KINETIC CONDENSATION AND EVAPORATION OF MINERALS IN A DYNAMICALLY EVOLVING PROTOPLANETARY DISK. S. Charnoz$^1$ and J. Aléon$^2$ (1) Charnoz@ipgp.fr, Université de Paris Cité, Institut de Physique du Globe de Paris, CNRS F-75005 Paris, France (2) Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, UMR 7590, Sorbonne Université, Museum National d’Histoire Naturelle, CNRS

Introduction: The formation of the first solids of the solar system takes place in a complex thermodynamical environment. While the molecular cloud feeds the Solar Nebula, the young disk expands outward. The typical infall time is about 100 Kyrs, a period during which the first and most refractory minerals (constituents of the so-called calcium-aluminum-rich inclusions, the CAIs from chondritic meteorites) form in the hottest regions, close to the proto-Sun. At larger distances from the star, the somewhat less refractory major mineral constituents of rocky planets would condense (such as forsteritic olivine, enstatite or metallic iron). At lower temperatures, in warm-to-cold regions (T < 1000 K) a fraction of interstellar minerals may be preserved, while Na- or K-rich minerals may form. Whereas there is a vast literature on condensation sequences where the condensation of minerals is calculated assuming equilibrium chemistry [1-4] (with or without fractionation during condensation [5]), there are very few attempts trying to couple at the same time a model of protoplanetary disk dynamics along with a time-dependant model of mineral condensation. Up to now such attempts have been done with oversimplified chemistry [6,7] preventing to make quantitative comparison with the elemental composition of mineral constituents of the chondrites families nor with their bulk composition. In particular, variations among the elemental ratios of different chondrites families (Al/Si, Mg/Si, Fe/Si ratios), are not explained quantitatively and the use of equilibrium condensation models limit the interpretation of models.

Toward a new model: Here we will present a novel approach, where the disk temperature and dynamics are computed as a function of time and space, and where mineral growth is calculated with a kinetic model, assuming the Hertz-Knudsen condensation/evaporation law [8]. Our aim is to compute the formation rate of major minerals as a function of time and space in an evolving disk model. We proceed as follows: The (T,P) structure of the disk is computed using a classical 1D alpha disk model [6].

Molecular cloud infall is taken into account in the form of a source term that feed the gas (H/He) and the dust component of the system (in the form of micronic ISM dust) with average composition corresponding to solar composition. Depending on the local (P,T) conditions, ISM dust may evaporate upon injection.

The gas chemistry is assumed to be at equilibrium, which is a reasonable assumption for T > 300 K. From the gas molecular composition, Hertz-Knudsen condensation fluxes can be computed using the standard theory for a selection of minerals. The evaporation fluxes, are pre-computed using [8]. The differences between the condensation and evaporation fluxes allow to compute the growth of a selection of minerals. Then each mineral is individually tracked in the disk following the dust dynamics. Species that remain in the gas are tracked following the gas dynamics. At every timestep gas/solid exchanges are computed everywhere in the disk. Gas-gas and gas-grain reactions are considered, however solid state processes such as thermal-metamorphism and grain-grain reactions are not considered for now.

Applications: We will present the first applications of this model, focusing on the first 100 Kyrs and show that the young-disk complex dynamics favor the formation of a wide diversity of minerals. We will use refractory mineral sequences to address CAI formation and show that differences in dust atomic composition appears very early in the disk minerals as a result of the difference of the dynamics between the dust and gas (Figure 1). Even for the first solids that form in the disk, such a dynamical difference induces major element fractionations in the bulk dust with respect to the solar composition allowing to address the chemical fractionations observed in chondrite families. We also track the places where ISM material may be preserved in the disk and quantify the fraction of preserved ISM mineral as a function of distance in the Solar System. The compositions of the first planetesimals can be also tracked as we implement scaling laws for their formation [7]. Whereas we focus here on the most refractory minerals, extensions of this work will be devoted to more volatile elements from moderately volatile elements such as Na to water and to their role in the formation of the first planetary solids.
Figure 1: Surface density of major atoms, in minerals condensed in the disk, 5Kyrs after the start of the molecular-cloud infall. X axis is in astronomical units, Y axis is in moles/m².

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