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Coupled dynamical and thermodynamical evolution of the protolunar disk

C. Michaut (1) and S. Charnoz (2)

(1) Institut de Physique du Globe / Université Paris Diderot/ Sorbonne Paris Cité, France (michaut@ipgp.fr), (2) Laboratoire AIM /Université Paris Diderot / CEA/ Sorbonne Paris Cité, France (charnoz@cea.fr)

Abstract

The isotopic composition of the Earth's Moon is known to be very similar to the Earth's. In the frame of the popular model of lunar formation from a giant impact on the proto-earth, numerical simulations have shown that the proto-moon is mainly composed of impactor's material whose isotopic composition is very likely to be different from the Earth's. This is especially puzzling for the case of oxygen isotopes as the oxygen isotopic composition ($^{17}O/^{16}O$, $^{18}O/^{16}O$) varies greatly among Solar System objects. In a seminal paper [1], it has been proposed that isotopic equilibration in the protolunar disk could be achieved provided that the disk remains hot during at least $10^2 - 10^3$ years.

The disk structure is quite exotic in an astrophysical context: it is partly liquid in its midplane while vaporized in its upper layers. The cooling of the disk, and hence the development of gravitational instabilities, depends on its thermodynamic structure that is intimately coupled to its dynamical evolution. In particular, as the disk spreads, its surface density decreases and radiative cooling proceeds more effectively, which tends to decrease the pressure and temperature at the midplane of the disk. However, heating due to viscous spreading of the disk plays in the opposite way. For these reasons, the cooling timescale is difficult to estimate on the sole basis of dimensional arguments.

We present a two-phase one-dimensional numerical model for the protolunar disk that solves for the dynamical evolution and the thermodynamic structure of the disk. We take into account (a) viscous spreading, (b) viscous heating, (c) gravitational instability, (d) phase change (liquid⇔gas) including condensation of silicate gas into rain-drops in the silicate atmosphere that is a source of latent heat, (e) radiative cooling and (f) accretion on the proto-earth.

The time evolution of the disk is studied while the proto-moon accretes; its thermal and structural evolution is characterized as a function of the disk initial structure and physical properties. First results on the cooling timescale of the disk and implications on the initial oxygen isotopic composition and thermal structure of the Moon will be presented and discussed.

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References

[1] Pahlevan K., Stevenson D. J., Equilibration in the aftermath of the lunar-forming giant impact, Earth Planet. Sci. Lett., 262, 438-449, 2007.