VAPORISING PLANETESIMALS FORMED DURING THE SUN'S PARENT CLOUD COLLAPSE

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Introduction: Observations at high angular resolutions reveal complex structures (rings and gaps) in very young protoplanetary disks, suggesting the presence of already formed planets [1]. Evidences from iron meteorites and derived ages indicate that planetesimal formation may have already been efficient relatively close to the time of formation of the oldest chondritic components, the Calcium-Aluminum rich Inclusions, CAIs [2]. Our recent work [3] proposed that CAIs precursors formed at the earliest stages of our Solar System life, during the collapse of the Sun's parent cloud and the disk building. As such, formation of planetesimals may have already started during this stage.

Few are the studies in the literature that take into account planetesimal formation and cloud collapse. [4] found that, in disk only driven by global turbulence, there is no planetesimal formation during the build-up stage. They found that only in low turbulence regimes and when water vapor is well mixed with the gas, planetesimal can form close to the snow-line during the disk building. Here, we investigate, using numerical simulations, the efficiency of planetesimal formation at different metallicities, z, and dust fragmentation velocities , uf, in a forming disk fed by a collapsing pre-stellar cloud.

Method: We use the model of cloud collapse described in [3], the model for planetesimal formation in [4] and the 1D disk model in [5]. The cloud is spherical, isothermal and collapses with a constant accretion rate while conserving angular momentum. The material that is infalling into the forming disk is injected within the centrifugal radius, the location in the keplerian disk where the local angular momentum equals that of the infalling cloud material. We include physics for the dead zone, grain growth/fragmentation and dust thermal evolution [5]. Two conditions need to be satisfied to produce planetesimals: solids with Stokes number >0.01 and a dust-to-gas ratio in the midplane > 1 [4]. The fiducial composition of the cloud is the same as in [5]. Two phases (gas and solids) for each species (refractories, silicates, iron, CO, H2O), all embedded in a H2/He gas, are considered. Similarly to [5] we run four simulations with metallicity z=1, 2 and uf=1, 10 ms^{-1}.

Results: Fig.1 shows the time evolution of the location of several condensations fronts and shaded areas represent zones with different intervals of temperature. Locations of planetesimals are indicated with pink dots. We see an efficient formation of planetesimals from the earliest stages of the disk building (time > 20 kyr), close to the inner edge of the dead zone, where the temperature is low enough (T < 1650 K) to allow the condensation of dust.

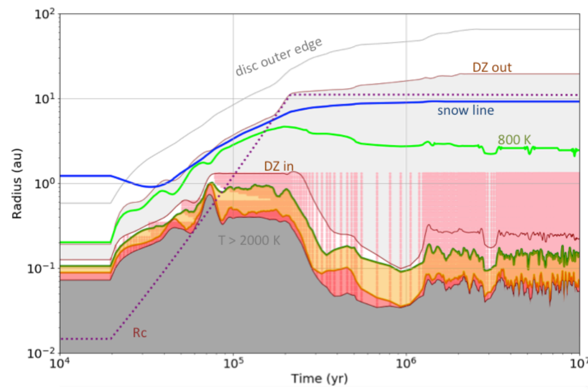

Fig1: *Time evolution of the location of different condensation fronts, different temperature intervals (T >2000 K, grey area; 1650<T(K)<2000, red area; 1500<T(K)<1650, yellow area), the snow line, the inner and the outer edge of the dead zone and the centrifugal radius, Rc, for our simulation at z=1 and uf=10 ms^{-1}. The locations of planetesimals are indicated with pink dots.*

They then experience radial drift toward the forming Sun, and, as the disk expands, can undergo high temperature events. Planetesimals forming at T<1650 K are then embedded in an environment with T>1650 K. Later, at the end of the collapse (time ~ 215 kyr) the disk cools down and condensation fronts move inward. At these later times, planetesimals end-up again in an environment with T<1650 K.

Discussion: Our results suggest that, once formed, planetesimals can experience very high temperatures and start to vaporize. Nevertheless, the process of internal differentiation, due, for example, to the short-lived radionuclide ^{26}Al, would start. Planetesimals located at different distances from the central star will be embedded in a gas at various temperatures and for different intervals of time. At these high temperatures (T >1650 K), the surface of the differentiated (or still differentiating) planetesimals may turn into a magma-ocean in a timescale shorter than those predicted by ^{26}Al heating only. Moreover, the vaporization of the mantle uppermost layers may eventually expose the planetesimal's iron-rich core to the surrounding gas, bringing to either its vaporization or, in case of survival, to substantial cooling. Nevertheless, vaporization of planetesimal surfaces at different conditions (local oxygen fugacity, heating and cooling timescale, dust composition) can produce fractionated bodies with a wide complex chemistry.

Conclusions: Planetesimal formation may occur in the inner hotter regions of the disk if a dead zone is present and if dust can grow with impact velocities uf ~10 m/s. Planetesimals can then experience high temperatures events (because of viscous heating of the gas) for different intervals of time during the disk expansion, before cooling again. We suggest that this can be a new mechanism to (i) induce an early magma ocean stage, (ii) reproduce the fast cooling rates observed in some classes of iron meteorites [6], and (iii) produce elemental fractionation in the rocky planets building blocks such as the Fe/Si ratio in Mercury [7].

References: [1] ALMA Partnership et al. (2015), ApJl, 808, L3. [2] Kruijer et al. (2019) Nature Astronomy, 2. [3] Pignatale et al. (2018), ApJl, 867, L23. [4] Drążkowska et al. (2018), A&A, 614, A62. [5] Charnoz et al. (2019), A&A, 627, A50. [6] Ruzicka et al. (2017), in Cambridge Planetary Science Series, Cambridge University Press, 136. [7] Ebel D. S. and Stuart S. T. (2018), in Mercury: the view after Messenger, Cambridge University Press, 497.