the surface of catalytic iron grain is poisoned at temperatures above 600 K (the poisoning is a loss of catalytic activity through conversion of surface carbide to unreactive carbon). The experimental results show that the CH_4 formation rates of CO and CO_2 at 550 K increase with pressure and show similar pressure dependence, but the CH_4 formation rates of CO_2 are about 0.01 times those of CO at same reaction conditions. This indicates that CO are converted into CH_4 via Fischer-Tropsch catalysis about 100 times faster than CO_2 in a subnebula.

By using the experimental data of the CH_4 formation rates, time scales for the conversions of CO into CH_4 ($t_{CO \rightarrow CH4}$) and of CO_2 into CH_4 ($t_{CO2 \rightarrow CH4}$) at 550 K in the gas-phase conditions of the solar nebula are estimated as a function of pressure (Figure 1). We assume that about 10 % of the cosmic component of iron was present as metal in the solar nebula [7] and that the particles were spherical with 1 μm in radius. The number densities of CO and CO_2 are given by solar composition [8], assuming that that all the carbon atoms are in the form of CO and CO_2, respectively. This assumption gives the upper estimation of time scales for the conversions of CO and CO_2 under the conditions of subnebula. From the evolutionary turbulent model of the Jovian subnebula [5], the pressure range encountered in the subdisk at 550 K is calculated to be about 10^{-4} to 10^{-3} bar. In this pressure range, if transport and cooling processes are not taken into account in the Jovian subnebula, CO and CO_2 are entirely converted into CH_4 via Fischer-Tropsch catalysis in $10^1 – 10^2$ and $10^4 – 10^5$ years, respectively.

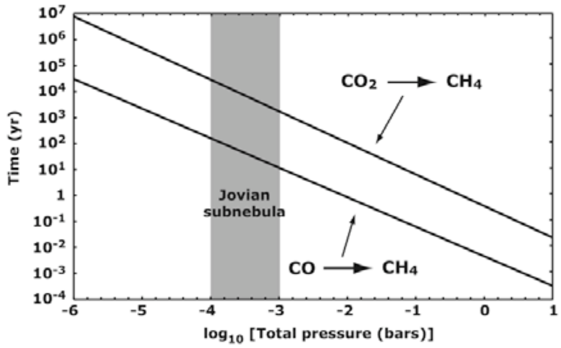

Figure 1: Time scales for the conversions of CO into CH_4 and of CO_2 into CH_4 at temperature of 550 K as a function of pressure in the gas-phase conditions of the solar nebula. The grey area corresponds to the pressure range encountered in the Jovian subnebula at temperature of 550 K where Fischer-Tropsch catalysis is the most efficient (see text).

Composition of ices produced in the Jovian subnebula: The Fischer-Tropsch catalysis is efficient up to the distance of 65 R_{Jup} in the Jovian subnebula since this latter never reaches the temperature of 550 K at higher distance to Jupiter. From Fig. 2, it can be seen that, at a given distance to the planet located within 65 R_{Jup}, $t_{CO \rightarrow CH4}$ is shorter than t_{fall} (time scale required by an element of the subdisk to accrete onto Jupiter) whereas $t_{CO2 \rightarrow CH4}$ is longer than t_{fall}. This implies that only CO can be efficiently converted into CH_4 via Fischer-Tropsch catalysis in our evolving model of the Jovian subnebula, the conversion of CO_2 to CH_4 being partial.

In order to determine if the produced CH_4 can be incorporated in ices formed in the Jovian subnebula, t_{fall} must be compared with the time scale (Δt in Fig. 2) required for the subdisk to cool down from 550 K (the temperature at which Fischer-Tropsch catalysis is efficient) to the condensation temperature of ices. From Fig. 2, it can be seen that Δt is still orders of magnitudes higher than t_{fall} in the zone of the Jovian subnebula where Fischer-Tropsch catalysis is efficient. In other words, this implies that any produced CH_4 via Fischer-Tropsch catalysis will be accreted onto Jupiter a long time before to being incorporated in the forming ices. Finally, we conclude that in an evolving turbulent subnebula, even if Fischer-Tropsch catalysis is active, it has no influence on the composition of the forming satellitesimals.

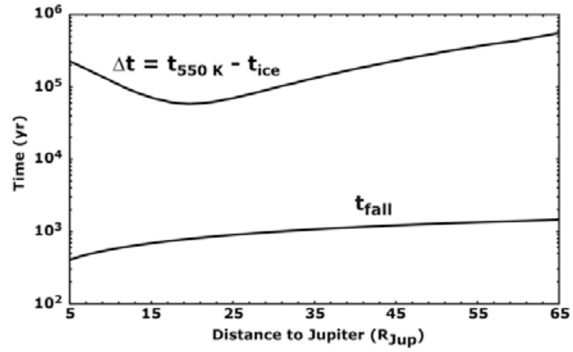

Figure 2: From top to bottom: time span taken by the subnebula to cool down from 550 K to the crystallization temperature of water (150 K) and falling time scale of the subdisk's material as a function of the distance to Jupiter.

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