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From discs to planets: the volatile molecules

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Abstract

The chemical composition of Solar and extrasolar planets is the subject of numerous studies as it governs partly their potential habitability. The present works aims at determining the chemical composition of planets formed in stellar systems of solar chemical composition. The main objective of this work is to provide valuable theoretical data of chemical composition for models of planet formation and evolution, and future interpretation of chemical composition of solar and extra-solar planets. To dot this, we combine the results of models of planet formation and ice formation in protoplanetary discs to derive the composition of planets. We finally obtain the chemical composition, ice:rock mass ratio and C:O molar ratio for planets in stellar systems of solar chemical composition.

1. Introduction

Solar and extrasolar planets are the subject of numerous studies in order to determine their chemical composition and internal structure. In the case of extrasolar planets, the composition is important as it governs partly their potential habitability. Moreover, observational determination of chemical composition of planetary atmospheres are becoming available, especially for transiting planets. The present works aims at determining the chemical composition of planetesimals and planets formed in stellar systems of solar chemical composition. The main objective of this work is to provide valuable theoretical data of chemical composition for models of planetesimals and comets, and planet formation and evolution, and future interpretation of chemical composition of solar and extra-solar planets. To dot this, we use different models allowing to calculate the chemical composition of planetesimals and planets by varying the surface density of discs, the insulation (irradiated and non irradiated discs), the formation or not of clathrates, and the initial chemical composition of species.

2. Method

We have developed a model calculating the composition of ices incorporated in planetesimals everywhere in the protoplanetary disc [1] and we computed the composition of ices incorporated in planets in different stellar systems with the use of a model of planetary formation [2].

2.1. Computation of ices in planetesimals

Starting from a gas phase (8 volatile molecules are considered in this study: H_2O, CO_2, CO, CH_3OH, CH_4 , NH_3, N_2, and H_2S), and using a model of ice formation in protoplanetary discs [1], we first compute the chemical composition of planetesimals for a population of protoplanetary disc (different surface densities) everywhere in the disc. The chemical composition of planetesimals is the one resulting from the processes of condensation and/or clathration (gas trapping in water ice) of species at a given distance to the star: the thermodynamic conditions of gas condensation/trapping (resp. ice/clathrate formation) are determined by the partial pressure of volatile molecules in the gas phase, and the temperature of the disc for different initial thermodynamics conditions [1].

2.2. Computation of volatiles species in planets

In order to determine the chemical composition of planets, we consider several planetary systems assumed to emerge from a protoplantary disc, whose initial density profile, mass and lifetime, is different, and follows, as much as possible, observational characteristics (see [2,3]). The model of planet formation [2] allows us to determine the formation path of the ten initial embryos in the disc and their growth during their migration for several discs (different initial surface densities), and for different initial distances to the star. We combine the results of the planet's formation model, which provides the amount of planetesimals accreted by every planet as a function of the distance to the central star, with the chemical composition of planetesimals everywhere in the disc [1] to derive the composition of planets.

3. Results

We obtain the chemical composition, ice:rock mass ratio and C:O molar ratio for planets in stellar systems of solar chemical composition [4]. From a initial homogeneous composition of the nebula, we produce a wide variety of planetary chemical compositions as a function of the mass of the disc and distance to the star (see Fig. 1). The volatile species incorporated in planets are mainly composed of H_2O, CO, CO_2 , CH_3OH and NH_3 (see Fig.2). Icy/ocean planets have systematically higher values of molecular abundances compared to giant and rocky planets. Gas giant planets are depleted in highly volatile molecules such as CH_4 , CO and N_2 compared to icy/ocean planets. The ice:rock mass ratio in icy/ocean and gas giant planets is respectively equal at maximum to 1.01±0.33 and 0.8±0.5, and is different from usual assumptions made in planet formation models, which suggested this ratio to be of 2-3. The C:O molar ratio in the atmosphere of gas giant planets is depleted at minimum of 30% compared to the solar value.

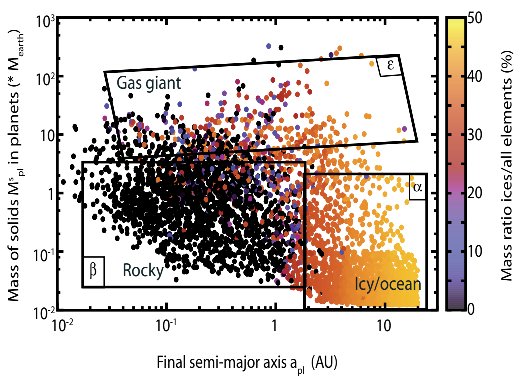

Figure 1: Average mass ratio of ices relative to the total solid mass of planets as a function of the final semi-major axis and the mass of the solid component, for 'irradiated' models.

Acknowledgements

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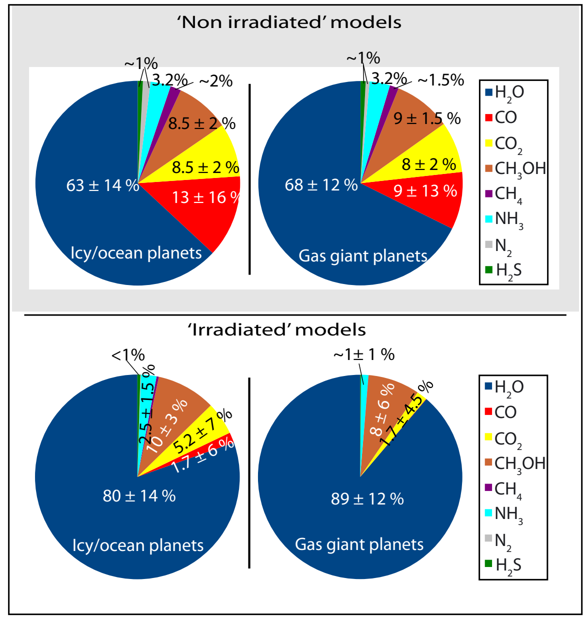

Figure 2: Average molar ratio (with standard deviation 2σ) of species X relative to all volatile species in icy/ocean and gas giant planets for all models, taking into account all chemical changes ($CO:CO_2$ variation and clathrate formation)This is the example of an included figure.

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