EPSC Abstracts
Vol. 13, EPSC-DPS2019-2057, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

The influence of rocklines on the mineral compositions and Fe/Ni ratios of solids in the protosolar nebula

Artem Aguichine (1), Olivier Mousis (1), Bertrand Devouard (2) and Thomas Ronnet (3)

(1) Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France, (2) Aix-Marseille Université, CNRS, INRA, IRD, Coll France, CEREGE UM34, 13545 Aix en Provence, France, (3) Lund Observatory, Department of Astronomy and Theoretical Physics, Lund University, Box 43, 221 00 Lund, Sweden (artyomaguichine@gmail.com)

Abstract

In our solar system, meteorites and terrestrial planets show varying proportions of silicates and metallic iron, with Fe being distributed between Fe alloys and silicates. An open question remains the nature of the processes at play in the control of the redox state of these mineral assemblages, and thus the compositions of the different phases and relative proportions of metal vs. silicates. Here, we explore the roles held by the rocklines (the concept of snowlines extended to more refractory solids) of the most abundant solids in the shaping of the Fe/Mg and Fe/Ni abundance profiles in the protosolar nebula. The radial transport of solid grains through the different snowlines, coupled to the diffusion of vapours, lead to local enrichments or depletions in minerals, and imply variations of the Fe/Mg (in silicates) and Fe/Ni (in metal) ratios in the inner zone of the protosolar nebula. We discuss our results in light of the relative abundances and compositions of minerals observed in meteorites.

1. Model

Following the work of [1], we compute the evolution of the protosolar nebula (PSN) as a disc of α-viscous H_2-He gas, in which trace species are advecting and diffusing. The evolution of the gas surface density Σ_g and that of a trace species Σ_i are given by equations [1, 2] :

$$\frac{\partial \Sigma_g}{\partial t} = \frac{3}{r}\frac{\partial}{\partial r}\left[r^{1/2}\frac{\partial}{\partial r}\left(r^{1/2}\Sigma_g \nu\right)\right], \qquad (1)$$

$$\frac{\partial \Sigma_i}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\Sigma_i v_i - D_i \Sigma_g \frac{\partial}{\partial r}\left(\frac{\Sigma_i}{\Sigma_g}\right)\right)\right] + \dot{Q}_i = 0, \qquad (2)$$

where ν is the gas kinematic viscosity. The trace species diffusivities D_i and radial velocities v_i are calculated using the two-population algorithm from [3]. The source term $\dot{Q}_i$ accounts for sublimation and condensation, and is computed according to [5]. All species evolve independently and no feedback on the gas is taken into account.

2. Trace species

For each molecule under consideration, the initial mass fraction is derived from protosolar abundances given by [4]. Table 1 summarizes all considered species, assuming all protosolar Fe, Ni, Mg, Si and S have been distributed among them. Chemical reactions are not considered in our study.

Table 1: wt.% and density of considered trace species.

Formula	wt.%	density (kg.m^{-3})
$FeSiO_3$	1.297×10^{-3}	3.95
$MgSiO_3$ 2	4.946×10^{-3}	3.20
Fe_2SiO_4 3	5.898×10^{-4}	4.39
Mg_2SiO_4	2.041×10^{-3}	3.22
FeS	2.870×10^{-3}	4.75
$Fe_{0.9}Ni_{0.1}$	2.103×10^{-3}	7.90
Ni	1.101×10^{-4}	8.90

3. Results

Figure 1 shows the Fe/Ni ratio profile in metal dust at different times, starting at the protosolar value of 13.21. At early ages of $0 - 50$ kyr, rocklines of FeS and $Fe_{0.9}Ni_{0.1}$ at $\sim$ 0.5 au lead to a Fe/Ni ratio two times greater than in the outer region of the disc. Below that peak, Fe is fully vaporised, leading to a Fe/Ni ratio of 0.

As shown in figure 2, the local increase of the Fe/Mg ratio at rocklines of $FeSiO_3$ and Fe_2SiO_4 is more moderate, but remains visible until the end of the computation.

Beyond all rocklines, the atomic ratios are shaped by the drift velocity of solid particles. The denser grains are, the lesser they drift because of inertia. For this reason, Ni rich species stay longer in outermost regions of the disc, resulting in a decrease of the Fe/Ni ratio. On the other hand, Fe being slightly denser than Mg, the Fe/Mg ratio tend to increase in the disc.

The position of rocklines is shown in figure 3. As the disc cools down, all trace species condensate and the effect of rocklines is dissipated.

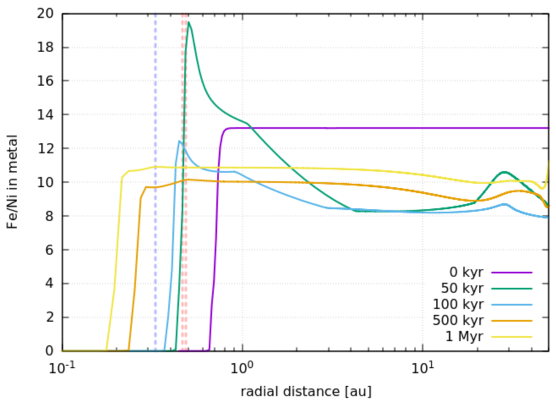

Figure 1: Fe/Ni ratio profiles in condensed metal. Vertical red and blue dashed lines correspond to rocklines of Fe- and Ni-rich species, respectively, at $t = 50$ kyr.

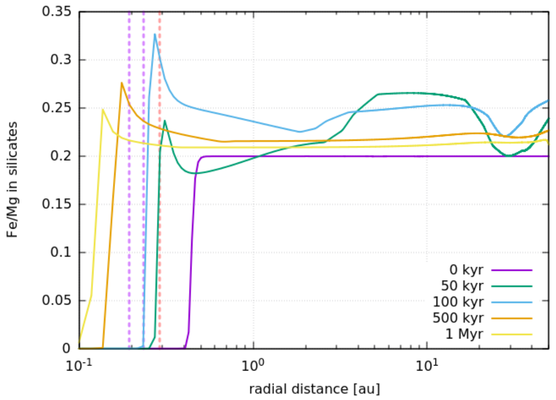

Figure 2: Fe/Mg ratio profiles in condensed silicates. Vertical red and purple dashed lines correspond to rocklines of Fe- and Mg-rich species, respectively, at $t = 50$ kyr.

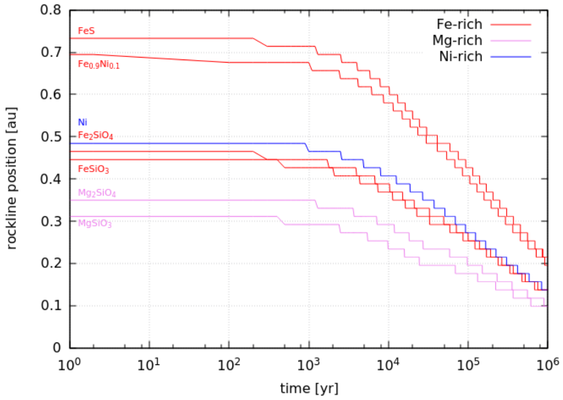

Figure 3: Evolution of positions of rocklines in time.

4. Summary and Conclusions

Throughout the PSN evolution, local variations of atomic ratios are due to i) difference in rocklines position and ii) difference in matter density. Simple cases with one or two species can be easily interpreted, but with more components thorough computations are required to extract the atomic ratios.

Because atomic ratio profiles strongly vary at early epochs of the PSN evolution, our results may explain some differences in compositional features observed among meteorites.

References

[1] Mousis, O., Ronnet, T., & Lunine, J. I.: Jupiter's Formation in the Vicinity of the Amorphous Ice Snowline, The Astrophysical Journal, Vol. 875, pp. 9, 2019.

[2] Desch, S. J., Estrada, P. R., Kalyaan, A., & Cuzzi, J. N.: Formulas for Radial Transport in Protoplanetary Disks, The Astrophysical Journal, Vol. 840, pp. 86, 2017.

[3] Birnstiel, T., Klahr, H., & Ercolano, B.: A simple model for the evolution of the dust population in protoplanetary disks, Astronomy and Astrophysics, Vol. 539, A148, 2012.

[4] Lodders, K., Palme, H., & Gail, H.-P.: Abundances of the Elements in the Solar System, Landolt Börnstein, Vol. 4B, pp. 712, 2009.

[5] Drazkowska, J., & Alibert, Y.: Planetesimal formation starts at the snow line, Astronomy and Astrophysics, Vol. 608, A92, 2017.